



通威农发
TWAD CO., LTD.



中国水产学会水产动物营养与饲料专业委员会

2024年学术年会

论文摘要集

中国·成都

2024.11.11-11.13



目录

专题一 营养与代谢	12
CDK2/CDX2/PepT1 信号途径在草鱼肠道小肽转运吸收中的作用研究进展.....	13
The role of CDK2/CDX2/PepT1 signaling pathway of intestinal oligopeptide transporting and absorption in grass carp (<i>Ctenopharyngodon idellus</i>).....	14
Competing endogenous RNA (ceRNA) in a non-model animal: Non-coding RNAs respond to heat stress in rainbow trout (<i>Oncorhynchus mykiss</i>) through ceRNA-regulated mechanisms.....	15
Foxq1 靶向 gyk 调节大口黑鲈糖稳态的机制研究.....	17
Mechanism of foxq1 targeting gyk to regulate glucose homeostasis in largemouth bass and development of Indel markers.....	18
IL-22 调控葡聚糖硫酸钠(DSS)诱导斑马鱼肠炎的作用机制研究.....	20
Study on the Mechanism of IL-22 in Regulating DSS-Induced Enteritis in Zebrafish.....	21
Mfn2 介导的线粒体融合促进黄颡鱼的脂肪酸 β -氧化.....	22
Moderate replacement of fish oil with palmitic acid-stimulated mitochondrial fusion promotes β -oxidation by Mfn2 interacting with Cpt1 α via its GTPase-domain	23
p38MAPK 和 PI3K/Akt 通路在虾青素减轻高糖诱导肝损伤的调控作用	24
Astaxanthin attenuates glucose-induced liver injury in largemouth bass: role of p38MAPK and PI3K/Akt signaling pathways	25
PGC-1 α 介导葡萄糖醛酸内酯缓解高脂饲料引起的大口黑鲈肝脏线粒体功能及脂质代谢紊乱	26
PGC-1 α mediates glucuronolactone alleviation of high-fat feed-induced disorders of hepatic mitochondrial function and lipid metabolism in largemouth bass	27
VD ₃ 对高糖日粮饲养下黄鳝的生长、存活率及糖代谢能力的影响	28
The effects of high carbohydrate diet supplemented with VD ₃ can improve the survival rate and glucose metabolism ability of rice field eel (<i>Monopterus albus</i>).....	29
比较两种海水鱼对葡萄糖和果糖的利用：对胰岛素分泌和急性低氧耐受性的影响	30
Comparative analysis of glucose and fructose tolerance in two marine fishes: effects on insulin secretion and acute hypoxia tolerance.....	31
ZnO NP 通过 FOXO3 的乙酰化增加 LC-PUFA 含量，从而减少 PO-ER 接触和过氧化物酶体 β 氧化	32
ZnO NP increasing LC-PUFA content via the acetylation of FOXO3 reduce PO-ER contacts and peroxisomal β -oxidation	33
丙氨酰-谷氨酰胺对大口黑鲈食源性肠炎的保护作用研究.....	34
Studies on the protective effect of alanyl-glutamine against foodborne enteritis in largemouth bass (<i>Micropterus salmoides</i>)	35
不同温度下花鲈对饲料磷需要量的研究.....	36
Dietary phosphorus requirement of spotted seabass (<i>Lateolabrax maculatus</i>) reared at different temperatures.....	37
不同脂肪源对黄鳝生长性能、抗氧化力、脂肪代谢和肠道健康的影响	38
Effects of different lipid sources on growth performance, antioxidant capacity, lipid metabolism and intestinal health of rice field eel (<i>Monopterus albus</i>)	39
草鱼 CCKR 的分子特征及其参与肠道对细菌感染的免疫应答反应	41

Molecular characterization of CCKR in <i>Ctenopharyngodon idella</i> and its involvement in the intestinal immune response to bacterial challenges	42
草鱼细菌性肠道炎症发生的调控网络及营养干预研究	43
Study on the regulatory network and nutritional intervention of intestinal inflammation induced by bacteria in Grass Carp	44
胆汁酸可恢复高植物蛋白饲料引起的凡纳滨对虾(<i>Litopenaeus vannamei</i>)铁死亡, 肌肉品质下降和肠道受损.....	45
Dietary bile acids recovers the ferroptosis, the decrease in flesh quality and intestinal health induced by high-plant protein diets of Pacific white shrimp (<i>Litopenaeus vannamei</i>).....	46
蛋白水平对亚硝酸盐应激后草鱼鳃损伤的影响	48
二烯丙基二硫化物通过保守机制--增强 Mfn2/Atgl 介导的脂滴-线粒体耦合来缓解肝脏脂肪变性	49
Diallyl Disulfide Alleviates Hepatic Steatosis by the Conservative Mechanism from Fish to Tetrapod: Augment Mfn2/Atgl-Mediated Lipid Droplet-Mitochondria Coupling.....	50
高脂饲料诱发黄鳝脂肪代谢紊乱、肝脏损伤以及肠道健康问题相关机制的探究	51
Investigation of the mechanism of lipid metabolism disorder, hepatic impairment and intestinal health induced by high-fat diet in rice field eel (<i>Monopterus albus</i>)	52
高脂诱导的氧化应激导致肠道炎症和脂质沉积.....	53
High fat diet-induced oxidative stress contributes to intestinal inflammation and lipid accumulation	54
mTORC1 和 CaSR-Gq-ERK1/2 通路协同感知氨基酸诱导胰岛 α 细胞增殖	55
Amino acid sensing induces α cell proliferation via synergism between the mTORC1 and CaSR-Gq signaling pathways.....	56
蛋白 1 (Srebp1) 抑制对斑点叉尾鮰糖脂转化调控和肝脏健康的影响	57
Inhibition of Srebp1 alleviates high carbohydrate diet-induced hepatic <i>de novo</i> lipogenesis through AMPK signaling and improves liver health in channel catfish.....	58
鳊鱼饲料中最适淀粉添加量研究.....	59
Quantification of the optimum starch level in the diet of juvenile mandarin fish <i>Siniperca chuati</i> 60	
鳊鱼营养和驯化研究.....	61
Research on the nutrition and domestication of mandarin fish	62
花鲈 (<i>Lateolabrax maculatus</i>) 血管内皮生长因子 b 的分子特征及其在降低脂肪沉积中的潜在作用	63
Molecular characterization of vascular endothelial growth factor b from spotted sea bass (<i>Lateolabrax maculatus</i>) and its potential roles in decreasing lipid deposition.....	64
黄颡鱼铁代谢相关基因的克隆及其对不同铁源的响应	65
Characterization of fifteen key genes involved in iron metabolism and their Responses to dietary iron sources in yellow catfish <i>Pelteobagrus fulvidraco</i>	66
肌醇在调节草鱼皮肤免疫反应中的作用	67
氯化钠缓解吉富罗非鱼冬季低温环境下的氧化应激反应	68
Sodium chloride alleviates oxidative stress induced by extreme winter cold in genetically improved farmed tilapia (GIFT; <i>Oreochromis niloticus</i>)	69
尼罗罗非鱼对高脂饲料摄入的适应机制研究	70
Studies on the mechanisms by which Nile tilapia (<i>Oreochromis niloticus</i>) adapt to the high-fat diet	71
水产动物饲源性损伤: 证据与挑战.....	72

Feeding induced damage in aquatic animals: evidences and challenges	73
四种饲料诱食剂对中华绒螯蟹幼蟹生长、食欲及消化吸收的比较研究	74
Comparative effects of four feed attractants on growth, appetite, digestion and absorption in juvenile Chinese mitten crab (<i>Eriocheir sinensis</i>)	75
饲料 SFA/MUFA 比对罗非鱼生长性能、肌肉品质和脂质代谢的影响	76
Effects of dietary SFA/MUFA ratio on growth performance, muscle quality and lipid metabolism of tilapia	77
饲料蛋氨酸水平对黄鳝幼鳝生长性能、肝肠健康、肌肉品质及氨基酸代谢的影响	78
The effect of dietary methionine levels on growth performance, liver and intestinal health and amino acid metabolism of juvenile swamp eels (<i>Monopterus albus</i>)	80
饲料蛋白质水平对以棉籽浓缩蛋白为主要蛋白质来源的凡纳滨对虾生长性能、免疫反应、消化能力、肠道菌群和转录组的影响	82
Effects of dietary protein levels on growth performance, immune response, digestibility, intestinal flora and transcriptome of <i>Litopenaeus vannamei</i> fed cottonseed protein concentrate as the main protein source	84
饲料磷脂水平对中华鲟 (<i>Acipenser sinensis</i>) 幼鱼生长性能、抗氧化力及脂肪代谢的影响研究	85
Effects of dietary phospholipids on growth performance, antioxidant capacity, and lipid metabolism of juvenile Chinese sturgeon (<i>Acipenser sinensis</i>), a critically endangered sturgeon in the Yangtze River	86
饲料中碳水化合物和脂肪水平对翘嘴鲌生长性能、肝脏组织学、抗氧化能力以及肌肉质构的影响	87
Effects of dietary carbohydrate and lipid levels on growth performance, hepatic histology and antioxidant capacity, and flesh texture of mandarin fish (<i>Siniperca chuatsi</i>)	88
饲料中添加肌醇对克氏原螯虾幼虾生长, 蜕皮性能和蜕皮激素信号通路的影响	89
The effects of dietary myo-inositol on growth, ecdysis performance, and ecdysone signaling pathway in juvenile freshwater crayfish, <i>Procambarus clarkii</i>	90
维生素 E 对鳊生长性能及血清生化指标的影响	91
Effects of Dietary Vitamin E on Growth Performance and Serum Biochemical Indexes of <i>Siniperca chuatsi</i>	92
线粒体柠檬酸穿梭: 缓解高脂饲料诱导鱼类代谢紊乱的潜在调控靶标	93
Inhibition of mitochondrial citrate shuttle alleviates metabolic syndromes induced by high-fat diet	94
蝎源抗菌肽 (IsCT) 改善生长中期草鱼肠道物理屏障	95
新型水凝胶日粮对中华绒螯蟹生长、消化和营养物质表观消化率的影响	96
Effects of new hydrogel diet on growth and apparent digestibility of <i>Eriocheir sinensis</i>	97
养殖鱼类越冬前精准投喂策略研究: 以草鱼为例	98
Research on precise feeding strategy of breeding fish before overwintering: Take grass carp as an example	99
营养感知分子 UBXD8 调控缙蛭高不饱和脂肪酸 (HUFA) 合成的作用及机制	100
The regulatory role and mechanism of nutrient-sensor UBXD8 in HUFA synthesis of <i>Sinonovacula constricta</i>	101
鱼类食物成瘾的分子机制及其在鳊鱼驯食饲料中的作用	102
珍珠龙胆石斑鱼(<i>Epinephelus fuscoguttatus</i> ♀× <i>E. lanceolatus</i> ♂) SUMO1、SUMO2 和 UBC9 基因克隆及序列分析	103

Molecular cloning and sequence analysis of the SUMO1, SUMO2 and UBC9 genes of the hybrid grouper (<i>Epinephelus fuscoguttatus</i> ♀ × <i>E. lanceolatus</i> ♂)	104
棕榈油在红鳍东方鲀饲料中的应用: 生长、体成分、肌肉质构和脂质代谢	105
Efficacy of Palm Oil Application in Tiger Puffer Diets: Growth, Body Composition, Muscle Texture, and Lipid Metabolism	106
组氨酸在调控大口黑鲈生长、营养代谢、免疫能力中具有重要作用	107
Histidine plays an important role in regulating the growth, nutritional metabolism and immunity of largemouth bass (<i>Micropterus salmoides</i>)	108
专题二 营养与品质	109
不同年龄长吻鮠肌肉营养品质及挥发性风味物质比较分析	110
Comparative analysis of nutritional quality and volatile flavor compounds in the muscles of <i>Leiocassis longirostris</i> at different ages	111
不同锌源对鳊生长、肌肉品质、抗氧化及免疫能力的影响	113
Effects of different zinc sources on growth, muscle quality, antioxidant and immune capacity of Mandarin fish (<i>Siniperca chuatsi</i>)	114
从抑制到激活: 胍基乙酸对草鱼成肌细胞增殖和分化的双重作用	115
大口黑鲈高度不饱和和脂肪酸合成特性及关键基因功能表征	116
Characterisation of Endogenous Highly Unsaturated Fatty Acids Synthesis and Key Enzyme Functions in Largemouth Bass (<i>Micropterus salmoides</i>)	117
大菱鲂幼鱼早期生长阶段的禁食会导致长期的生长抑制及体成分变化	118
Early-stage fasting leads to long-term growth inhibition and body composition changes in juvenile turbot <i>Scophthalmus maximus</i>	119
低鱼粉日粮中策略性的添加三种诱食剂来提高大口黑鲈的生长性能、健康状况和肉品质	120
Strategically using three feed attractants to improve the growth performance, health status and meat quality of largemouth bass (<i>Micropterus salmoides</i>) under a low-fishmeal diet	121
短期低剂量黄曲霉毒素 B1 对草鱼的 Hormesis 效应及毒性损伤评价	122
Assessment of the hormesis effect and toxic damage of short-term low-dose aflatoxin B1 in Grass Carp (<i>Ctenopharyngodon idellus</i>)	123
高 SFA/MUFA 比饲料优化鱼油漂洗策略: 提升黄河鲤肌肉脂肪酸营养和质构品质	124
Optimizing fish oil-washing strategy with high dietary SFA/MUFA ratio: Enhancing the muscle fatty acid nutrition and textural quality of Yellow River carp	125
谷氨酸通过 PPAT 介导的从头合成途径和 ATP 介导的转化途径调节湘云鲫肌肉 IMP 合成的机制研究	126
Glutamate regulates the PPAT-mediated de novo synthesis and ATP-mediated transformation pathways to boost IMP production in Triploid Crucian Carp	127
横沙新洲河道优势种类鱼类的脂肪酸组成及营养品质评价	128
基于生长、体成分和抗氧化能力研究饲料中添加川芎水提取物对鲫体脂和肉质的影响	129
Study the effects of dietary aqueous extract of <i>Ligusticum Chuanxiong</i> Hort. on body fat and meat quality based on growth, body composition and antioxidant capacity of crucian carp (<i>Carassius auratus gibelio</i>)	130
精氨酸对草鱼肌肉能量代谢的影响及其可能作用机制	131
日粮中黑水虻幼虫几丁质对大口黑鲈生长性能、健康状况和肌肉发育的影响	132
Effects of black soldier fly larvae chitin in diet on growth performance, health status and muscle development of largemouth bass <i>Micropterus salmoides</i>	133
水解鱼蛋白体外对弧菌的抗菌活性及其在大菱鲂体内对哈维氏弧菌抗病力的探究	134

Exploring antibacterial activity of fish protein hydrolysate <i>in vitro</i> against <i>Vibrio</i> strains and disease resistance to <i>V. harveyi</i> in turbot (<i>Scophthalmus maximus</i>)	135
糖萜素对克氏原螯虾的生长性能、肌肉抗氧化能力和品质的影响	136
Moderate dietary sacchariterpenin supplement ameliorates growth performance, muscle antioxidant capacity and quality of the crayfish (<i>Procambarus clarkii</i>)	137
外源肌肽提高了克氏原螯虾生长性能和肌肉品质	139
Carnosine supplementation improved the growth performance and flesh quality of the red swamp crayfish (<i>Procambarus clarkii</i>)	140
缬氨酸对草鱼生长性能和肌肉营养沉积的影响	142
亚油酸通过 5-脂氧合酶途径诱导肌肉氧化应激	143
Excessive Linoleic Acid Induces Muscle Oxidative Stress through 5-lipoxygenase-Dependent Peroxidation	144
氧化豆粕和氧化豆油对团头鲂肌肉氧化稳定性、品质、氨基酸组成和脂肪酸组成的影响	145
Effects of oxidized soybean meal and oxidized soybean oil on muscle oxidative stability, flesh quality, amino acid profile and fatty acid profile of <i>Megalobrama amblycephala</i>	146
异亮氨酸对生长后期草鱼生长性能及肌肉胞外基质的影响	147
运动训练和高脂饲料对斑点叉尾鮰营养成分和肌肉品质的影响	148
Effects of exercise training and high-fat diet on nutritional composition and flesh quality in channel catfish (<i>Ictalurus punctatus</i>)	149
长江口不同生态类型鱼类的脂肪酸组成及营养品质评价	150
支链氨基酸与 miR-203a/ <i>fosb</i> 协同促进鲤的骨骼肌生长	151
脂质脂肪酸组成可以影响其在卵形鲳鲹饲料中的应用水平	152
The fatty acid composition of lipid can affect its application level in diet of <i>Trachinotus ovatus</i>	153
组氨酸通过调节肌肉 pH 和硬度改善草鱼肌肉品质	154
专题三 亲本与幼体营养	155
不同粒径开口饲料对克氏原螯虾仔虾生长性能和营养组成的影响	156
Influence of Different Feed Particle Sizes on the Growth Performance and Nutrition Composition in Crayfish, <i>Procambarus clarkii</i> Larvae	157
不同饲料添加物对脊尾白虾 (<i>Exopalaemon carinicauda</i>) 卵巢和精子发育的影响	159
Effects of different feed additives on the development of ovaries and testicles in the ridgetail white shrimp <i>Exopalaemon carinicauda</i> (Decapoda, Caridea, Palaemonidae)	160
不同碳水化合物对小规格草鱼生长性能、血清生化指标、抗氧化以及肠道健康的影响 ...	161
不同碳水化合物水平对中规格草鱼生长、血清生化指标、抗氧化以及肠道健康的影响 ...	162
不同温度对脊尾白虾 (<i>Exopalaemon carinicauda</i>) 生长与性腺发育相关指标的影响	163
Effects of different temperatures on growth and gonad development related indexes of the ridgetail white shrimp, <i>Exopalaemon carinicauda</i>	164
胆固醇通过 <i>Srb</i> 和 <i>Star</i> 途径调控三疣梭子蟹卵巢发育的分子机制	165
Molecular mechanisms of cholesterol regulation of ovarian development in swimming crab through <i>Srb</i> and <i>Star</i> pathways	166
对虾亲体脂质营养研究现状与展望	167
Current status and prospects of lipid nutrition in Penaeid shrimp broodstock	168
花生四烯酸对雌性红螯螯虾卵巢发育和繁殖性能的影响	169
Optimal arachidonic acid supplementation enhances ovarian development and reproductive	

performance in female redclaw crayfish, <i>Cherax quadricarinatus</i>	170
生物饵料冻干粉在雌性凡纳对虾亲体性腺发育及脂质代谢中的调控作用	171
Regulatory effect of freeze-dried biological bait powder on gonadal development and lipid metabolism in female <i>Penaeus vannamei</i> broodstock	172
饲料 DHA 对半滑舌鳎雄鱼性类固醇激素合成的调控作用	173
Dietary DHA regulated the androgen production in male Chinese tongue sole <i>Cynoglossus semilaevis</i>	174
外源甾醇及胆固醇与磷脂配比对凡纳对虾卵巢发育的调控作用	175
Regulatory effects of exogenous sterols and cholesterol-phospholipid ratio on ovarian development in Pacific white shrimp (<i>Penaeus vannamei</i>).....	176
维生素 E 促进半滑舌鳎生长及繁育的内分泌机制解析	177
Endocrine mechanism of vitamin E in promoting the growth and breeding of half-smooth tongue sole	178
虾青素对罗氏沼虾亲体性腺发育的影响	180
The effect of astaxanthin on the gonadal development of broodstock <i>Macrobrachium rosenbergii</i>	181
小肽对罗氏沼虾 (<i>Macrobrachium rosenbergii</i>) 亲体卵巢发育的影响.....	183
Effects of small peptides on the ovarian development of broodstock in <i>Macrobrachium rosenbergii</i>	184
专题四 新型饲料原料和添加剂的研发与应用	185
18 β -甘草次酸对高脂日粮诱导大口黑鲈肝损伤的影响.....	186
Effects of 18 β -glycyrrhetic acid on liver injury of largemouth bass induced by high fat diet..	187
阿魏酸对草鱼生长性能和消化吸收能力的影响及其机制研究	188
白藜芦醇改善西伯利亚鲟的消化能力和肠道健康, 并提高其抗热应激能力	189
Resveratrol improves the Siberian sturgeon's digestive capacity and gut health, as well as increase its resistance to heat stress	190
不同蛋白水平饲料中添加 α -酮戊二酸对中华绒螯蟹 (<i>Eriocheir sinensis</i>) 生长和蛋白质代谢的影响	191
Effect of alpha-ketoglutarate supplementation on growth and protein metabolism in Chinese Mitten crab (<i>Eriocheir sinensis</i>) under varying protein diets.....	192
大豆酶解蛋白替代不同鱼粉对大口黑鲈摄食、生长和健康状况的影响	193
Effects of enzymatic hydrolysis soybean protein replacing different fish meal on feeding, growth performance and health condition of Largemouth Bass.....	194
大豆酶解蛋白替代不同鱼粉对南美白对虾摄食和生长的影响	195
大豆浓缩蛋白替代鱼粉并补充蛋氨酸在杂交鲟饲料中的评估	196
Evaluation of soybean protein concentrate replacing fish meal with methionine supplementation in diets for hybrid sturgeon (<i>Acipenser baerii</i> ♀ \times <i>A. schrenckii</i> ♂).....	198
大豆异黄酮对中华绒螯蟹幼蟹生长性能、抗氧化能力、非特异性免疫和脂质代谢的影响	200
Effects of soy isoflavones on growth performance, antioxidant capacity, non-specific immunity and lipid metabolism of juvenile Chinese mitten crab, <i>Eriocheir sinensis</i>	201
大黄素改善高植物蛋白诱导的彭泽鲫肝脏代谢功能紊乱	202
Emodin improved the hepatic metabolic dysfunction induced by high plant-protein diet in Pengze crucian carp (<i>Carassius auratus</i> var. Pengze).....	203
胆汁酸对草鱼头肾、脾脏、皮肤的免疫功能的作用及其机制	204
胆汁酸在水产动物中的研究进展.....	205

Research progress of bile acids in aquatic animals.....	206
胆汁酸在水产饲料中应用及其研究进展.....	207
Bile acids application in aquafeeds and their research progress	208
当归副产物对颗粒饲料的保护作用及其对鲫生长和缺氧应激的影响	209
Protective Effects of <i>Angelica sinensis</i> By-product on Pellet Feed and its Effects on the Growth and Hypoxic Stress in Crucian Carp.....	210
低聚原花青素对乌鳢生长性能、抗氧化能力、免疫功能、肝脏和肠道健康的影响	211
Effects of oligomeric proanthocyanidins on growth performance, antioxidant capability, immunity, liver and intestinal health of <i>Channa argus</i>	212
低鱼粉饲料中酵母培养物对中华绒螯蟹幼蟹生长性能、肠道健康及抗热应激能力的影响.....	214
Supplementation of yeast culture to low-fishmeal diets im-proves growth, intestinal health, and heat stress resistance in juvenile Chinese mitten crab (<i>Eriocheir sinensis</i>).....	215
低鱼粉饲料中酶解玉米蛋白粉替代鱼粉对中华绒螯蟹幼蟹生长性能、蛋白合成和抗热应激能力的影响.....	216
Effects of replacing fish meal with enzymatic corn gluten meal in low fish meal diet on growth performance, protein synthesis and heat stress resistance of <i>Eriocheir sinensis</i>	217
鱼粉饲料中添加槲皮素对中华绒螯蟹生长和健康的影响.....	218
Quercetin supplementation improved the growth and health of juvenile Chinese mitten crabs (<i>Eriocheir sinensis</i>) fed low-fishmeal diets	219
浮萍——有潜力的蛋白饲料.....	220
Duckweed - a potential protein feed	221
复方中草药对大鳞副泥鳅生长性能、血清生化及抗氧化能力的影响	222
高糖饲料中添加二甲双胍对珍珠龙胆石斑鱼生长性能、糖代谢酶活性和肠道菌群的影响.....	223
Effect of metformin supplementation to high-carbohydrate diets on growth, serum biochemistry, gluconeogenic enzyme activity and intestinal flora of hybrid grouper (<i>Epinephelus fuscoguttatus</i> ♀× <i>Epinephelus lanceolatus</i> ♂).....	224
高糖饲料中添加苦瓜粉对鲤生长性能、糖脂代谢及其相关基因表达水平的影响	225
Effects of bitter melon powder on growth performance, glucose and lipid metabolism and related gene expression in common carp fed high-sugar diet.....	226
海藻多糖改善过氧化氢应激对加州鲈肠道损伤.....	227
Seaweed polysaccharides improve the intestinal damage induced by hydrogen peroxide stress in largemouth bass (<i>Micropterus salmoides</i>)	228
褐藻酸钠通过肝肠轴缓解高糖饲料诱导黄鳝健康损伤.....	229
Sodium alginate ameliorates healthy injury induced by high carbohydrate diets in <i>Monopterus albus</i> through gut-liver axis.....	230
黑水虻油替代鱼油对拟穴青蟹生长性能、抗氧化能力、脂质代谢和线粒体功能的影响	231
Effects of substituting fish oil with black soldier fly larvae oil on growth, antioxidant capacity, lipid metabolism, and mitochondrial function in <i>Scylla paramamosain</i>	232
几种功能性物质对大菱鲂粪便稳定性和肠道健康的影响.....	233
Effects of several functional additives on fecal stability and intestinal health of turbot.....	234
姜黄素对赭曲霉毒素 A 和低氧应激联合导致的草鱼肝损伤的缓解作用	235
姜黄素缓解慢性热应激下西伯利亚鲟心脏氧化应激、细胞凋亡和线粒体功能损伤	236
Curcumin alleviates oxidative stress, apoptosis and mitochondrial impairment in the heart of Siberian sturgeon(<i>Acipenser baerii</i>) under chronic heat stress	237
酵母培养物通过改善中华绒螯蟹肝肠健康缓解慢性热应激.....	239

Dietary yeast culture can protect against chronic heat stress by improving the survival, antioxidant capacity, immune response, and gut health of juvenile Chinese mitten crab (<i>Eriocheir sinensis</i>)	240
芥酸在鱼类健康中的两面性.....	241
Both sides of erucic acid: its beneficial and toxic properties in fish.....	242
金藻多糖对杂交鲟幼鱼 (<i>Acipenser baerii</i> Brandt ♀ × <i>A. schrenckii</i> Brandt ♂) 生长性能、鱼体营养成分、血清指标及肠道菌群的影响.....	243
Effect of dietary polysaccharides from <i>Prymnesium parvum</i> on growth performance, body composition, serum index and intestinal microflora of juvenile hybrid sturgeon (<i>Acipenser baerii</i> Brandt ♀ × <i>A. schrenckii</i> Brandt ♂).....	244
菌体蛋白替代鱼粉对合方鲫生长性能、生理生化及肌肉品质的影响研究.....	245
The Effect of Single-Cell Protein Substitution of Fishmeal on the Growth Performance, Physiological and Biochemical Properties, and Muscle Quality of Hefang Crucian Carp (<i>Carassius auratus cuvieri</i> ♀ × <i>Carassius auratus red var</i> ♂).....	246
苦瓜皂苷促进鲤鱼饲料中高糖节约蛋白质作用的有效性评价.....	247
<i>Momordica charantia</i> saponins administration in low-protein-high-starch diet improves growth, blood biochemical, intestinal health and microflora composition of juvenile common carp (<i>Cyprinus carpio</i>).....	248
螺旋藻替代鱼粉对黄鳝生长性能、抗氧化及免疫力的影响.....	249
迷迭香酸抑制伊丽莎白白菌感染诱导的牛蛙炎症反应的作用机制.....	250
The Mechanism of Rosmarinic Acid in Inhibiting the Inflammatory Response Induced by <i>Elizabethkingia</i> Infection in Bullfrogs.....	251
棉籽粕替代鱼粉饲料中添加青蒿素对卵形鲳鲆生长性能、消化酶活性、脂代谢和菌群的影响.....	252
Artemisinin supplementation improves growth, lipid metabolism, and intestinal microbiota of Golden pompano (<i>Trachinotus ovatus</i>) fed cottonseed meal diets.....	253
评价人工合成虾青素和藻源虾青素对饲喂高脂饲料的卵形鲳鲆生长特性、脂质代谢和肝脏健康的影响.....	254
Evaluating the impact of synthetic and algal-sourced astaxanthin on growth characteristics, lipid metabolism, and hepatic health in <i>Trachinotus ovatus</i> fed a high-fat diet.....	255
全植物蛋白饲料中添加肌酸提高了克氏原螯虾生长性能和肌肉生长.....	256
Creatine supplementation to all-plant-protein diets improved the growth performance and muscle growth of the red swamp crayfish (<i>Procambarus clarkii</i>).....	257
桑叶多糖可减轻高淀粉饲料对大口黑鲈肝脏损伤和淀粉代谢紊乱的影响.....	258
Mulberry leaf polysaccharide alleviates liver damage and starch metabolism disorder in Largemouth bass induced by a high-starch diet.....	259
桑叶提取物对鳊脾、肾、鳃结构及功能的影响.....	260
Effects of mulberry leaf extract on the structure and function of spleen, kidney and gill of <i>Siniperca chuatsi</i>	261
沙葱黄酮对乌鳢生长、抗氧化和肝糖代谢的作用.....	262
水飞蓟素对幼草鱼肠道免疫功能的影响和机制.....	263
水飞蓟素缓解伏马毒素 B1 诱导的幼草鱼肝胰腺损伤的可能性机制：促进线粒体自噬.....	264
饲料氯化胆碱对用鳙幼鱼生长性能、抗氧化性能和肠道功能的影响.....	265
Effects of dietary choline chloride on growth performance, antioxidant properties, and intestinal function of juvenile bighead carp (<i>Aristichthys nobilis</i>).....	266

饲料纳米氧化锰通过 mtROS 依赖性 Hsf1 ^{Ser326} 磷酸化引发黄颡鱼肝脏脂毒性和线粒体自噬	267
MnO ₂ nanoparticles trigger hepatic lipotoxicity and mitophagy in yellow catfish <i>Pelteobagrus fulvidraco</i> via mtROS-dependent Hsf1 ^{Ser326} phosphorylation.....	268
饲料添加阿魏酸对中华绒螯蟹幼蟹生长性能、糖代谢及脂质代谢的影响	269
Effects of ferulic acid on growth performance, glucose metabolism and lipid metabolism of juvenile Chinese mitten crab, <i>Eriocheir sinensis</i>	270
饲料中添加 L-谷氨酸对大口黑鲈生长性能、肌肉生长相关基因表达及肠道健康的影响..	271
Effects of Dietary L-glutamic acid on the Growth Performance, Gene Expression Associated with Muscle Growth-Related Gene Expression, and Intestinal Health of Juvenile Largemouth Bass (<i>Micropterus salmoides</i>).....	272
饲料中添加当归脂溶性提取物对鲤生长、体成分、代谢与抗氧化能力的影响	273
The effects of dietary fat soluble extract of <i>Angelica sinensis</i> on the growth, body composition, metabolism, and antioxidant capacity of <i>Cyprinus carpio</i> var. Jian	274
饲料中添加发酵吊笼养殖附着物替代海泥对刺参生长的影响	275
Effect of dietary fermented attachments of suspension cage to feed instead of sea mud on growth of <i>Apostichopus japonicus</i>	276
饲料中添加发酵石榴皮多酚对凡纳滨对虾血清生化、免疫、肝胰脏健康和抗病力的影响	277
Effects of dietary fermented pomegranate peel polyphenols on serum biochemistry, immunity, hepatopancreatic health and disease resistance in white shrimp (<i>Litopenaeus vannamei</i>)	278
饲料中添加甘露寡糖促进大菱鲆幼鱼皮肤创伤愈合	280
The supplementation of mannan oligosaccharide promotes the skin wound healing of juvenile turbot, <i>Scophthalmus maximus</i>	281
饲料中添加谷氨酸可增强急性碱度胁迫下尼罗罗非鱼的抗氧化能力、氨解毒能力和离子调节能力	282
Dietary supplementation with glutamate enhanced antioxidant capacity, ammonia detoxification and ion regulation ability in Nile tilapia (<i>Oreochromis niloticus</i>) exposed to acute alkalinity stress..	283
饲料中添加几丁质对中华绒螯蟹幼蟹生长性能, 抗氧化能力, 免疫和脂质代谢的影响 ...	284
Effects of dietary Chitin on growth performance, antioxidant capacity, immunity and lipid metabolism of juvenile Chinese Mitten crab, <i>Eriocheir sinensis</i>	285
饲料中添加烟酸对盐度胁迫下尼罗罗非鱼的生长、渗透调节能力和糖代谢的影响	286
Effects of dietary niacin supplementation on growth, osmotic regulation, and carbohydrate metabolism of Nile tilapia under salinity stress	287
饲料中添加栀子对大口黑鲈生长性能、抗氧化能力、炎症反应和 GLP-1R/AKT/Nrf2 通路的影响	288
Effects of dietary <i>Gardenia jasminoides</i> Ellis fruit on growth performance, antioxidant capacity, inflammatory response and GLP-1R/AKT/Nrf2 pathway of largemouth bass (<i>Micropterus salmoides</i>)	289
高糖营养背景下, L-肉碱对黄鳝生长性能、抗氧化力和脂肪代谢的影响	290
Under the background of high-carbohydrate nutrition, the effects of L-carnitine on the growth performance, antioxidant capacity, and lipid metabolism of rice field eel (<i>Monopterus albus</i>) ...	291
乌苏里拟鲿对 14 种动物性蛋白源表观消化率的研究	292
Apparent Digestibility of Fourteen Animal Protein Ingredients for <i>Pseudobagrus ussuriensis</i> ...	293
岩藻多糖激活 Sirt1 调控 Perk-Eif2 α -Atf4 轴缓解高脂诱导的海水鱼肝脂质沉积.....	294
Fucoidan Reduces Hepatic Lipid Accumulation in black seabream by Activating Sirt1 to Modulate the Perk-Eif2 α -Atf4 Pathway.....	295

叶酸对草鱼生长性能、肝脏脂质代谢和能量代谢的影响.....	296
乙醇梭菌蛋白替代鱼粉对青鱼幼鱼生长、血清生化、肌肉质构及品质的影响.....	297
Effects of fishmeal replacement by <i>Clostridium autoethanogenum</i> protein on growth performance, serum biochemistry, Muscle Texture and quality of black carp (<i>Mylopharyngodon piceus</i>).....	298
在高糖饲料中添加植物甾醇对大口黑鲈 (<i>Micropterus salmoides</i>) 生长、抗氧化能力、组织形态和肠道微生物的影响.....	299
Effect of phytosterols added to high carbohydrate diets on growth, antioxidant capacity, tissue morphology and gut microbiota of largemouth bass (<i>Micropterus salmoides</i>).....	300
外源琥珀酸通过促进肝肠健康提高大口黑鲈对高淀粉饲料的利用.....	302
Exogenous succinic acid improved the utilization of high-starch diet in largemouth bass (<i>Micropterus salmoides</i>) via enhancing enterohepatic health.....	303
转录组与微生物组分析：探究黄粉虫作为凡纳滨对虾饲料主要蛋白源的影响.....	304
Integrating transcriptome and microbiome analyses to understand the effects of using <i>Tenebrio molitor</i> as a primary protein source in <i>Litopenaeus vannamei</i> diets.....	305
左旋肉碱对高脂饲料喂鲤肌肉营养代谢、肠道健康和肠道微生物的影响.....	307
专题五 水产微生态营养.....	308
贝莱斯芽孢杆菌 H16 抗菌物质的纯化鉴定和特性研究.....	309
Purification and Characteristics of Antimicrobial Peptide produced by <i>Bacillus velezensis</i> strain H16.....	310
不同益生元在中华绒螯蟹肠道菌群体外发酵中的益生效果比较.....	311
Comparison of Probiotic Effects of Different Prebiotics on In Vitro Fermentation of Gut Microbiota in Chinese Mitten Crab.....	312
豆粕提质处理重塑微生物代谢功能以缓解高豆粕诱导的克氏原螯虾肠道氧化损伤.....	313
Soybean meal-refined treatment mitigated high soybean meal diet-induced oxidative damage in the gut of crayfish via microbial metabolic function remodeling.....	314
短小芽孢杆菌 SE5 调控斜带石斑鱼 (<i>Epinephelus coioides</i>) 肠道上皮细胞 β 防御素表达机制的初探.....	315
The preliminary exploration of mechanisms underlying the regulation of β -defensin expression in intestinal epithelial cells of <i>Epinephelus coioides</i> by inactivated <i>Bacillus pumilus</i>	316
复方植物精油对益生菌及致病菌的影响.....	318
Effects of compound plant essential oil on probiotics and pathogenic bacterias.....	319
姜黄素对慢性热胁迫后西伯利亚鲟肠道与肝脏的抗氧化功能及肠道微生物组成的影响...320	320
The effect of curcumin on the antioxidant function and gut microbial composition of Siberian sturgeon intestine and liver after chronic heat stress.....	322
酵母培养物和复合益生菌对黄鳝生长性能、血清生化指标、肝肠健康和肌肉质构特性的影响.....	324
Effects of yeast culture and complex probiotics on growth performance, serum biochemical indices, liver and intestinal health and muscle texture characteristics of <i>Monopterus albus</i>	325
乳酸乳球菌对高温条件下美洲鲈生长、代谢及肠道微生物群落结构的影响.....	327
Effects of dietary <i>Lactococcus lactis</i> on growth, metabolism and intestinal microbial community structure of American shad (<i>Alosa sapidissima</i>) under high temperature.....	328
三种益生菌对卵形鲳鲹生长及肠道菌群的影响.....	329
Effects of Probiotics on Growth Performance and Intestinal Microflora of Golden Pompano (<i>Trachinotus ovatus</i>).....	330
饲料中补充索氏鲸杆菌 WT-1 (<i>Cetobacterium somerae</i> WT-1) 后生元可促进大菱鲆	

(<i>Scophthalmus maximus</i> L.) 的生长性能、肠道健康及免疫功能.....	331
Dietary supplementation with postbiotics from <i>Cetobacterium somerae</i> WT-1 promotes growth performance, intestinal health, and immune function in turbot (<i>Scophthalmus maximus</i> L.).....	332
饲料中添加丁酸梭菌代谢产物通过改善肝肠健康提高凡纳滨对虾生长性能	333
Dietary supplementation with <i>Clostridium butyricum</i> metabolites improves growth performance of <i>Litopenaeus vannamei</i> by improving liver and intestinal health	334
微生物组视角：有机铜在促进凡纳滨对虾健康养殖中的作用	335
Microbiome insights: the role of organic copper in enhancing healthy shrimp (<i>Penaeus vannamei</i> Boone, 1931) culture.....	336

专题一

营养与代谢

CDK2/CDX2/PepT1 信号途径在草鱼肠道小肽转运吸收中的作用研究进展

何志敏, 刘臻

长沙学院生物与化学工程学院水生动物与品质调控湖南省重点实验室, 湖南长沙, 410003

摘要: PepT1 是一种质子依赖型寡肽转运载体, 其主要分布于动物的肠道中, 对于二肽、三肽等小分子肽具有很强的转运能力。前期, 我们明确了草鱼肠道 PepT1 转运小肽受到上游转录因子尾型同源盒基因 2(Caudal Type Homeobox 2, CDX2)的调控。基于以上研究背景及研究基础, 本研究采用缺陷型酵母功能互补试验、CRISPR-Cas9 技术、酵母双杂交及膜蛋白双杂交、蛋白分子对接、定点突变、westernblot、实时荧光定量 PCR, 养殖试验等分析草鱼 PepT1 的小肽转运功能、遗传功能、小肽转运偏好性、CDX2 及其磷酸化参与 PepT1 转运小肽信号分子机制。结果显示: 草鱼 PepT1 能转运小肽且具有偏好性, 对三肽的结合偏好性普遍高于二肽, 酵母生长实验证实 PepT1 对小肽转运的偏好性: GHK>KE>WA>AAA>GL>LG>AA>AW, 偏好性转运小肽能促进 PepT1 表达、草鱼生长发育并增强其抗氧化能力; 蛋白分子对接及酵母双杂交试验证明 CDX2 能与 PepT1 及 CDK2 相互作用; CDX2 关键磷酸位点的突变会降低 CDX2 的磷酸化水平及蛋白表达水平, CDK2 能提高 CDX2 的磷酸化水平, 并增强其稳定性, CDK2 抑制剂 Roscovitine 能抑制 CDK2 的磷酸激酶活性从而降低 CDX2 的磷酸化水平进而降低其稳定性。本研究证实了草鱼 PepT1 转运小肽的能力及偏好性的特点, 明确了偏好性小肽对草鱼生长发育等方面的促进作用, 初步揭示了磷酸化 CDK2/CDX2/PepT1 信号途径磷酸化调控小肽转运的分子机制, 为草鱼 PepT1 转运小肽的调控研究提供新的研究视角, 为丰富鱼类肠道小肽吸收及饲料蛋白高效利用的理论基础。

关键词: PepT1; 小肽转运; 磷酸化; 偏好性

The role of CDK2/CDX2/PepT1 signaling pathway of intestinal oligopeptide transporting and absorption in grass carp (*Ctenopharyngodon idellus*)

Zhimin He, Zhen Liu

Hunan Provincial Key Laboratory of Nutrition and Quality Control of Aquatic Animals, Department of Biological and Chemical Engineering, Changsha University, Changsha 410022, China

Abstract: PepT1 is a proton-dependent oligopeptide transport carrier, which is mainly distributed in the intestinal tract of animals and has a strong transport capacity for oligopeptides such as dipeptide and tripeptides. In previous study, we clarified that the oligopeptide transporting of intestinal PepT1 was regulated by the upstream transcription factor tail-type homeobox gene 2 (CDX2). Based on the previous research background and basis, Functional complementation assay of defective yeast, CRISPR-Cas9 technology, yeast two-hybrid and two-hybrid membrane protein tests, protein molecular docking, site-directed mutagenesis, westernblot, real-time PCR, feeding trials were employed to analyze the oligopeptide transporting and genetic functions, oligopeptide transporting preference, and the molecular mechanism of CDX2 and its phosphorylation mediating oligopeptide transporting of PepT1. The results showed that the grass carp PepT1 owns the ability to transport oligopeptide and the feature of preference; it showed higher preference to tripeptides than depeptides; Yeast growth experiments confirmed the preference of oligopeptide transporting as follow: GHK> KE> WA> AAA> GL> LG> AA> AW, preferred oligopeptide can promote the expression of PepT1, the growth and development and enhance their antioxidant capacity of grass carp; Protein molecule docking and yeast two-hybrid assay investigated that CDX2 interacted with PepT1 and CDK2, respectively; The key phosphosites mutations of CDX2 reduced the phosphorylation and protein expression levels of CDX2; CDK2 increased the phosphorylation level and protein stability of CDX2. The inhibitor roscovitine decreased the phosphokinase activity of CDK2 and thus reduced the phosphorylation level of CDX2 and subsequently reduce its stability. This study confirmed the ability of PepT1 to transport oligopeptides and preference, clarified the effect of preferred oligopeptides on promoting the growth and development of grass carp, preliminarily revealed that the molecular mechanism of phosphorylation of CDK2/CDX2/PepT1 signal pathway regulated the oligopeptides. This study provides a new perspective on the regulation of oligopeptides transported by PepT1, theoretical basis for the absorption of intestinal oligopeptides and the efficient utilization of feed proteins.

Key words: PepT1; oligopeptide transportation; phosphorylation; preference

资助项目：国家自然科学基金重点项目（U21A20267，31902345）、湖南省自然科学基金面上项目（2023JJ30075）、湖南省教育厅重点项目(22A0597)

通讯作者：何志敏，E-Mail: z20180831@ccsu.edu.cn；刘臻，E-Mail: z20040625@ccsu.edu.cn

Competing endogenous RNA (ceRNA) in a non-model animal: Non-coding RNAs respond to heat stress in rainbow trout (*Oncorhynchus mykiss*) through ceRNA-regulated mechanisms

Jinqiang Quan¹, Guiyan Zhao, Zhe Liu, Lanlan Li, Junhao Lu

College of Animal Science & Technology, Gansu Agricultural University, Lanzhou 730070, PR China

Abstract

[Objective] Rainbow trout (*Oncorhynchus mykiss*) is a typical cold-water fish. With global warming and extreme heat, high summer temperatures are the biggest threat to rainbow trout farming. Rainbow trout initiate stress defense mechanisms in response to thermal stimuli, and competing endogenous RNA (ceRNA) regulation of target genes (mRNAs) mediated by non-coding RNAs (microRNAs [miRNAs], long non-coding RNAs) may be the main strategy for responding to thermal stimuli and enhancing adaptation.

[Methods] This study studied on the molecular mechanism of non-coding RNA and its target genes in the regulation of endogenous competitive RNA (ceRNA) in the liver tissues of the normal group (18°C) and the heat stress group (24°C) through high-throughput sequencing and bioinformatics analysis. And the targeting relationship between the key novel-m0007-5p and *hsp90ab1*, LOC110485411 was further verified by dual luciferase reporter gene assay. The role of LOC110485411, novel-m0007-5p and *hsp90ab1* in the regulation of heat stress was further verified at the cellular level by establishing the primary hepatocyte model of rainbow trout.

[Results] We screened the LOC110485411–novel-m0007-5p–*hsp90ab1* ceRNA relationship pairs for affect heat stress in rainbow trout and validated their targeting relationships and functions based on preliminary high-throughput sequencing analysis results. The transfection of exogenous novel-m0007-5p mimics and inhibitors into primary rainbow trout hepatocytes effectively bound and inhibited the target genes *hsp90ab1* and LOC110485411 without significant effects on hepatocyte viability, proliferation, and apoptosis. The inhibitory effect of novel-m0007-5p overexpression on *hsp90ab1* and LOC110485411 under heat stress was time-efficient. Similarly, small interfering RNAs (siRNAs) affected *hsp90ab1* mRNA expression by silencing LOC110485411 expression time-efficiently.

[Conclusions] In conclusion, we found that in rainbow trout, LOC110485411 and *hsp90ab1* can bind competitively to novel-m0007-5p via ‘sponge adsorption’ and that interference with LOC110485411 affects *hsp90ab1* expression. These results provide potential for anti-stress drug screening in rainbow trout.

资助项目：国家自然科学基金地区项目（31660727）、国家自然科学基金地区项目（31660735）、甘肃农业大学青年教师基金（GAU-DK-QNJJ-202101）

通讯作者：权金强，E-Mail: quanjinqiang@163.com

Key words: Rainbow trout, heat stress, ceRNA, non-coding RNA, regulatory mechanism

Foxq1 靶向 gyk 调节大口黑鲈糖稳态的机制研究

雷彩霞¹, 宋含茹^{1,2}, 宋红梅¹, 李胜杰^{1*}

(1. 中国水产科学研究院珠江水产研究所, 广东 广州 510380; 2. 湖州师范学院生命科学学院, 浙江 湖州 313000)

摘要:【目的】探究 gyk 介导 foxq1 调控大口黑鲈糖稳态的作用和机制, 从而为降低饲料鱼粉添加水平提供参考。【方法】克隆 gyk 和 foxq1 基因序列, 分析其组织表达分布及高糖日粮对基因表达影响; 综合利用荧光素酶报告基因、碱基突变等技术探究 foxq1 对 gyk 的转录调节; 构建 gyk 和 foxq1 的腺病毒过表达和干扰重组质粒, 转染后检测肝脏、肌肉和血浆的多种指标的变化。【结果】1) 本研究获得 gyk 基因 5'端侧翼序列 2056 bp, 完整编码区序列 1686 bp; Foxq1 基因完整编码区序列 843bp。组织表达谱分析发现 gyk 基因在肌肉组织表达最高, 其次为肝脏和脂肪, 而在脾脏和肾脏的表达量最低; Foxq1 在肌肉和肝脏中表达量最高, 在肾脏和脾脏中表达量最低。在饲喂高淀粉饲料后 24h 内, 其两个基因在肝脏和肌肉组织中表达量与血糖浓度均呈先上升后下降的变化趋势; 2) 构建 5 个 gyk 启动子不同长度载体 (-10~-2056 bp; -10~-1652 bp; -10~-1367 bp; -10~-823 bp; -10~-595 bp), 荧光素酶报告基因显示-1652~-2056 bp 序列的缺失导致荧光素酶信号较全长序列明显减弱, 表明其最小活性区域位于-1652~-2056 bp 之间。利用生物信息学分析在此区域内发现转录因子 foxq1 的结合位点。因此, 构建 foxq1 的过表达质粒与 gyk 全长启动子载体进行 HEK293T 细胞共转染, 发现过表达 foxq1 能显著增强 gyk 的启动子活性。此外, 利用碱基突变对 foxq1 潜在结合位点进行突变, 发现突变后的 gyk 启动子活性较对照组显著下降; 3) 利用腺病毒构建 gyk 和 foxq1 过表达载体和干扰序列, 发现 gyk 和 foxq1 的表达与大口黑鲈血糖水平呈负相关, 对胰岛素分泌具有正向调节作用, 但对血浆甘油三酯、胆固醇、低密度脂蛋白胆固醇和高密度脂蛋白胆固醇含量无显著影响; 在过表达和 shRNA 介导的 gyk 和 foxq1 敲降试验中, 发现 gyk 和 foxq1 对肝脏和肌肉中参与甘油三酯合成、糖酵解、糖原合成和磷酸戊糖途径的关键基因表达有正向调控作用; 对肝脏和肌肉中参与葡萄糖生成的关键基因有负调控作用。此外, 过表达 gyk 的基础上干扰 foxq1, 发现试验鱼血糖较 gyk 过表达组显著上升, 而在干扰 gyk 的基础上进行 foxq1 基因过表达, 发现试验鱼血糖较 gyk 敲降组显著下降。【结论】gyk 介导 foxq1 通过促进胰岛素分泌、糖原合成和磷酸戊糖途径, 抑制葡萄糖生成, 而对促进葡萄糖转化为甘油三酯作用较弱。本研究结果可丰富鱼类糖稳态调节理论, 为提高大口黑鲈碳水化合物的利用率和减少日粮鱼粉提供了参考。

关键词: 大口黑鲈; 糖稳态; Gyk; Foxq1

Mechanism of foxq1 targeting gyk to regulate glucose homeostasis in largemouth bass and development of Indel markers

Lei caixia¹, Song hanru^{1,2}, Song hongmei¹, Li shengjie^{1,*}

¹*Pearl River Fisheries Research Institute, China Academy of Fishery Sciences, Guangzhou China 510380;*

²*College of Life Science, Huzhou University, Huzhou China 313000)*

Abstract: [Objective] To investigate the role and mechanism of gyk-mediated foxq1 in regulating sugar homeostasis in largemouth bass, so as to provide a reference for reducing the level of feed fishmeal addition. [Methods] We cloned the sequences of gyk and foxq1 genes, analysed the distribution of their expression in tissues and the effects of high-sugar diets on gene expression; investigated the transcriptional regulation of gyk by foxq1 using a combination of luciferase reporter genes and base mutations; constructed adenoviral overexpression and interference recombinant plasmids for gyk and foxq1, and detected the changes of various indexes in the liver, muscle and blood plasma after transfection. [Results] 1) In this study, we obtained 2056 bp of flanking sequence at the 5' end of gyk gene, 1686 bp of complete coding region sequence; 843 bp of complete coding region sequence of foxq1 gene, and the highest expression of gyk gene was found in muscle tissues, followed by liver and adipose, and the lowest expression was found in spleen and kidneys; and the highest expression of foxq1 was found in muscle and liver, and the lowest expression was found in spleen and kidney. muscle and liver, and lowest in kidney and spleen. The expression of its two genes in liver and muscle tissues showed a trend of increasing and then decreasing in relation to blood glucose concentration within 24 h after feeding high starch diets. 2) Construction of five gyk promoter vectors of different lengths (-10~-2056 bp; -10~-1652 bp; -10~-1367 bp; -10~-823 bp; -10~-595 bp), the luciferase reporter gene showed that the deletion of the -1652~-2056 bp sequence resulted in a significantly weaker luciferase signal compared to the full-length sequence, suggesting that the region of minimal activity is located between -1652~-2056 bp. Bioinformatics analysis was used to identify the binding site for the transcription factor foxq1 within this region. Therefore, an overexpression plasmid of foxq1 was constructed and co-transfected with the gyk full-length promoter vector in HEK293T cells, and it was found that overexpression of foxq1 significantly enhanced the promoter activity of gyk. In addition, the potential binding site of foxq1 was mutated using base mutation, and it was found that the promoter activity of mutated gyk was significantly decreased compared with that of the control group. 3) Using adenoviruses to construct gyk and foxq1 overexpression vectors and interfering sequences, it was found that the expression of gyk and foxq1 was negatively correlated with the blood glucose level of the Largemouth Bass, and positively regulated insulin secretion, but it was not on the plasma triglycerides, cholesterol, LDL cholesterol and HDL cholesterol. In the overexpression and shRNA-mediated knockdown

assays of *gyk* and *foxq1*, it was found that *gyk* and *foxq1* positively regulated the expression of key genes involved in triglyceride synthesis, glycolysis, glycogen synthesis and pentose phosphate pathway in the liver and muscle, and negatively regulated the expression of key genes involved in gluconeogenesis in the liver and muscle. and negatively regulated the expression of key genes involved in gluconeogenesis in liver and muscle. In addition, disrupting *foxq1* on the basis of overexpression of *gyk* showed a significant increase in blood glucose compared with the *gyk* overexpression group, while overexpression of *foxq1* on the basis of disrupting *gik* showed a significant decrease in blood glucose compared with the *gyk* knockdown group. [Conclusion] *gyk* mediates *foxq1* to inhibit gluconeogenesis by promoting insulin secretion, glycogen synthesis, and pentose phosphate pathway, while it has a weak effect on promoting the conversion of glucose to triglycerides. The results of this study may enrich the theory of sugar homeostasis regulation in fish and provide a reference for improving carbohydrate utilisation and reducing dietary fish meal in largemouth bass.

Key words: Largemouth bass; Glucose homeostasis; *Gyk*; *Foxq1*

IL-22 调控葡聚糖硫酸钠(DSS)诱导斑马鱼肠炎的作用机制研究

师文凯¹, 王文韬¹, 梁书菲¹, 翁以卓¹, 王志浩¹, 陈梦麒¹, 艾庆辉^{1,2}, 麦康森^{1,2}, 万敏^{1,2*}

(1. 中国海洋大学海水养殖重点实验室(教育部)、水产动物营养与饲料重点实验室(农业农村部), 山东 青岛 266003; 2. 青岛海洋科学与技术国家实验室, 海洋渔业科学与食物产出过程功能实验室, 山东 青岛 266237)

摘要: 在高密度规模化养殖模式下, 鱼类的生存环境愈发复杂, 导致肠炎频发并引发大规模鱼类死亡, 给水产养殖业带来了巨大的经济损失。白细胞介素-22 (Interleukin-22, IL-22) 作为一种重要的细胞因子, 在调节肠道免疫系统中发挥着关键作用。然而, 目前的研究表明, IL-22 在不同动物模型中的作用机制和效果存在显著差异。本文以野生型斑马鱼和 IL-22 敲除型斑马鱼为研究对象, 采用葡聚糖硫酸钠 (DSS) 诱导的肠炎模型, 探究 IL-22 在斑马鱼肠道炎症过程中的作用及其具体机制。主要研究结果如下: (1) 在葡聚糖硫酸钠 (DSS) 诱导的模型中, 与野生型斑马鱼相比, IL-22 敲除型斑马鱼的存活率显著提高, 炎症因子的表达明显下降, 且肠道的结构与功能更加完整。(2) 在 DSS 模型下, 相较于野生型斑马鱼, IL-22 敲除型斑马鱼中内质网应激相关基因和蛋白的表达显著下调, 肠道纤维化现象得到显著改善。(3) 肠道菌群分析结果显示, IL-22 敲除型斑马鱼的肠道生丝微菌属 (*Hyphomicrobium*) 细菌含量显著增加, 其代谢产物吡咯喹啉醌的产量亦明显提升。(4) 在 DSS 模型中, 添加吡咯喹啉醌可显著降低斑马鱼炎症因子的表达, 缓解内质网应激反应, 并改善肠道结构。

综上所述, 本研究揭示了 IL-22 在斑马鱼中 DSS 诱导的肠炎发病机制, 并探讨了生丝微菌及其代谢产物吡咯喹啉醌对斑马鱼肠道炎症的缓解作用, 强调了其作为水产养殖中有益饲料添加剂的潜在应用价值。

关键词: IL-22; 肠道炎症; 生丝微菌; 吡咯喹啉醌

Study on the Mechanism of IL-22 in Regulating DSS-Induced Enteritis in Zebrafish

Wenkai Shi¹, Wentao Wang¹, Shufei Liang¹, Yizhuo Weng¹, Zhihao Wang¹, Mengqi Chen¹,
Qinghui Ai^{1,2}, Kangsen Mai^{1,2}, Min Wan^{1,2,*}

(1. Key Laboratory of Mariculture (Ministry of Education and), and Key Laboratory of Aquaculture Nutrition and Feed (Ministry of Agriculture and Rural Affairs), Ocean University of China, Qingdao China 266003; 2. Laboratory for Marine Fisheries Science and Food Production Processes, Qingdao National Laboratory for Marine Science and Technology, Qingdao China 266237)

Abstract: Under high-density, large-scale aquaculture systems, the living environment for fish has become increasingly complex, leading to frequent occurrences of enteritis and resulting in massive fish mortality, which has caused significant economic losses in the aquaculture industry. Interleukin-22 (IL-22), an important cytokine, plays a crucial role in regulating the intestinal immune system. However, current research indicates that the mechanisms and effects of IL-22 vary significantly across different animal models. This study focuses on wild-type zebrafish and IL-22 knockout zebrafish, utilizing a dextran sulfate sodium (DSS)-induced enteritis model to investigate the role of IL-22 in the intestinal inflammation process of zebrafish and its underlying mechanisms. The main findings of the study are as follows: (1) In the dextran sulfate sodium (DSS)-induced model, IL-22 knockout zebrafish exhibited a significantly higher survival rate compared to wild-type zebrafish, with a marked decrease in the expression of inflammatory factors and a more intact structure and function of the intestine. (2) Under the DSS model, the expression of endoplasmic reticulum stress-related genes and proteins was significantly downregulated in IL-22 knockout zebrafish compared to wild-type zebrafish, resulting in a notable improvement in intestinal fibrosis. (3) Analysis of the intestinal microbiota revealed a significant increase in the abundance of *Hyphomicrobium* in the intestines of IL-22 knockout zebrafish, along with a marked enhancement in the production of its metabolite, pyrroloquinoline quinone. (4) In the DSS model, the addition of pyrroloquinoline quinone significantly reduced the expression of inflammatory factors in zebrafish, alleviated endoplasmic reticulum stress responses, and improved intestinal structure.

In conclusion, this study elucidates the role of IL-22 in the pathogenesis of DSS-induced enteritis in zebrafish and explores the alleviating effects of *Hyphomicrobium* and its metabolite, pyrroloquinoline quinone, on intestinal inflammation in zebrafish. This research underscores the potential application value of these findings as beneficial feed additives in aquaculture.

Key words: IL-22; intestinal inflammation; *Hyphomicrobium*; pyrroloquinoline quinone.

资助项目：国家自然科学基金面上项目（32473175），国家重点研发计划“海洋农业与淡水渔业科技创新”重点专项（2023YFD2400600）

通讯作者：万敏，E-Mail: wanmin@ouc.edu.cn

Mfn2 介导的线粒体融合促进黄颡鱼的脂肪酸 β -氧化

王令娇¹, 罗智¹, 宋玉峰^{1*}

(1. 华中农业大学水产学院, 湖北 武汉 430070)

摘要: 【目的】线粒体是脂肪酸 β -氧化的主要场所, 因此, 线粒体的完整性与稳态是脂肪酸 β -氧化的基础。而线粒体作为双层膜结构的细胞器, 需要不断的融合与分裂来维持其稳态。然而, 目前就线粒体如何直接影响脂肪酸 β -氧化尚无证据。此外, 饲料脂肪酸配比优化缓解鱼类肝脂沉积的机制仍有待深入。【方法】因此, 本研究以黄颡鱼为研究对象, 设定不同棕榈油 (PA) /鱼油(FO)比例的饲料, 投喂 8 周后取其肝脏分析。【结果】本研究取得的主要结论如下: 1, 适量棕榈油替代鱼油可通过激活脂肪酸 β -氧化而缓解黄颡鱼肝脂沉积情况; 2, 适量棕榈油替代鱼油可经抑制 Mfn-2 泛素化, 而激活黄颡鱼肝脏内的线粒体融合机制; 3, Mfn-2 可经其自身的 GTPase-domain 与 Cpt-1 α 产生蛋白互作机制, 而互作机制又可以直接促进下游脂肪酸 β -氧化。【结论】更为重要的是, 本研究首次发现 Mfn-2 介导线粒体融合可通过促进脂肪酸进入线粒体的速率而调控线粒体的 β -氧化。

关键词: Mfn2; 线粒体融合; 脂肪酸 β -氧化; Cpt1 α ; 脂肪酸配比

Moderate replacement of fish oil with palmitic acid-stimulated mitochondrial fusion promotes β -oxidation by Mfn2 interacting with Cpt1 α via its GTPase-domain

Ling-jiao Wang¹, Zhi Luo¹, Yu-Feng Song^{1*},

(1. Fishery College, Huazhong Agricultural University, Wuhan 430070, China)

Abstract: [Objective] Since mitochondrial matrix is the main site where the fatty acids (FAs) β -oxidation takes place. Meanwhile, maintenance of mitochondrial integrity and homeostasis, which is achieved through continual fusion, is extremely critical for FAs β -oxidation. However, despite this well-accepted fact, no study has yet explored whether and how mitochondrial fusion directly promotes FAs β -oxidation. Moreover, the underlying mechanism of a balanced FAs ratio favors hepatic lipid homeostasis are still largely unclear. [Methods] To address these gaps, this study was conducted to investigate the mechanism by which proper dietary FAs ratio promotes hepatic FAs β -oxidation, focusing on the role of Mfn2-mediated mitochondrial fusion regulating Cpt1 α in this process. To this end, a model animal for lipid metabolism, yellow catfish (*Pelteobagrus fulvidraco*), were fed six different diets with a range of FAs ratio in vivo for 8 weeks, and in vitro experiments were conducted to intercept Mfn2-mediated mitochondrial fusion in isolated hepatocytes by transfecting them with si-mfn2, also to demonstrate key regions of Cpt1 α /Mfn2 interactions by constructing the deletion mutants of Mfn2 and Cpt1 α . [Results] The key findings of studies are as follows: 1. Proper palmitic acid (PA) replacing fish oil (FO) was profit for alleviating hepatic lipid accumulation, instead of hepatic health risk, mainly via activating mitochondrial FAs β -oxidation. 2. Proper PA substitute stimulated mfn2-mediated mitochondrial fusion by weakening Mfn2 ubiquitination and then contributing to its protein retention. 3. Mfn2-mediated mitochondrial fusion promoted FAs β -oxidation by Mfn2 directly interacting with Cpt1 α via its GTPase-domains, which is essential for the maintenance of Cpt1 activity. [Conclusion] Importantly, our findings also revealed a previously unidentified mechanism of Mfn2-mediated mitochondrial fusion facilitating FAs β -oxidation by directly enhancing the capability of FA trafficking to mitochondrion (MT), not only by enlarging mitochondrial matrix, which highlighting the critical contribution of mitochondrial fusion in maintaining hepatic lipid homeostasis. Notably, our results confirmed these mechanisms are conservative from fish to mammals.

Key words: Mfn2; Mitochondrial Fusion; β -oxidation; Cpt1 α ; Fatty Acids Ratio

p38MAPK 和 PI3K/Akt 通路在虾青素减轻高糖诱导肝损伤的调控作用

廖志宏¹, 何玄枢¹, 陈安琪¹, 牛津^{1*}

(1 中山大学生命科学院生物防治国家重点实验室, 广东省水生经济动物重点实验室与南方海洋科学与工程广东省重点实验室(珠海), 广州 510260)

摘要: 虾青素 (ASX) 已被证明对鱼类的各种生理过程具有有益的影响。大口黑鲈是研究葡萄糖诱导的肝脏疾病的常用模型, 因此研究其肝脏健康的调节机制非常必要。采用对照组 (CON)、高糖组 (HC) 和高糖+虾青素组 (HCA) 喂养大口黑鲈 8 周, 然后进行葡萄糖耐量试验 (GTT)。采用低糖和高糖联合不同浓度虾青素处理原代肝细胞 48 h, 结合组织病理学、酶学、转录组学、分子生物学和细胞生物学研究大口黑鲈肝损伤机制。本研究为虾青素对高糖喂养的大口黑鲈生长性能降低和肝损伤的保护作用提供了依据。在 GTT 中, HCA 组在葡萄糖负荷后表现出葡萄糖耐量的改善。虽然虾青素并没有恢复 GTT 期间不同时间肝脏中胰岛素抵抗相关基因的表达, 但长期饮食中添加虾青素可以通过调节 PTP1B/PI3K/Akt 信号通路改善了胰岛素抵抗通路。肝脏转录组分析表明, 虾青素在高糖组的葡萄糖稳态的调节中发挥重要作用。在体外研究中, 虾青素处理提高细胞活力和降低细胞凋亡率和体内的活性氧 (ROS)。此外, 虾青素可通过调节 p38MAPK/bcl-2/caspase-3 信号通路改善高糖诱导的细胞凋亡。虾青素通过调控 p38MAPK/bcl-2/caspase-3 通路发挥抗凋亡作用, 通过激活 PTP1B/PI3K/Akt 通路改善胰岛素抵抗。本研究从新的角度阐明了虾青素在大口黑鲈肝损伤中的作用机制, 为胰岛素抵抗的治疗提供了新的靶点。

关键词: 虾青素; 大口黑鲈; 肝损伤; 细胞凋亡; 胰岛素抵抗

资助项目: 国家自然科学基金面上项目 (32172982)

通讯作者: 牛津, E-Mail: niuj3@mail.sysu.edu.cn

Astaxanthin attenuates glucose-induced liver injury in largemouth bass: role of p38MAPK and PI3K/Akt signaling pathways

Zhihong Liao¹, Xuanshu He¹, Anqi Chen¹, Jin Niu^{1*}

(1. State key Laboratory of Biocontrol, Guangdong Provincial Key Laboratory for Aquatic Economic Animals and Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), School of Life Sciences, Sun Yat-Sen University, Guangzhou, 510260)

Abstract: Astaxanthin (ASX) has been documented to exert beneficial influence on various processes in fish. Largemouth bass serves as a common model for studying glucose-induced liver disease, making it imperative to investigate the regulatory mechanisms underlying its liver health. Largemouth bass were fed with a control diet (CON), a high carbohydrate diet (HC), or a HC diet supplemented astaxanthin (HCA) for 8-weeks, followed by the glucose tolerance test (GTT). Primary hepatocytes were treated with low glucose and high glucose combined with different concentrations of astaxanthin for 48 h. The histopathology, enzymology, transcriptomics, molecular biology and cell biology were combined to investigate the mechanism of liver injury. This study provides evidence for the protective effects of ASX against growth performance reduction and hepatic liver injury in largemouth bass fed HC diet. In GTT, HCA diet exhibited an improvement in glucose tolerance following glucose loading. Although HCA diet did not restore the expression of insulin resistance-related genes in livers at different time during the GTT, the addition of ASX in the long-term diet did improve the insulin resistance pathway by regulating the PTP1B/PI3K/Akt signaling pathway. Hepatic transcriptome analyses showed that ASX plays an essential role in the modulation of glucose homeostasis in response to treatment with HC diet. In *in vitro* study, the treatment with ASX resulted in an exaltation in cell viability and a reduction in the rate of cell apoptosis and reactive oxygen species (ROS). Additionally, astaxanthin was observed to improve apoptosis induced by high-glucose via p38MAPK/bcl-2/caspase-3 signaling pathway. In conclusion, astaxanthin exhibited a protective effect against apoptosis by regulating p38MAPK/bcl-2/caspase-3 pathway, and ameliorated insulin resistance by activating the PTP1B/PI3K/Akt pathway. This study elucidated the mechanism of astaxanthin in the liver injury of largemouth bass from a new perspective and provided a new target for the treatment of insulin resistance.

Key Words: Astaxanthin; largemouth bass; liver injury; Apoptosis; insulin resistance

PGC-1 α 介导葡萄糖醛酸内酯缓解高脂饲料引起的大口黑鲈肝 脏线粒体功能及脂质代谢紊乱

刘昊昆^{1,2}, 花罗海^{1,2}, 朱晓鸣^{1,2}, 韩冬^{1,2,3}, 金俊琰^{1,2}, 张志敏^{1,2}, 解绶启^{1,2,3}

(1.中国科学院水生生物研究所水产品种创制与高效养殖重点实验室, 湖北 武汉 430072; 2.中国科学院
大学现代农业科学学院, 中国 北京 100049; 3.湖北生水产动物营养与饲料工程研究中心, 湖北 武汉
430072)

摘要: 葡萄糖醛酸内酯(葡醛内酯)是用于治疗肝脏炎症等肝脏疾病的药物,其在体内的有效形式为葡萄糖醛酸。内源性的葡萄糖醛酸由肝脏产生,通过与毒物及药物结合,形成无毒或低毒的葡萄糖醛酸结合物而由尿排出。为研究葡萄糖醛酸内酯对高脂饲料诱导大口黑鲈(*Micropterus salmoides*)生长、健康和脂肪肝的影响,实验设计了对照饲料(LFD、10%粗脂肪)、高脂饲料(HFD、15%粗脂肪)和高脂饲料中添加不同梯度的葡醛内酯(200、400、600、800和4000mg/kg)处理组,进行了为期8周的养殖实验。结果表明,高脂饲料中添加400-600mg/kg葡醛内酯显著促进大口黑鲈的生长性能($P<0.05$),根据SGR和葡醛内酯添加水平的二次拟合曲线得出大口黑鲈高脂饲料中的葡醛内酯的最适添加水平为583.29mg/kg。高脂饲料中添加葡醛内酯减轻了高脂饲料诱导的脂肪肝,表现为血浆和肝脏脂质积累水平下降,以及脂代谢、氧化应激、炎症和细胞凋亡的改善。高脂饲料中添加葡醛内酯上调了PGC-1 α 、NRF1和TFAM的表达($P<0.05$),促进线粒体生物发生;改善了三羧酸循环,抑制线粒体氧化磷酸化相关蛋白(COX4、NDUFA2)的异常激活($P<0.05$);抑制Parkin/Pink1介导的线粒体自噬,从而增强线粒体功能。抑制剂SR-18292处理降低了葡醛内酯缓解高脂诱导的脂质代谢紊乱以及线粒体功能障碍的作用。进一步通过蛋白互作预测、分子对接和染色质免疫共沉淀实验,验证PGC-1 α 介导了葡醛内酯发挥的改善线粒体功能和脂质代谢紊乱的作用。

关键词: 葡醛内酯; 脂肪肝; PGC-1 α ; 线粒体; 大口黑鲈

PGC-1 α mediates glucuronolactone alleviation of high-fat feed-induced disorders of hepatic mitochondrial function and lipid metabolism in largemouth bass

Haokun Liu^{1,2}, Luohai Hua^{1,2}, Xiaoming Zhu^{1,2}, Dong Han^{1,2,3}, Junyan Jin^{1,2}, Zhimin Zhang^{1,2},
Shouqi Xie^{1,2,3}

(1. State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan China 430072; 2. College of Advanced Agricultural Sciences, University of Chinese Academy of Sciences, Beijing China 100049; 3. Hubei Engineering Research Center for Aquatic Animal Nutrition and Feed, Wuhan 430072, China)

Abstract: Glucuronolactone is a drug used to treat liver diseases such as liver inflammation and metabolic fatty liver, and its active form in the body is glucuronic acid. Endogenous glucuronic acid is produced by the liver and excreted in the urine by binding to poisons and drugs to form non-toxic or low-toxic glucuronic acid conjugates. To investigate the effect of glucuronolactone on growth, health and fatty liver in largemouth bass (*Micropterus salmoides*) induced by high-fat diets, experiments were designed with the control diets (LFD, 10% crude fat), high-fat diets (HFD, 15% crude fat), and high fat diet supplemented with different gradients of glucuronolactone (Glu) (200, 400, 600, 800 and 4000 mg/kg) groups for an 8-week breeding experiment. The results showed that fish fed HFD supplemented with 400-600 mg/kg Glu significantly promoted the growth performance, and the optimal level of Glu was 583.29 mg/kg in HFD for largemouth bass. Supplementation of Glu also alleviated fatty liver induced by HFD, characterized by the declined accumulation of lipids, the decrease of lipid profile in plasma, and the improvement of lipid metabolism, oxidative stress, inflammation and apoptosis. In terms of mitochondrial function, fish fed HFD supplemented with Glu up-regulated the expression of PGC-1 α , NRF1 and TFAM, promoted mitochondrial biogenesis; In addition, supplemented with Glu also recovered TCA cycle metabolism, inhibited the abnormal activation of mitochondrial oxidative phosphorylation, elevated mitochondrial membrane potential, inhibited mitochondrial autophagy. The inhibition of PGC-1 α reduced the effects of Glu. Furthermore, the results of protein interaction prediction, molecular docking, and ChIP indicated that Glu could improve mitochondrial dysfunction through the regulation of PGC-1 α to reduce oxidative stress, inflammation and lipid metabolism disorder induced by HFD.

Key words: Glucuronolactone; fatty liver; PGC-1 α ; mitochondria; largemouth bass

VD₃对高糖日粮饲养下黄鳝的生长、存活率及糖代谢能力的影响

罗天伦¹, 吴杉杉¹, 李加敏¹, 沈凯凯², 方鹏¹, 蒋家威¹, 彭墨*²

(1. 江西农业大学, 动物科学技术学院, 江西 南昌 330045; 2. 南昌大学, 生命科学学院, 江西南昌 330031)

摘要: 为研究高糖饲料中添加 VD₃ 对黄鳝存活率及糖代谢的影响, 选取健康的黄鳝幼鱼[初体重(17.13±0.08)g]为实验对象, 随机分为 3 组, 每组 4 个重复, 每个重复 60 尾鱼, 分别投喂正常糖水平(15%)、高糖水平(35%)和高糖水平添加 2 000 IU/kg 维生素 D₃ (分别命名 CON 组、HC 组和 HCVD₃ 组)的 3 种等氮等脂饲料, 进行为期 8 周的养殖实验。结果显示, 各实验组生长性能及体成分均无显著影响; HC 组存活率显著下降, 添加 VD₃ 后, 存活率显著增加, 且与 CON 组差异不显著。HCVD₃ 组脏体指数和肥满度较 HC 组均显著上升。血清谷丙转氨酶 (ALT) 和谷草转氨酶 (AST) 含量在 HC 组达到最大值; 血清甘油三酯 (TG) 含量在 HCVD₃ 组达到最大值。肠道淀粉酶和胰蛋白酶的活性 HC 组显著低于其他各组, 而胰蛋白酶活性显著高于其他各组。HC 组黄鳝肝脏中糖原含量较 CON 组显著升高, 己糖激酶 (HK) 和磷酸果糖激酶 (PFK) 活性也显著升高; HCVD₃ 组肝糖原含量较 HC 组显著下降, 且 PFK 活性显著高于 HC 组。肌肉 PFK 活性在 HCVD₃ 组达到最高值。HC 组黄鳝肝脏和肠道过氧化氢酶(CAT)活性均显著低于 CON 组, 添加 VD₃ 后, 总超氧化物歧化酶(T-SOD)均显著升高, 丙二醛 (MDA) 活性均显著降低。HCVD₃ 组黄鳝肠道促炎细胞因子 (*il-1β*、*myd88*)、抗炎细胞因子 (*il-10*) 和肠道紧密连接蛋白基因 (*zo-1*、*zo-2*、*claudin-12*) 相对表达量显著优于 HC 组。研究表明, 在本实验条件下, 高糖 (35%) 日粮会显著降低实验鱼的存活率、增加肝糖原积累、降低其抗氧化能力、并破坏肠道健康; 而高糖饲料中添加 2 000 IU/kgVD₃ 后, 可通过增强鱼体抗氧化能力和免疫力, 改善肠道屏障功能, 进而提高鱼体存活率; 此外, 高糖饲料中添加 VD₃ 会增强鱼体对糖的利用能力。本研究可为黄鳝的糖代谢调控和人工饲料的配置提供基础理论依据和指导。

关键词: 黄鳝; VD₃; 糖代谢; 抗氧化能力; 肠道健康

资助项目: 国家自然科学基金项目 (31960732); 江西省“双千项目”首批培养类项目 (自然科学类) 科技创新高端人才 (青年) 项目 (jxsq2019201081)

第一作者: 罗天伦, 研究方向: 从事水产动物营养与饲料研究, E-mail: 2499054254@qq.com

通信作者: 彭墨, 研究方向: 从事水产动物营养与饲料研究, E-mail: pengmowell@jxau.edu.cn

The effects of high carbohydrate diet supplemented with VD₃ can improve the survival rate and glucose metabolism ability of rice field eel (*Monopterus albus*)

Tianlun Luo¹, Shanshan Wu¹, Jiamin Li¹, Kaikai Shen², Peng Fang¹, Jiawei Jiang¹, Mo Peng^{1*}

(1. College of Animal Science and Technology, Jiangxi Agricultural University, Nanchang 330045, China;

2. School of Life Science, Nanchang University, Nanchang 330031, China)

Abstract: To investigate the impact of dietary vitamin D₃ (VD₃) on the survival rate and glucose metabolism ability of *Monopterus albus* fed high-carbohydrate diets, healthy *M. albus* juveniles (17.13±0.08g) were assigned into 3 groups, each with 4 replicates of 60 fish. The fish were fed diets with normal, high carbohydrate level, and high carbohydrate level supplementing with 2 000 IU/kg VD₃ (referred to as CON, HC and HCVD₃ groups, respectively). After 8 weeks, no significant differences in growth performance or body composition were observed among the groups. However, The survival rate of HC group was significantly decreased, but after addition of VD₃, SR was significantly increased, and the difference was not significant compared with CON group. The visceral somatic index (VSI) and condition factor (CF) were significantly higher in the HCVD₃ group than in the HC group. The HC group showed the highest levels of serum alanine aminotransferase (ALT) and aspartate aminotransferase (AST), while the HCVD₃ group had the highest serum triglyceride (TG) content. Intestinal amylase and trypsin activities were lower than in the HC group but higher in lipase. Liver glycogen content in HC group was significantly higher than CON group, as were the activities of hexokinase (HK) and phosphofructokinase (PFK). In contrast, the HCVD₃ group had lower liver glycogen but higher PFK activity. Muscle PFK activity peaked in the HCVD₃ group. Additionally, catalase (CAT) activities in the liver and intestinal tract of *M. albus* were lower in the HC group, while total superoxide dismutase (T-SOD) was increased, and malondialdehyde (MDA) activities were decreased with VD₃ supplementation. The HCVD₃ group also showed significantly higher relative expression levels of intestinal proinflammatory cytokines (*il-1β*, *myd88*), anti-inflammatory cytokines (*il-10*) and intestinal compact linking protein genes (*zo-1*, *zo-2*, *claudin-12*) than the HC group. In conclusion, a high carbohydrate diet reduced the survival rate, increased liver glycogen accumulation, reduced antioxidant capacity, and impaired intestinal health in *M. albus*. Supplementation with 2 000 IU/kg VD₃ mitigated these effects, improving survival and enhancing carbohydrate utilization in fish fed a high-carbohydrate diet. This study provides foundational insights and guidance for glucose metabolism regulation and the artificial feed formulation for *M. albus*.

Key Words: *Monopterus albus*; Vitamin D₃; Glucose metabolism; Antioxidant capacity; Intestinal health

比较两种海水鱼对葡萄糖和果糖的利用：对胰岛素分泌和急性低氧耐受性的影响

马强，徐后国，卫育良，梁萌青*

（中国水产科学研究院黄海水产研究所，山东 青岛 266071）

摘要：【目的】大多数鱼类在摄食高水平碳水化合物饲料后会出现持续性高血糖，但鱼类利用糖的机制还不清楚。【方法】本研究中，分别给红鳍东方鲀和大菱鲆腹腔注射或口服葡萄糖或果糖（500 mg/kg 体重），随后测定了血清葡萄糖、果糖、丙酮酸、胰岛素的含量以及对急性低氧的耐受性。【结果】发现河鲀和大菱鲆在腹腔注射葡萄糖后，血清葡萄糖含量呈现出先升高后降低的趋势，峰值分别出现在注射后的 0.5 小时和 1 小时。河鲀的肝脏糖原、血清葡萄糖、果糖、丙酮酸、胰岛素含量均低于大菱鲆。葡萄糖和果糖只诱导了大菱鲆的胰岛素分泌，但不影响河鲀的胰岛素水平。葡萄糖对胰岛素分泌的刺激作用强于果糖。此外，河鲀和大菱鲆是非常不耐受急性低氧的，但补充葡萄糖和果糖可通过激活无氧糖酵解来提高两种鱼对低氧的耐受性。【结论】本研究的结果对理解鱼类对葡萄糖和果糖的代谢机制以及提高其对低氧的耐受性提供了重要信息。

关键词：葡萄糖耐受；果糖耐受；碳水化合物利用；胰岛素分泌；低氧耐受性

资助项目：国家自然科学基金青年科学基金（32202950）、中国博士后科学基金（2022M713471）

通讯作者：梁萌青，E-mail: liangmq@ysfri.ac.cn

Comparative analysis of glucose and fructose tolerance in two marine fishes: effects on insulin secretion and acute hypoxia tolerance

Qiang Ma, Houguo Xu, Yuliang Wei, Mengqing Liang*

(Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Qingdao China 266071)

Abstract: [Objective] Most fish show a persistent postprandial hyperglycemia after intake of high-carbohydrate diet. However, the mechanism of carbohydrate metabolism in fish is still unclear. [Methods] In the present study, tiger puffer (*Takifugu rubripes*) and turbot (*Scophthalmus maximus*) were intraperitoneally injected or orally administered with glucose or fructose (500 mg/kg body weight). Afterwards, serum glucose, fructose, pyruvate, insulin levels and acute hypoxia tolerance were measured. [Results] Our results showed increased serum glucose level and then decreased post intraperitoneal injection with glucose, and reached a peak after 0.5 hours in turbot and 1 hours in tiger puffer. Tiger puffer had significantly lower liver glycogen, serum glucose, fructose, pyruvate and insulin contents than turbot. Glucose and fructose only induced insulin secretion in turbot, but did not change serum insulin level in tiger puffer. Glucose was a stronger stimulator of insulin than fructose in the two marine species. In addition, turbot and tiger puffer were intolerant to acute hypoxia, whereas supplementation with glucose or fructose improved hypoxia tolerance in the two marine fishes by activating anaerobic glycolysis. [Conclusion] Our results provide important information for understanding the mechanism for glucose and fructose utilization and improving hypoxia tolerance in fish.

Key words: Glucose tolerance test; Fructose tolerance test; Carbohydrate utilization; Insulin secretion; Hypoxia tolerance

ZnO NP 通过 FOXO3 的乙酰化增加 LC-PUFA 含量，从而减少 PO-ER 接触和过氧化物酶体 β 氧化

钟俊城¹, 温小波¹, 吴坤¹

(1. 华南农业大学海洋学院, 广东省岭南现代农业实验室, 广东广州 510642)

摘要:【目的】脂肪酸 (FA) 是一类高度多样化的分子, 可以具有可变的链长、双键数量和羟基化位点。是包括人类在内的脊椎动物正常生长和发育所需的生理上重要的化合物, 可在缓解炎症、心脑血管疾病方面发挥关键作用, 并且对某些类型的癌症有益。【方法】首先我们通过对 ZnO NP 饲喂 10 周的黄颡鱼的肝脏进行全面的评估, 发现其肝脏中脂质积累严重, 并且 LCFA&VLCFA 比值和绝对定量均在肝脏中上升, 通过检查该过程中起作用的酶和基因的水平, 以及超微结构观察到 PO-ER 的接触减少, 我们将 FA 含量与在 FA 代谢的十字网络中发挥重要作用的 ACBD5 基因联系起来。【结果】在这里, 我们发现了一种 ZnO NPs 调控 LCFA&VLCFA 含量的机制, 通过降低 SIRT1 的水平, 阻碍 SIRT1 对 FOXO3 的去乙酰化作用, 影响其胞质定位与进入细胞核与 ACBD5 启动子结合的能力, 抑制 ACBD5 的转录, 导致 ACBD5 表达水平的下降, 影响 LCFA&VLCFA 导入, 过氧化物酶体的 β -oxidation 和 PO-ER 的接触, 最后导致肝脏中 LCFA&VLCFA 含量的上升。【结论】Zn 通过影响 ACBD5 影响 PO-ER 共同构建的 FA 代谢网络, 影响 FA 的含量。

关键词: 超长链脂肪酸; 脂代谢; β -oxidation; 过氧化物酶体; 去乙酰化; SIRT1

ZnO NP increasing LC-PUFA content via the acetylation of FOXO3 reduce PO-ER contacts and peroxisomal β -oxidation

Juncheng Zhong¹, Xiaobo Wen¹, Kun Wu¹

(1. College of Marine Sciences of South China Agricultural University & Guangdong Laboratory for Lingnan Modern Agriculture, Guangzhou 510642, Guangdong, China)

Abstract: (Objective) Fatty acids (FA) are a highly diverse class of molecules that can have variable chain lengths, number of double bonds, and hydroxylation sites. They are physiologically important compounds required for normal growth and development in vertebrates, including humans, and can play a key role in mitigating inflammation, cardiovascular disease, and are beneficial in some types of cancer. (Methods) Firstly, we performed a comprehensive evaluation of the liver of *Pelteobagrus fulvidraco* fed with ZnO NP for 10 weeks, and found that there was a severe accumulation of lipids in the liver and that the LCFA & VLCFA ratio and absolute quantification were increased in the liver. By examining the levels of enzymes and genes that play a role in the process, as well as by ultrastructurally observing the decrease in the contact of the PO-ER, we correlated the FA levels to the ACBD5 gene, which plays an important role in the cross network of FA metabolism. (Results) Here, we identified a mechanism by which ZnO NPs regulate LCFA&VLCFA content by decreasing the level of SIRT1, hindering the deacetylation of FOXO3 by SIRT1, affecting its cytoplasmic localization and ability to enter the nucleus and bind to the ACBD5 promoter, inhibiting ACBD5 transcription, leading to a decrease in the expression level of ACBD5. Zn affects the import of LCFA & VLCFA, the β -oxidation of peroxisomes and the contact of PO-ER, and finally leads to the increase of LCFA & VLCFA content in the liver. (Conclusion) Zn affects FA content by influencing the FA metabolic network co-constructed by PO-ER through affecting ACBD5.

Key words : VLCFA; Lipid metabolism; β -oxidation; Peroxisomes; Deacetylation; SIRT1

丙氨酰-谷氨酰胺对大口黑鲈食源性肠炎的保护作用研究

岳荣艳³, 文军¹, 王鑫棚¹, 林仕梅^{1,2}, 陈拥军^{1,2}, 罗莉^{1,2}, 何远法^{1,2*}

(1. 西南大学水产学院, 水产动物营养与饲料实验室, 重庆 400716; 2. 西南大学, 淡水鱼类资源与生殖发育教育部重点实验室, 重庆 400716)

摘要: 本实验旨在探究丙氨酰-谷氨酰胺 (alanyl-glutamine, AG) 对大口黑鲈食源性肠炎的保护作用, 配制 3 种等氮 (49%) 等脂 (11%) 饲料, 分别为 42%鱼粉组 (正对照, FM), 豆粕替代 50%鱼粉组 (负对照, SBM50), 豆粕基础上添加 1%丙氨酰-谷氨酰胺 (SBM+1%AG)。实验选取 240 尾健康的大口黑鲈幼鱼 (10.40 ± 0.06 g), 随机分为 3 个组, 每组 4 个重复, 每个重复 20 尾, 养殖 8 周。实验结果显示, SBM+1%AG 组末均重、增重率及特定生长率均显著高于 FM 组和 SBM50 组 ($P < 0.05$)。SBM+1%AG 组肠道皱襞高度显著高于 SBM50 组 ($P < 0.05$), 与 FM 组相比无显著差异 ($P > 0.05$)。透射电镜结果发现, SBM50 组出现肠绒毛脱落, 细胞核固缩, 杯状细胞空泡化, 线粒体基质溶解及双层膜溶解等病理性症状, 而 SBM+1%AG 组一定程度能够缓解以上病理性症状。此外, SBM+1%AG 组血清游离氨基酸含量 (包括甘氨酸、丙氨酸、谷氨酰胺、天门冬氨酸、组氨酸、脯氨酸、赖氨酸和蛋氨酸) 均显著高于 SBM50 组 ($P < 0.05$)。SBM+1%AG 组血清半胱天冬蛋白酶-3 含量显著低于 SBM50 和 FM 组 ($P < 0.05$)。综上所述, 丙氨酰-谷氨酰胺能够缓解高水平豆粕诱发的肠道炎症和生长性能下降, 其潜在的保护机制需进一步深入研究。

关键词: 丙氨酰-谷氨酰胺; 大口黑鲈; 肠道炎症; 透射电镜

资助项目: 国家自然科学基金 (32202951), 中央高校基本科研业务费项目 (SWU-KQ22069)

通讯作者: 何远法, E-mail: heyuanfa2022@swu.edu.cn

Studies on the protective effect of alanyl-glutamine against foodborne enteritis in largemouth bass (*Micropterus salmoides*)

Rongyan Yue¹, Jun Wen¹, Xinpeng Wang¹, Shimei Lin^{1,2}, Yongjun Chen^{1,2}, Li Luo^{1,2}, Yuanfa He^{1,2*}
(1. Laboratory of Aquatic Animal Nutrition and Feed, College of Fisheries, Southwest University, Chongqing 400715, P.R. China; 2. Key Laboratory of Freshwater Fish Reproduction and Development (Ministry of Education), Southwest University, Chongqing 400715, P.R. China)

Abstract: The aim of this experiment was to investigate the protective effect of alanyl-glutamine (AG) on foodborne enteritis in largemouth bass (*Micropterus salmoides*). Three isonitrogenous (49%) and isolipidic (11%) feeds were formulated: 42% fishmeal group (positive control, FM), soybean meal replacing 50% fishmeal group (negative control, SBM50), and soybean meal based on 1% alaninyl-glutamine (SBM+1% AG). Two hundred and forty healthy juvenile largemouth bass (10.40 ± 0.06 g) were selected for the experiment and randomly divided into three groups 3 groups in quadruplicate with 20 fish per tank. The results of the 8-week experiment showed that the final average weight, weight gain rate and specific growth rate of the SBM+1%AG group were significantly higher than those of the FM and SBM50 groups ($P < 0.05$). The folds height of intestinal tract of the SBM+1%AG group was significantly higher than that of the SBM50 group ($P < 0.05$), and there was no significant difference compared with that of the FM group ($P > 0.05$). Transmission electron microscopy results revealed that the SBM50 group showed pathological symptoms such as intestinal villi detachment, nucleus consolidation, vacuolization of cuprocytes, mitochondrial matrix and bilayer membrane dissolution, while the SBM+1%AG group was able to alleviate the above pathological symptoms to some extent. In addition, the serum free amino acid contents (including glycine, alanine, glutamine, aspartate acid, hstidine, proline, lysine and methionine) of the SBM+1%AG group were significantly higher than those of the SBM50 group ($P < 0.05$). The serum caspase-3 level was significantly lower in the SBM+1%AG group than in the SBM50 or FM group ($P < 0.05$). In conclusion, alanyl-glutamine was able to alleviate intestinal inflammation and growth performance reduction induced by high levels of soybean meal, and its potential protective mechanism needs to be further investigated in depth.

Keywords: Alanyl-glutamine; Largemouth bass; Intestinal inflammation; Transmission electron microscopy

不同温度下花鲈对饲料磷需要量的研究

郭家荣^{1,2}, 李学山^{1*}, 鲁康乐¹, 宋凯¹, 王玲¹, 张春晓^{1*}

(1. 集美大学水产学院厦门市饲料质量检测与安全评价重点实验室, 厦门 361021;

2. 湖南省水产科学研究所 长沙 410153)

摘要:【目的】本研究以花鲈(3.53±0.34g)为研究对象,探究饲料磷水平对适温(27°C)和高温(33°C)饲养下花鲈的生长性能、脂代谢、抗氧化状态和肠道微生物群的影响。【方法】分别配制了五种有效磷水平分别为0.35%、0.55%、0.71%、0.82%和0.92%的饲料,实验期间每天投喂两次,持续10周。【结果】与27°C相比,33°C的水温显著降低了花鲈的生长性能和饲料利用率,并造成花鲈氧化应激和脂肪异常沉积。同时,高温增加了花鲈对磷的摄入量和抗氧化酶的活性,并改变花鲈肠道微生物组成(如增加*Bacillus*的丰度)以适应高温环境。在饲料中添加0.55%-0.82%的磷可以缓解因磷摄入不足引起的脂质过度沉积和脂质代谢紊乱。此外,在饲料中添加0.71%-0.92%的磷可以增加花鲈肠道微生物群的多样性和潜在的益生菌(如*Lactococcus*与*Bacillus*)的丰度,减少潜在的致病菌(*Plesiomonas*)的丰度。【结论】以增重率为评价指标,二次回归模型分析表明,花鲈在27°C和33°C条件下的最适饲料磷水平分别为0.72%和0.78%。

关键词:花鲈; 磷; 温度; 生长; 肠道菌群

Dietary phosphorus requirement of spotted seabass (*Lateolabrax maculatus*) reared at different temperatures

Jiarong Guo^{1,2}, Xueshan Li^{1*}, Kangle Lu¹, Kai Song¹, Ling Wang¹, Chunxiao Zhang^{1*}

(1.Xiamen Key Laboratory for Feed Quality Testing and Safety Evaluation, Fisheries College, Jimei University, Xiamen 361021, People's Republic of China 2.Hunan Fisheries Science Institute, Changsha 410153, , People's Republic of China)

Abstract: [Objective] This study was conducted to investigate the effects of dietary phosphorus levels on growth performance, lipid metabolism, antioxidant status and intestinal microflora of spotted seabass (3.53 ± 0.34 g) at moderate (27°C) and high (33°C) temperatures. [Methods] Five diets were formulated with effective phosphorus levels of 0.35%, 0.55%, 0.71%, 0.82% and 0.92%, respectively, and fed twice daily for 10 weeks during the experimental period. [Results] Water temperature of 33°C significantly reduced growth performance and feed utilization, and caused oxidative stress and abnormal fat deposition in spotted seabass compared with 27°C. Meanwhile, high temperature increased the phosphorus uptake and antioxidant enzyme activity, and changed the intestinal microflora composition (e.g., increased abundance of *Bacillus*) of spotted seabass to adapt to the high temperature environment. The addition of 0.55%-0.82% phosphorus to the diet alleviated the excessive lipid deposition and lipid metabolism disorders caused by insufficient phosphorus intake. In addition, the addition of 0.71%-0.92% phosphorus to the diet increased the diversity of intestinal microflora and the abundance of potentially probiotic bacteria (e.g., *Lactococcus* and *Bacillus*) and reduced the abundance of potentially pathogenic bacteria (*Plesiomonas*) in spotted seabass. [Conclusion] Using weight gain rate as an evaluation indicator, quadratic regression model analysis showed that the optimum feed phosphorus levels for spotted seabass reared at 27°C and 33°C were 0.72% and 0.78%, respectively.

Key words: *Lateolabrax maculatus*; phosphorus; temperature; growth; intestinal microflora

资助项目：国家自然科学基金（项目号：31972804 和 32202955）

通讯作者：张春晓，E-mail: cxzhang@jmu.edu.cn；李学山，E-mail: xsli@jmu.edu.cn

不同脂肪源对黄鳢生长性能、抗氧化力、脂肪代谢和肠道健康的影响

罗澳¹, 李加敏¹, 彭墨^{1*}

(1. 江西农业大学动物科学技术学院, 江西 南昌 330045)

摘要:【目的】本试验旨在研究饲料中添加不同的脂肪源对黄鳢(初始体重: $22.01 \pm 0.01\text{g}$)生长性能、抗氧化力、脂肪代谢和肠道健康的影响。【方法】根据饲料中分别添加的鱼油(FO组)、黑水虻油(BSFO组)、棕榈油(PO组)、橄榄油(OO组)和大豆油(SO组)的不同, 1200尾黄鳢被随机分为6个处理组。每个处理4个重复, 饱食投喂56d。【结果】黑水虻油组末均重、增重率和特定生长率与鱼油组无显著差异($P > 0.05$), 其余组均显著低于鱼油组($P < 0.05$)。与鱼油组相比, 橄榄油组和大豆油组显著增加了脏体比($P < 0.05$), 而各组间成活率、饲料转化率、肝体比和肥满度均无显著差异($P > 0.05$)。与鱼油组相比, 橄榄油组和大豆油组全鱼粗脂肪含量显著提高($P < 0.05$)。对肝脏脂肪含量来讲, 棕榈油组与大豆油组无显著差异($P > 0.05$), 但显著高于其余组($P < 0.05$), 这与肝脏油红O切片结果相似; 各组间肌肉脂肪含量无显著差异($P > 0.05$)。另外, 黑水虻油组肝脏超氧化物歧化酶(SOD)及谷胱甘肽过氧化物酶(GPX)活性与鱼油组无显著性差异($P > 0.05$), 且显著高于其余组($P < 0.05$); 而橄榄油组过氧化氢酶(CAT)活性显著高于棕榈油和大豆油组($P < 0.05$), 但与鱼油组与黑水虻油组无显著差异($P > 0.05$)。棕榈油组肠道SOD活性显著高于其余组($P < 0.05$), 大豆油组GPX活性显著低于其余组($P < 0.05$)。与鱼油组相比, 大豆油组显著增强了肝脏脂肪酸合成酶(*fas*)、乙酰辅酶A羧化酶(*acc*)、肝脂酶(*hl*)和激素敏感性脂肪酶(*hsl*)的活性($P < 0.05$), 且显著上调了过氧化物增值受体(*ppara*)、二酯酰甘油酰基转移酶2(*dgat2*)、苹果酸酶1(*me1*)、单酰基甘油脂肪酶(*mgll*)、*acc*和*hsl*等基因的mRNA表达量($P < 0.05$)。与鱼油组相比, 其余各组均显著上调了肠道紧密连接蛋白*zo1*(*zo-1*)和*zo2*(*zo-2*)基因的mRNA表达量($P < 0.05$), 黑水虻油组、橄榄油组和大豆油组显著上调了紧密连接蛋白*claudin1*(*claudin-1*)基因的mRNA表达量($P < 0.05$), 但仅黑水虻油组提高了闭合蛋白(*occludin*)基因的mRNA表达量($P < 0.05$)。【结论】本研究表明, 黑水虻油替代鱼油对黄鳢生长性能无影响, 且黑水虻油可提高肝脏抗氧化力、降低肝脂沉积、增强肠道屏障功能, 发挥促进肝肠健康的作用。棕榈油、橄榄油和大豆油替代鱼油会对生长性能、全鱼体脂肪等方面产生不利影响。(未发表)

关键词: 黄鳢; 脂肪源; 生长性能; 抗氧化力; 脂肪代谢; 肠道健康

Effects of different lipid sources on growth performance, antioxidant capacity, lipid metabolism and intestinal health of rice field eel (*Monopterus albus*)

Ao Luo¹, Jiamin Li¹, Mo Peng^{1*}

(1. College of Animal Science and Technology, Jiangxi Agricultural University, Nanchang China 330045)

Abstract: [Objective] The aim of this experiment was to investigate the effect of different lipid sources added to the feed on growth performance, antioxidant capacity, lipid metabolism and intestinal health of *Monopterus albus* (initial body weight: 22.01 ± 0.01 g). [Methods] Based on the addition of fish oil (FO group), black soldier fly oil (BSFO group), palm oil (PO group), olive oil (OO group), and soybean oil (SO group) in the feed, 1,200 individuals of rice field eels were randomly assigned to six treatment groups, with four replicates per treatment, four replicates of each treatment were fed on a full diet for 56 d. [Results] There were no significant differences in final average weight, weight gain rate, and specific growth rate between BSFO group and FO group ($P > 0.05$), All other groups were significantly lower than FO group ($P < 0.05$). Compared to the FO group, the OO group and SO group significantly increased the viscera-to-body ratio ($P < 0.05$), There were no significant differences in survival rate, feed conversion ratio, hepatosomatic index, and condition factor among all groups ($P > 0.05$). Compared to the FO group, the crude lipid content of the whole fish in both OO group and SO group were significantly increased ($P < 0.05$). In terms of liver lipid content, there was no significant difference between the PO group and the SO group ($P > 0.05$), but both were significantly higher than the other groups ($P < 0.05$), which is consistent with the results of Oil Red O staining of liver sections. There were no significant differences in muscle lipid content among all groups ($P > 0.05$). Furthermore, there were no significant differences in the activities of superoxide dismutase (SOD) and glutathione peroxidase (GPX) in the liver of the BSFO group compared to the FO group ($P > 0.05$), but these activities were significantly higher in the BSFO group than in the other groups ($P < 0.05$). Additionally, the catalase (CAT) activity in the OO group was significantly higher than that in the PO and SO groups ($P < 0.05$), while there were no significant differences between the OO group and the FO or BSFO groups ($P > 0.05$). The intestinal superoxide dismutase (SOD) activity in the PO group was significantly higher than that in the other groups ($P < 0.05$), while the glutathione peroxidase (GPX) activity in the SO group was significantly lower than that in the other groups ($P < 0.05$). Compared to the FO group, the SO group significantly enhanced the activities of liver fatty acid synthase (*fas*), acetyl-CoA carboxylase (*acc*), hepatic lipase (*hl*), and hormone-sensitive lipase (*hsl*) ($P < 0.05$). Additionally, the SO group significantly upregulated the mRNA expression levels of peroxisome proliferator-activated receptor alpha (*ppara*), diacylglycerol acyltransferase 2 (*dgat2*), malic enzyme 1 (*me1*), monoacylglycerol

lipase (*mgll*), *acc*, and *hsl* genes ($P < 0.05$). Compared to the FO group, all other groups significantly upregulated the mRNA expression levels of the intestinal tight junction proteins *zo1* (*zo-1*) and *zo2* (*zo-2*) genes ($P < 0.05$). Furthermore, the BSFO group, OO group, and SO group significantly upregulated the mRNA expression of the *claudin-1* gene ($P < 0.05$). However, only the BSFO group increased the mRNA expression of the *occludin* gene ($P < 0.05$) **[Conclusion]** This study demonstrates that replacing fish oil with black soldier fly oil has no impact on the growth performance of rice field eels. Moreover, BSFO enhances hepatic antioxidant capacity, reduces hepatic lipid deposition, strengthens intestinal barrier function, and promotes liver and intestinal health. Conversely, substituting fish oil with palm oil, olive oil, or soybean oil exerts adverse effects on growth performance as well as various aspects including whole-body lipid content. (Unpublished)

Key words: *Monopterus albus*; lipid sources; growth performance; antioxidant capacity; lipid metabolism; intestinal health

草鱼 CCKR 的分子特征及其参与肠道对细菌感染的免疫应答反应

彭冉^{1,2}, 瞿符发¹, 唐建洲¹, 曹申平¹, 周勇华¹, 何志敏¹, 毛庄文¹, 周罗璟¹, 李建中^{2*}, 刘臻^{1*}

- (1. 长沙学院生物与化学工程学院, 水生动物营养与品质调控湖南省重点实验室, 湖南 长沙 410022;
2. 湖南师范大学生命科学学院, 淡水鱼类发育生物学国家重点实验室, 湖南 长沙 410081)

摘要: 胆囊收缩素受体 (CCKR) 是内分泌系统中胃肠激素胆囊收缩素的重要识别受体, 在哺乳动物免疫反应的调节中发挥着重要作用。本研究从草鱼中发现了一种新型 CCK 受体 (*CiCCKR*)。与其他已报道的 CCKR 蛋白一样, *CiCCKR* 含有 7 个跨膜螺旋结构域, 跨膜区 III 中有一个 ERY 基团, 跨膜区 VII 中有一个 NPIIY 基团。表达谱分析显示, *CiCCKR* 主要在大脑中表达, 在肠道中表达量其次。系统进化分析表明, 草鱼 CCKR 属于鱼类 CCKR 家族, 与 *Megalobrama amblycephala* 的关系最为密切。体内注射实验表明, CCK 和 CCKR 对嗜水气单胞菌、维氏气单胞菌和细菌胞壁酰二肽 (MDP) 的刺激有强烈的反应, 它们在草鱼肠道中的表达水平显著上调。此外, 与 MDP 组相比, CCK 联合 MDP 组的炎症因子 (TNF- α 、IL-1 β 、IL-8) 和 PepT1/NOD2 通路基因 (PepT1、NOD2、RIP2) 的表达水平明显下调, CCKR 通路基因 (CCKR、GANS) 的表达水平明显上调。体外和体内实验表明, *CiCCKR* 基因敲降及其抑制剂丙谷胺能通过 PepT1/NOD2 通路有效调节 MDP 诱导的肠道炎症。这些研究表明, *CiCCKR* 可能在肠道对细菌感染的免疫反应中发挥着关键作用。

关键词: 草鱼; 胆囊收缩素受体; 胞壁酰二肽; 肠道炎症

Molecular characterization of CCKR in *Ctenopharyngodon idella* and its involvement in the intestinal immune response to bacterial challenges

Ran Peng^{1,2}, Fufa Qu¹, Jianzhou Tang¹, Shenping Cao¹, Yonghua Zhou¹, Zhimin He¹, Zhuangwen Mao¹, Luoqing Zhou¹, Jianzhong Li^{2*}, Zhen Liu^{1*}

(1. Hunan Provincial Key Laboratory of Nutrition and Quality Control of Aquatic Animals, Department of Biological and Chemical Engineering, Changsha University, Changsha China 410022; 2. Yueyang Yumeikang Biotechnology Co., Ltd., Yueyang China 414100)

Abstract: Cholecystokinin receptor (CCKR), an important recognition receptor for the gastrointestinal hormone cholecystokinin in the endocrine system, plays an important role in the regulation of immune responses in mammals. In this study, a novel CCK receptor (*CiCCKR*) was identified from grass carp *Ctenopharyngodon idella*. Like other reported CCKR proteins, *CiCCKR* contained seven transmembrane helical domains, an ERY motif in transmembrane region III and a NPIIY motif in transmembrane region VII. Expression profiling showed that *CiCCKR* was expressed predominantly in the brain and to a lesser extent in the gut. Phylogenetic analysis revealed that grass carp CCKR belonged to the fish CCKR family. and showed the closest relationship to *Megalobrama amblycephala*. *In vivo* injection experiments showed that CCK and CCKR exhibited a strong response to the stimulation of *Aeromonas hydrophila*, *Aeromonas veronii* and Muramyl Dipeptide (MDP), and that their expression levels were significantly up-regulated in the intestine of grass carp. Additionally, the expression levels of inflammatory factors (TNF- α , IL-1 β , IL-8) and PepT1/NOD2 pathway genes (PepT1, NOD2, RIP2) were significantly down-regulated, and the expression levels of CCKR pathway genes (CCKR, GANS) were significantly up-regulated in the CCK combined with MDP group compared to the MDP group. *In vitro* and *in vivo* experiments indicated that *CiCCKR* knockdown and its inhibitor proglumide treatment effectively regulated MDP-induced intestinal inflammation by PepT1/NOD2 pathway. These findings suggested that *CiCCKR* may play a critical role in intestinal immune response to bacterial challenge.

Key words: *Ctenopharyngodon idella*, Cholecystokinin receptor, Muramyl Dipeptide, Intestinal inflammation

草鱼细菌性肠道炎症发生的调控网络及营养干预研究⁴

瞿符发¹, 唐建洲¹, 曹申平¹, 周勇华¹, 何志敏¹, 毛庄文¹, 周罗璟¹, 樊均德², 刘臻

1*

(1. 长沙学院生物与化学工程学院, 水生动物营养与品质调控湖南省重点实验室, 湖南 长沙 410022;

2. 岳阳渔美康生物科技有限公司, 湖南 岳阳 414100)

摘要: 细菌性肠炎是草鱼集约化养殖过程中频繁发生且危害严重的传染性疾病。研究表明, 嗜水气单胞菌等病原细菌可诱发肠道内细菌炎性小肽和大分子 PAMPs 产生, 进而导致草鱼肠道炎症反应, 但其作用机制及潜在营养干预方向尚不清晰。本论文以草鱼为研究对象, 综合细胞生物学、分子生物学等技术方法, 解析了嗜水气单胞菌等病原细菌在草鱼体内代谢产物 (LPS、PGN 和 MDP) 的变化规律, 明确了病原细菌、肠道细菌炎性小肽和大分子 PAMPs 与草鱼肠道炎症发生的关联性, 阐明了细菌炎性小肽 (MDP) 和大分子 PAMPs (LPS、PGN) 对草鱼肠道炎症的诱发作用; 从离体和在体层次揭示了免疫 (C1ql2、DAF、PepT1 等) 和内分泌相关基因 (CCK、GLP-1、Ghrelin) 对 MDP/LPS 诱发的肠道炎症反应的调控作用; 在上述研究基础上, 深入探究了外源营养性小肽通过 PepT1 途径干预病原细菌诱发肠道炎症反应的分子机制, 从肠道代谢-免疫-内分泌网络调控多维度解析病原细菌诱发肠道炎症发生及营养干预机制, 将为鱼类细菌性肠炎发病机理及饲料营养预防提供理论依据和技术支撑。

关键词: 草鱼; 嗜水气单胞菌; 脂多糖; 胞壁酰二肽; 肠道炎症

资助项目: 国家自然科学基金 (U21A20267 和 32373143)、湖南省科技创新计划资助 (2023RC1072)、湖南省自然科学基金 (2022JJ10053)

通讯作者: 刘臻, E-Mail: 25300085@qq.com

Study on the regulatory network and nutritional intervention of intestinal inflammation induced by bacteria in Grass Carp

Fufa Qu¹, Jianzhou Tang¹, Shenping Cao¹, Yonghua Zhou¹, Zhimin He¹, Zhuangwen Mao¹,
Luoqing Zhou¹, Junde Fan², Zhen Liu^{1*}

(1. Hunan Provincial Key Laboratory of Nutrition and Quality Control of Aquatic Animals, Department of Biological and Chemical Engineering, Changsha University, Changsha China 410022; 2. Yueyang Yumeikang Biotechnology Co., Ltd., Yueyang China 414100)

Abstract: Bacterial enteritis is one of the most frequent and serious infectious diseases occurred in the process of intensive cultivation of grass carp. Previous studies have shown that pathogenic bacteria such as *Aeromonas hydrophila* can induce the production of bacterial peptides and PAMPs (pathogen associated molecular pattern) in the intestine which in turn results in intestinal inflammatory response in grass carp, but its role and nutritional intervention mechanism are still unclear. Therefore, grass carp was used as the research object in this study, to clarify the metabolic characteristics of pathogenic bacteria in the intestine of grass carp and their relationship with bacterial peptide (MDP, etc.) and PAMPs (LPS, etc.) by cell biology and molecular biology techniques, to reveal the role of bacterial peptides and PAMPs in inducing intestinal inflammation in grass carp, and to analyze the regulatory role of immune- (C1ql2, DAF, PepT1, etc.) and endocrine-related genes (CCK, GLP-1, Ghrelin, etc.) in MDP or LPS induced intestinal inflammation *in vivo* and *in vitro*. On the basis of the above studies, we intend to further explore the effects and mechanism of exogenous nutritional peptide on the intestinal inflammatory response of grass carp induced by pathogenic bacteria through PepT1 pathway, to analyze the mechanism of intestinal inflammation and nutritional intervention induced by pathogenic bacteria in grass carp with the multi-dimensional regulation of intestinal metabolism-immune-endocrine network, so as to provide theoretical basis and technical support for the pathogenesis of bacterial enteritis and its prevention through feed nutrition in fish farming.

Key words: *Ctenopharyngodon idella*; *Aeromonas hydrophila*; Lipopolysaccharide; Muramyl dipeptide; Intestinal inflammation

胆汁酸可恢复高植物蛋白饲料引起的凡纳滨对虾(*Litopenaeus vannamei*)铁死亡，肌肉品质下降和肠道受损

屈康渊¹²，邓君明¹²，董晓慧¹²，迟淑艳¹²，谭北平¹²，谢诗玮^{12*}

(1.广东海洋大学水产学院水产动物营养与饲料实验室，广东 湛江 524088；2. 广东省水生动物精准营养与高效饲料研究中心，广东 湛江 524088)

摘要：【目的】胆汁酸（BAs）现已被证实可提高对虾的生长性能，并在对虾的脂质代谢中发挥重要作用。为了研究高植物蛋白饲料中添加胆汁酸（BAs）对凡纳滨对虾(*Litopenaeus vannamei*)的生长性能、肌肉品质、肠道健康和铁死亡的影响。【方法】我们配制了七种不同的饲料，阳性对照组为正常 25%鱼粉（PC）和阴性对照组为替代 12.5%鱼粉（NC）。其他五种饲料在 NC 的基础上分别添加 50, 100, 200, 400, 800mg/kg 的 BAs（NC50-NC800）。【结果】与阳性对照组 PC 相比，阴性对照组 NC 终末体重（FBW）和增重率（WGR）没有显著差异。与添加 BAs 组相比，喂食含有 400mg/kg BAs 饲料的对虾 FBW, 和 WGR 显著增加。与喂食 PC 组的对虾相比，喂食 NC 组饲料显著增加了对虾的全身粗脂肪。此外，TUNEL 染色和透射电镜结果显示，饲喂 NC 组对虾肠道 GPX4 免疫荧光相对率显著低于其他组，NC 组线粒体嵴消失，脂质过氧化代谢物 MDA 显著上升，此外，高植物蛋白饲料显著上调铁死亡相关基因 (*ACSCL4, GPX4, HO1, Fettrin*)。然而，添加 BAs 可有效降低上述指标。此外，在高植物蛋白中添加 BAs 能够降低虾肉的蒸煮损失，提高虾肉的紧致度，胶黏性，粘聚性，恢复性，弹性；上调肌肉纤维生长基因 (*tgf-β, igf, smych2, smych6a*)。蛋白印迹和 HE 切片结果显示 BAs 能够促进肌蛋白 (Akt, 4E-BP1, Raptor, MyoD1) 的表达和显著增加肌肉纤维的直径。肠道电镜结果分析表明，高植物蛋白饲料中添加 BAs 能够提高对虾肠道褶皱宽度和高度，增加微绒毛密度。添加胆汁酸能够维持对虾的正常肠道健康。此外，肠道菌群分析表明，PC 组与 NC 组比，高植物蛋白饮食调频并降低了对虾的肠道菌群多样性。门水平上，相比 NC 组，添加 BAs 降低了变形菌门的相对丰度，增加了有益菌拟杆菌门的相对丰度。在属水平上，添加胆汁酸能够下调黏着杆菌属和上调舍氏菌属的相对丰度。【结论】在高植物蛋白饲料中添加 BAs 能够改善凡纳滨对虾的生长性能，肌肉品质，铁死亡和肠道健康。从而减轻高植物蛋白饮食对其造成的不利影响。

关键词：胆汁酸，高植物蛋白，铁死亡，肌肉品质，微生物群落

Dietary bile acids recovers the ferroptosis, the decrease in flesh quality and intestinal health induced by high-plant protein diets of Pacific white shrimp (*Litopenaeus vannamei*)

Kangyuan Qu¹², Junming Deng, Xiaohui Dong¹², Shuyan Chi¹², Beiping Tan¹², Shiwei Xie^{12*}

(1. Laboratory of Aquatic Animal Nutrition and Feed, School of Fisheries, Guangdong Ocean University,

Zhanjiang China 524088; 2 Guangdong Province Research Center for Accurate Nutrition and High-Efficiency

Feeding of Aquatic Animals, Zhanjiang 524088, China)

Abstract: [Objective] Bile acids (BAs) have been shown to improve the growth performance of shrimp and play an important role in shrimp lipid metabolism. The effects of adding bile acids (BAs) to a high-vegetable protein diet on the growth performance, flesh quality, intestinal health and ferroptosis of *Litopenaeus vannamei* were studied. [Methods] We formulated seven different feeds, with normal 25% fish meal (PC) as the positive control group and alternative 12.5% fish meal (NC) as the negative control group. The other five feeds were formulated by adding 50, 100, 200, 400, and 800 mg/kg BAs to the NC (NC50-NC800), respectively. [Results] Compared with the positive control group PC, there was no significant difference in the final body weight (FBW) and weight gain rate (WGR) of the negative control group NC. Compared with the group supplemented with BAs, the FBW and WGR of the prawns fed a diet containing 400 mg/kg BAs were significantly increased. Compared with PC group, the shrimp in the NC group fed with the feed significantly increased the whole body crude lipid. In addition, TUNEL staining and transmission electron microscopy results showed that the relative rate of GPX4 immunoluminescence in the intestines of shrimp in the NC group was significantly lower than that in the other groups. The mitochondrial cristae disappeared in the NC group, and the lipid peroxidation metabolite MDA increased significantly. In addition, high-plant protein feed significantly up-regulated ferroptosis-related genes (*ACSCL4*, *GPX4*, *HOI*, *Fettrin*). However, the addition of BAs can effectively reduce the above indicators. Adding BAs to a high-plant protein diets can reduce cooking loss and improve the Hardness, cohesiveness, Resilience, and Springness of shrimp muscle. It also upregulates muscle fiber growth genes (*tgf- β* , *igf*, *smych2*, *smych6a*). Western blot and HE section results showed that BAs could promote the expression of myofibrillar proteins (Akt, 4E-BP1, Raptor, MyoD1) and significantly increase the diameter of muscle fibers. Analysis of intestinal electron microscopy results showed that the addition of BAs to a high-plant protein diets could increase the width and height of the shrimp intestinal folds and increase the density of microvilli. The addition of BAs can maintain the normal intestinal health of shrimp. Intestinal microbiota analysis showed that compared to the PC group, NC group modulated and reduced the intestinal microbiota diversity of the shrimp. At the phylum level, compared to the NC group, the addition of BAs reduced the relative abundance of the Proteobacteria phylum and increased the relative abundance of the beneficial bacterium

Bacteroidetes phylum. At the genus level, the addition of BAs down-regulated the relative abundance of the genus *Tenacibaculum* and up-regulated the relative abundance of the genus *Shewanella*. [Conclusion] Adding BAs to a high-plant protein diets can improve the growth performance, flesh quality, ferroptosis, and intestinal health of *L. vannamei*. thereby attenuating the adverse effect induced by the high-plant protein diets of Pacific white shrimp.

Keywords: Bile acids, high plant protein, ferroptosis, flesh quality, microbiota

通讯作者： 谢诗玮，教授，E-Mail: xswzsd@163.com

基金项目： 国家自然科学基金（32002402），国家重点研发计划“海洋农业与淡水渔业科技创新”重点专项子课题(2023YFD240200)，广东省自然科学基金青年提升项目(2023A1515030007)。

蛋白水平对亚硝酸盐应激后草鱼鳃损伤的影响

刘红菊¹, 冯琳¹, 姜维丹¹, 吴培¹, 刘杨¹, 周小秋^{1*}

(1.四川农业大学动物营养研究所, 成都 611130)

摘要: 试验通过配制 6 种不同蛋白质水平 (16%、19%、22%、25%、28%和 31%) 的饲料, 探讨急性亚硝酸盐应激下, 饲料中蛋白质水平对生长后期草鱼鳃组织损伤、内质网应激、细胞自噬和凋亡的影响。试验选用饲喂 60 天不同蛋白质水平 (16%、19%、22%、25%、28%和 31%) 饲料的草鱼, 置于亚硝酸盐浓度为 10 mg/L 的水体中进行 96 h 的急性亚硝酸盐应激试验。结果表明: 1) 适宜水平蛋白质显著降低了草鱼血清葡萄糖和皮质醇的含量 ($P<0.05$); 2) 饲料中 22%-25%蛋白质水平可有效缓解亚硝酸盐诱导的草鱼鳃组织结构损伤, 显著降低鳃中 NO、ONOO⁻、ROS、MDA 和 PC 的含量 ($P<0.05$); 3) 适宜水平饲料蛋白质显著降低了草鱼鳃中 *grp78*、*perk*、*eif2 α* 、*atf4*、*chop*、*atf6*、*ire1* 和 *xbp1* 的 mRNA 水平以及 GRP78 和 p-PERK 的蛋白水平 ($P<0.05$), 抑制了鳃组织亚硝酸盐诱导的内质网应激; 显著下调了细胞自噬分子 *ulk1*、*beclin1*、*atg5* 和 *lc3* 的 mRNA 水平以及 LC3II 的蛋白水平 ($P<0.05$), 显著上调了 p62 的 mRNA 及蛋白水平 ($P<0.05$), 缓解了亚硝酸盐诱导的鳃过度自噬; 显著降低了鳃中 caspase-3,-8,-9 的活性, 下调了促凋亡因子 *traf2*、*bax*、*apaf-1* 和 *trail* 的 mRNA 水平以及 Cyt-c 的蛋白水平 ($P<0.05$), 上调了抗凋亡因子 *bcl-2* 和 *mcl-1* 的 mRNA 水平 ($P<0.05$), 抑制了亚硝酸盐诱导的鳃细胞凋亡的线粒体和死亡受体途径。综上, 饲料适宜蛋白水平 (22%-25%) 可通过降低草鱼鳃氧化损伤、内质网应激、细胞自噬和凋亡减轻鳃组织结构损伤, 进而提高草鱼抗亚硝酸盐胁迫能力。

关键词: 蛋白质; 亚硝酸盐应激; 内质网应激; 自噬; 草鱼

资助项目: 国家自然科学基金 (31972810); 国家现代农业产业技术体系 (CARS-45); 四川省科技计划 (2019YFN0036)

通讯作者: 周小秋, E-Mail: zhouxq@sicau.edu.cn

二烯丙基二硫化物通过保守机制--增强 Mfn2/Atgl 介导的脂滴-线粒体耦合来缓解肝脏脂肪变性

王令娇^{1#}, 赖晓红^{1#}, 罗智¹², 奉广莉¹, 宋玉峰^{1*}

(1.华中农业大学水产学院农业部淡水动物育种重点实验室, 湖北 武汉 430070; 2.海洋渔业科学与食品生产过程实验室, 青岛海洋科学与技术国家实验室, 山东 青岛 266237)

摘要:【目的】尽管越来越多的证据强调了线粒体-脂滴 (LD) 耦合在维持脂质平衡中的重要性, 但在揭示线粒体-LD 耦合在肝脏脂质代谢中的作用方面进展甚微。此外, 有人提出大蒜有机硫化合物二烯丙基二硫化物 (DADS) 可预防肝脏脂肪变性, 但迄今为止还没有研究关注其分子机制。针对这些空白, 本研究调查了线粒体-脂滴耦联调节肝脏脂质代谢的系统控制机制, 并探讨了它们在 DADS 缓解肝脂肪变性过程中的功能。【方法】以黄颡鱼为脂代谢动物模型, 喂食四种不同的饲料 (对照组、高脂组、DADS 组和高脂+DADS 组) 8 周; 在体外实验中抑制离体肝细胞中 Mfn2/Atgl 介导的线粒体-LD 偶联。【结果】(1) 肝脏脂滴脂肪分解和线粒体 β 氧化的激活可能是 DADS 缓解肝脏脂肪变性的主要驱动力; (2) 其基本机制是, DADS 通过促进线粒体定位的 Mfn2 与脂滴定位的 Atgl 之间的相互作用, 增强线粒体-脂滴耦联, 从而促进肝脏脂滴脂肪分解和脂肪酸从脂滴转移到线粒体进行后续的 β 氧化; (3) Mfn2 介导的线粒体融合促进线粒体形成更多的 PDM, 而 PDM 在肝细胞中具有更高的 β 氧化能力。【结论】本研究揭示了一种以前未曾披露的机制, 即 Mfn2/Atgl-线粒体-LD 耦合缓解肝脏脂滴积累, 这是一种从鱼类到四足动物的保守策略。这项研究为线粒体-LD 耦合提供了另一个维度, 并为肝脏脂肪变性的治疗干预开辟了新途径。

关键词: 脂滴-线粒体耦合; 肝脏脂肪变性; 线粒体动力学; 二烯丙基二硫化物; Mfn2/Atgl

资助项目: 国家自然科学基金 (32273156)、生物育种重大专项 (2023ZD04054) 和中央高校基础科研基金 (20062023SCYJ003)

通讯作者: 宋玉峰, E-Mail: syf880310@mail.hzau.edu.cn

Diallyl Disulfide Alleviates Hepatic Steatosis by the Conservative Mechanism from Fish to Tetrapod: Augment Mfn2/Atgl-Mediated Lipid Droplet-Mitochondria Coupling

Ling-Jiao Wang^{a#}, Xiao-Hong Lai^{a#}, Zhi Luo^{a, b}, Guang-Li Feng^a, Yu-Feng Song^{a*}

(1. Key Laboratory of Freshwater Animal Breeding, Ministry of Agriculture, Fishery College, Huazhong Agricultural University, Wuhan 430070, China; 2. Laboratory for Marine Fisheries Science and Food Production Processes, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266237, China)

Abstract: [Objective] Despite increasing evidences has highlighted the importance of mitochondria-lipid droplet (LD) coupling in maintaining lipid homeostasis, little progress in unraveling the role of mitochondria-LD coupling in hepatic lipid metabolism has been made. Additionally, diallyl disulfide (DADS), a garlic organosulfur compound, has been proposed to prevent hepatic steatosis; however, no studies have focused on the molecular mechanism to date. To address these gaps, this study investigated the systemic control mechanisms of mitochondria-LD coupling regulating hepatic lipid metabolism, and also explored their function in the process of DADS alleviating hepatic steatosis. [Methods] To this end, an animal model of lipid metabolism, yellow catfish *Pelteobagrus fulvidraco* were fed four different diets (control, high-fat, DADS and high-fat + DADS diet) *in vivo* for 8 weeks; *in vitro* experiments were conducted to inhibit Mfn2/Atgl-mediated mitochondria-LD coupling in isolated hepatocytes. [Results] (1) the activations of hepatic LDs lipolysis and mitochondrial β -oxidation are likely the major drivers for DADS alleviating hepatic steatosis; (2) the underlying mechanism is that DADS enhances mitochondria-LD coupling by promoting the interaction between mitochondrion-localized Mfn2 with LD-localized Atgl, which facilitates the hepatic LDs lipolysis and the transfer of fatty acids (FAs) from LDs to mitochondria for subsequent β -oxidation; (3) Mfn2-mediated mitochondrial fusion facilitates mitochondria to form more PDM, which possess higher β -oxidation capacity in hepatocytes. [Conclusion] The present research unveils a previously undisclosed mechanism by which Mfn2/Atgl-mitochondria-LD coupling relieves hepatic LDs accumulation, which is a conserved strategy from fish to tetrapod. This study provides another dimension for mitochondria-LD coupling and opens up new avenues for the therapeutic interventions in hepatic steatosis.

Key words: Lipid Droplet-Mitochondria Coupling; Hepatic Steatosis; Mitochondrial Dynamic; Diallyl Disulfide; Mfn2/Atgl

高脂饲料诱发黄鳝脂肪代谢紊乱、肝脏损伤以及肠道健康问题 相关机制的探究

李权, 胡毅¹, 张俊智^{1*}

(1.湖南农业大学水产学院, 湖南 长沙 410128; * 通讯作者, E-mail addresses: huyi740322@163.com

(胡毅), zhjun123@hunau.edu.cn (张俊智))

摘要: 为了探究高脂饲料影响黄鳝脂肪代谢紊乱、肝脏损伤及肠道健康的机制, 设计了三组等氮饲料: low组 (3.10%粗脂肪)、normal组 (6.03%粗脂肪) 和high组 (12.05%粗脂肪), 并进行了为期 8 周的养殖实验。实验结果显示, 过量脂肪摄入显著降低了黄鳝的生长性能 ($P < 0.05$); 随着饲料脂肪含量的增加, 脂质合成相关基因的表达及肝脏粗脂肪含量显著上升, 尤其在high组中, 血清GOT和GPT水平明显提高 ($P < 0.05$), 表明肝脏脂肪沉积并伴随一定程度的损伤; 此外, 过高的饲料脂肪导致黄鳝肝脏抗氧化酶活性显著下降, 内质网应激相关基因显著上调 ($P < 0.05$); 肠道消化酶活性和绒毛高度在高脂环境下显著降低 ($P < 0.05$)。高脂饲料还下调了肠道紧密连接蛋白的表达, 同时上调了促炎因子的表达; 致病菌在高脂环境中的相对丰度显著上升 ($P < 0.05$)。综上所述, 本实验结果表明, 高脂饲料导致肝脏脂肪沉积和氧化应激损伤, 同时引发内质网应激, 加剧肝脏损伤。此外, 高脂破坏肠道黏膜屏障, 导致炎症加剧, 促使致病菌大量增殖。

关键词: 高脂饲料; 脂代谢; 内质网应激; 肠道微生物; 黄鳝

Investigation of the mechanism of lipid metabolism disorder, hepatic impairment and intestinal health induced by high-fat diet in rice field eel (*Monopterus albus*)

Quan Li¹, Dongxiao Lin¹, Shude Xu¹, Jihong Dai¹, Yi Hu^{1*}, Junzhi Zhang^{1*}

(1. Fisheries College, Hunan Agricultural University, Changsha 410128, PR China; * Corresponding author, E-mail addresses: huyi740322@163.com (Y.H.); zhjun123@hunau.edu.cn (J.Z.))

Abstract : In order to investigate the mechanism of high-fat feeds on fat metabolism disorders, liver damage and intestinal health of rice field eels, three groups of isonitrogenous feeds were designed: low group (3.10% crude fat), normal group (6.03% crude fat) and high group (12.05% crude fat), and the breeding experiments were carried out for a period of 8 weeks. The experimental results showed that excessive fat intake significantly reduced the growth performance of eels ($P < 0.05$); the expression of lipid synthesis-related genes and liver crude fat content increased significantly with the increase of feed fat content, especially in the high group, the levels of serum GOT and GPT were significantly increased ($P < 0.05$), which indicated that liver fat deposition was accompanied with a certain degree of damage; moreover, excessive feed fat led to a significant decrease in liver antioxidant enzyme activities and a significant up-regulation of endoplasmic reticulum stress-related genes in eels ($P < 0.05$); intestinal digestive enzyme activities and villus height were significantly reduced in the high-fat environment ($P < 0.05$). High-fat feed also down-regulated the expression of intestinal tight junction proteins, while up-regulating the expression of pro-inflammatory factors ($P < 0.05$); the relative abundance of pathogenic bacteria was significantly increased in the high-fat environment ($P < 0.05$). In summary, the results of this experiment indicated that high-fat feed led to hepatic fat deposition and oxidative stress injury, as well as triggered long-term endoplasmic reticulum stress and exacerbated liver injury. In addition, the high-fat environment reduced the height of intestinal villi and induced hyperpermeability, which led to increased inflammation and deteriorated the intestinal environment, contributing to the proliferation of pathogenic bacteria.

Key words: High-fat feed; Lipid metabolism; Endoplasmic reticulum stress; Gut microbes; *Monopterus albus*

高脂诱导的氧化应激导致肠道炎症和脂质沉积

余岸良¹, 魏晓雷¹, Ester Zito^{3,4}, 郑华¹, 仲崇超¹, 罗智^{1,2,*}

(1. 华中农业大学水产学院湖北洪山实验室, 中国武汉 430070; 2. 青岛海洋科学与技术国家实验室海洋渔业科学与食品生产过程实验室, 中国青岛 266237; 3. 马里奥-内格里农业科学研究所 (Istituto di Ricerche Farmacologiche Mario Negri IRCCS), 意大利 米兰 20156; 4. 乌尔比诺卡洛博大学生物分子科学系, 意大利 乌尔比诺 61029)

摘要:【目的】过度摄入脂肪与机体肠道健康和脂质沉积息息相关, 但其潜在机制仍然难以捉摸。【方法】在养殖实验和细胞实验中, 使用免疫组织化学, 测定 TG 含量和 FAS 酶活, 最后检测不同处理下的炎症和脂代谢关键基因 mRNA 水平和蛋白水平。【结果】在这项研究中, 高脂摄入会诱发肠道脂质积累和屏障损伤, 激活氧化应激, 并激活半胱氨酰天冬氨酸特异性蛋白酶 3 (caspase 3) / gasdermin E (GsdmE) 的细胞焦亡进而诱发肠道炎症; 高脂摄食激活 Caspase 3 对固醇调节元件结合蛋白 1 (Srebp1) 前体裂解, 进而产生 Srebp1 的活性裂解形式; D444 被鉴定为 Caspase 3 对 Srebp1 前体裂解的位点。从机理上讲, 过表达 Caspase 3 裂解的 Srebp1 (Flag-N-Srebp1) 会进一步增加脂质合成相关基因[脂肪酸合成酶(fas)、乙酰 CoA 羧化酶(acca)和硬脂酰-CoA 去饱和酶 1(scd1)]的启动子的活性, 进而诱导脂质积累。【结论】综上所述, 氧化应激介导了高膳食脂肪和脂肪酸诱导的依赖于 Caspase 3 的细胞焦亡, 从而诱发了肠道炎症和脂质积累。

关键词: 脂肪摄入; 氧化应激; 细胞焦亡; 炎症反应; 脂质代谢

资助项目: 国家重点研发计划资助 (2018YFD0900400)

通讯作者: 罗智, E-mail: luozhi99@mail.hzau.edu.cn; luozhi99@aliyun.com

High fat diet-induced oxidative stress contributes to intestinal inflammation and lipid accumulation

Angen Yu¹, Xiaolei Wei¹, Ester Zito^{3,4}, Hua Zheng¹, Chongchao Zhong¹, Zhi Luo^{1,2,*}

(1. Hubei Hongshan Laboratory, Fishery College, Huazhong Agricultural University, Wuhan 430070, China; 2. Laboratory for Marine Fisheries Science and Food Production Processes, Qingdao National Laboratory for Marine Science and Technology, Qingdao, 266237, China; 3. Istituto di Ricerche Farmacologiche Mario Negri IRCCS, 20156 Milan, Italy; 4. Department of Biomolecular Sciences, University of Urbino Carlo Bo, 61029 Urbino, Italy)

Abstract: [Objective] Excessive dietary fat intake was associated with intestinal inflammation and lipid accumulation, but the underlying mechanism remained elusive. [Methods] Immunohistochemistry was used in culture and cellular experiments to determine TG content and FAS enzyme activity, and finally mRNA levels and protein levels of key genes for inflammation and lipid metabolism under different treatments. [Results] In the study, high dietary fat intake induced intestinal lipid accumulation and barrier damage, activated oxidative stress and induced intestinal inflammation by activating cysteinyl aspartate specific proteinase 3 (caspase 3)/ gasdermin E (GsdmE) -dependent pyroptosis; high dietary fat intake induced full-length sterol regulatory element binding protein 1 (Srebp1) cleavage by caspase 3, which in turn produced the active cleaved forms of Srebp1; D444 was identified as the cleavage site of full-length Srebp1 by caspase 3. Mechanistically, overexpression of the cleaved Srebp1 (Flag-N-Srebp1) by caspase 3 increased the activities of lipogenic genes [*fatty acid synthase (fas)*, *acetyl CoA carboxylase (acca)* and *stearoyl-CoA desaturase 1 (scd1)*] promoters, which in turn induced lipid accumulation. [Conclusion] Taken together, oxidative stress mediated high dietary fat- and FA-induced caspase 3-dependent pyroptosis and lipid accumulation, and thereby induced intestinal inflammation.

Keywords: Dietary fat intake; Oxidative stress; Pyroptosis; Inflammation response; Lipid accumulation

mTORC1 和 CaSR-Gq-ERK1/2 通路协同感知氨基酸诱导胰岛 α 细胞增殖

巩玉龙^{1,2,7}, 杨槟源^{1,7}, 张定东^{1,3}, 张悦¹, 唐子涵¹, 杨柳¹, Katie C. Coate⁴, Yin Linlin¹,
Brittney A. Covington¹, Ravi S. Patel¹, Walter A. Siv⁴, Katelyn Sellick⁴, Matthew Shou⁴, Chang
Wenhan⁵, E. Danielle Dean^{1,4}, Alvin C. Powers^{1,4,6}, 陈文标¹

(¹Department of Molecular Physiology & Biophysics, Vanderbilt University, 2215 Garland Ave, Nashville, TN, 37232, USA. ²淡水生态与生物技术国家重点实验室, 中国科学院水生生物研究所, 武汉, 中国。 ³南京农业大学动物科技学院, 南京, 中国。 ⁴Division of Diabetes, Endocrinology and Metabolism, Department of Medicine, Vanderbilt University Medical Center, 2215 Garland Ave, Nashville, TN, 37232, USA. ⁵University of California San Francisco and San Francisco VA Medical Center, San Francisco, CA, 94158, USA. ⁶VA Tennessee Valley Healthcare System, Nashville, TN, 37212, USA. ⁷Contributed equally.)

摘要: 胰高血糖素是调节细胞外氨基酸 (AA) 稳态的关键因子。胰高血糖素信号缺陷将导致高氨基酸血症, 并进一步引发胰岛 α 细胞的过度增殖。已有研究表明 mTORC1 信号参与了这一过程, 但其他 AA 感知信号在 α 细胞增殖中的作用尚未被探究。本研究使用胰高血糖素受体缺失斑马鱼 (*gcgr*^{-/-}) 和小鼠胰岛模型, 发现氨基酸诱导的胰岛 α 细胞增殖需要细胞外信号调节激酶 (ERK1/2) 的激活, 而这一过程由 AA 敏感的钙感受器 (CaSR) 介导。CaSR 的缺失减弱了 α 细胞增殖, 而重新表达 CaSR 或在 α 细胞中激活 Gq (而非 Gi) 信号可以挽救 α 细胞增殖。研究进一步发现, α 细胞中 mTORC1 的激活依赖于 CaSR-Gq-ERK1/2。此外, Gq 和 mTORC1 的共同激活在非高氨基酸的情况下诱导了 α 细胞增殖。这些结果揭示了 α 细胞中一条新的 AA 感知途径, 并明确了氨基酸感知介导 α 细胞增殖的必要和充分通路。

关键词: 氨基酸; 胰岛 α 细胞增殖; CaSR-Gq-ERK1/2; mTORC1

Amino acid sensing induces α cell proliferation via synergism between the mTORC1 and CaSR-Gq signaling pathways

Yulong Gong^{1,2,7}, Bingyuan Yang^{1,7}, Dingdong Zhang^{1,3}, Yue Zhang¹,
Zihan Tang¹, Liu Yang¹, Katie C. Coate⁴, Linlin Yin¹, Brittney A. Covington¹, Ravi S. Patel¹,
Walter A. Siv⁴, Katelyn Sellick⁴, Matthew Shou⁴, Wenhan Chang⁵, E. Danielle Dean^{1,4}, Alvin C.
Powers^{1,4,6} & Wenbiao Chen¹

(1. Department of Molecular Physiology & Biophysics, Vanderbilt University, 2215 Garland Ave, Nashville, TN, 37232, USA; 2. State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, Hubei, 430072, China; 3. College of Animal Science and Technology, Nanjing Agricultural University, Nanjing, 210095, China; 4. Division of Diabetes, Endocrinology and Metabolism, Department of Medicine, Vanderbilt University Medical Center, 2215 Garland Ave, Nashville, TN, 37232, USA; 5. University of California San Francisco and San Francisco VA Medical Center, San Francisco, CA, 94158, US; 6. VA Tennessee Valley Healthcare System, Nashville, TN, 37212, US; 7. Contributed equally.)

Abstract: Glucagon has emerged as a key regulator of extracellular amino acid (AA) homeostasis. Insufficient glucagon signaling results in hyperaminoacidemia, which drives adaptive proliferation of glucagon-producing α cells. Aside from mammalian target of rapamycin complex 1 (mTORC1), the role of other AA sensors in α cell proliferation has not been described. Here, using both genders of mouse islets and glucagon receptor (*gcgr*)-deficient zebrafish, we show α cell proliferation requires activation of the extracellular signal-regulated protein kinase (ERK1/2) by the AA-sensitive calcium sensing receptor (CaSR). Inactivation of CaSR dampened α cell proliferation, which was rescued by re-expression of CaSR or activation of Gq, but not Gi, signaling in α cells. CaSR was also unexpectedly necessary for mTORC1 activation in α cells. Furthermore, coactivation of Gq and mTORC1 induced α cell proliferation independent of hyperaminoacidemia. These results reveal another AA-sensitive mediator and identify pathways necessary and sufficient for amino acid-induced α cell proliferation.

Key words: Amino acid sensing; α cell proliferation; CaSR-Gq-ERK1/2; mTORC1

蛋白 1 (Srebp1) 抑制对斑点叉尾鮰糖脂转化调控和肝脏健康的影响

刘雨龙, 陆启升, 韩国立, 郑毓童, 曹静越, 席龙伟, 刘昊昆, 金俊琰, 张志敏, 杨云霞, 朱晓鸣, 解绶启, 韩冬*

(中国科学院水生生物研究所, 湖北 武汉 430072)

摘要: 高碳水化合物日粮 (HCD) 摄食可能会诱导鱼类肝脏糖向脂肪的过度转化, 固醇调节元件结合蛋白 1 (Srebp1) 在其中发挥重要作用。白桦脂酸 (BA) 据报道可靶向抑制 Srebp1 的表达。在本研究中, 我们探讨了日粮补充 BA 对 HCD 诱导的斑点叉尾鮰肝脏糖生脂代谢和肝脏健康的影响。斑点叉尾鮰的实验饲料设计有三组: 正常糖水平组 (NCD, 18%糖水平饲料)、高糖水平组 (HCD, 36%糖水平饲料)、高糖添加组 (HCV+BA, 36%糖水平饲料添加 150mg/kg BA)。经过 8 周的饲养试验, 我们发现日粮 BA 降低了肝体指数 (HSI) 和肥满度 (CF), 而不影响饲喂 HCD 的斑点叉尾鮰的生长。日粮 BA 显著降低了 HCD 诱导的过度脂质积累 (油红 O 面积、TG 含量和糖生脂关键基因表达, $P<0.05$)。此外, 我们发现, 日粮 BA 通过激活单磷酸腺苷活化蛋白激酶 (AMPK) 的磷酸化和抑制饲喂 HCD 的斑点叉尾鮰肝脏中的固醇调节元件结合蛋白 1 (SREBP1) 来预防肝脏脂质积累 ($P<0.05$)。肝脏 H&E 染色结果表明日粮 BA 显著缓解了 HCD 诱导的肝损伤, 且日粮 BA 降低了 ALT、AST、 α -sma 和 $tgf-1\beta$ 的表达, 下调了 ER 应激相关基因 ($eif2a$ 、 bip 、 $atf4$ 、 $xbp1$) 的表达 ($P<0.05$)。总之, 本研究表明在饲喂 HCD 的斑点叉尾鮰中, 日粮添加 BA 可以调节肝脏糖生脂代谢, 改善肝脏炎症表现, 降低内质网应激反应。

关键词: SREBP1; 糖生脂; AMPK; 斑点叉尾鮰

资助项目: 国家自然科学基金项目 (U21A20266, 31972771, 31672670)、国家特色淡水鱼产业技术体系 (CARS-46)、国家重点研发项目(2023YFD2400600, 2022YFD2400900)

通讯作者: 韩冬, E-Mail: hand21cn@ihb.ac.cn

Inhibition of Srebp1 alleviates high carbohydrate diet-induced hepatic *de novo* lipogenesis through AMPK signaling and improves liver health in channel catfish

Yulong Liu, Qisheng Lu, Guoli Han, Yutong Zheng, Jingyue Cao, Longwei Xi, Haokun Liu, Junyan Jin, Zhimin Zhang, Yunxia Yang, Xiaoming Zhu, Shouqi Xie, Dong Han*
(Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, Hubei 430072, China)

Abstract: A high carbohydrate diet (HCD) induced excessive hepatic *de novo* lipogenesis, which caused metabolic disorder and impaired the health of fish species. Betulinic acid (BA) has been applied to ameliorate fatty liver and anti-inflammatory in mammals. Here, we investigated the effects of dietary BA supplementation on HCD-induced hepatic *de novo* lipogenesis and liver health in channel catfish (*Ictalurus punctatus*). The catfish were fed with three diets: NCD (18 % carbohydrate), HCD (36 % carbohydrate), HCD+BA (36 % carbohydrate with 150 mg/kg BA). After an 8-week feeding trial, we found that dietary BA decreased hepatosomatic index (HSI) and condition factor (CF) without affecting the growth of channel catfish fed HCD. Dietary BA significantly reduced the HCD-induced excessive lipid accumulation (oil red O area, TG content, and *de novo* lipogenesis gene expression, $P < 0.05$). Moreover, we found that dietary BA prevented hepatic lipid accumulation via activating phosphorylation of adenosine monophosphate-activated protein kinase (AMPK) and inhibiting sterol regulatory element-binding protein 1 (SREBP1) ($P < 0.05$) in liver of channel catfish fed HCD. Besides, we also found that dietary BA significantly prevented HCD-induced liver damage, as confirmed by liver H&E staining, reduced inflammation biomarkers (ALT, AST, hydroxyproline, α -sma and *tgf-1 β*), downregulated expression of ER stress-related genes (*eif2a*, *bip*, *atf4*, *xbp1*) ($P < 0.05$). Overall, the present study indicated that dietary BA inclusion attenuated hepatic *de novo* lipogenesis, improved liver inflammation and reduced ER stress in channel catfish fed HCD.

Key words: SREBP1; *de novo* lipogenesis; AMPK; Channel catfish

鳊幼鱼饲料中最适淀粉添加量研究

刘锡凤¹, 谭海月¹, 刘洪康¹, 赵敏², 翟旭亮³, 薛洋³, 罗莉^{1*}, 陈拥军^{1*}

(1. 西南大学水产学院, 西部(重庆)科学城种质创制大科学中心, 淡水鱼类资源与生殖发育教育部重点实验室, 重庆 400715; 2. 山东新希望六和集团有限公司, 青岛 266061; 3. 重庆市水产技术推广总站, 重庆 400400)

摘要: 本研究旨在探究淀粉水平对鳊鱼生长性能、体组成、肝脏糖代谢和肝组织学形态等方面的影响, 以期确定鳊鱼饲料中的最适淀粉添加量。以木薯淀粉为糖源, 配制了 5 种等氮(粗蛋白约 47%)等脂(8.5%)的试验饲料, 淀粉水平跨度为 7%~19%, 分别简称为 S7、S10、S13、S16 和 S19 组。每组饲料设置 4 个重复, 饲喂初始体重为 37.5g 的鳊幼鱼 8 周。实验结果显示, 随饲料淀粉水平增加, 鳊鱼生长性能(终末体重、特定生长率和增重率)和饲料效率在添加 13%淀粉时显著增加并保持稳定, 各处理组的摄食率并无显著变化。HE 染色显示, S7 组和 S10 组鳊鱼肝细胞中存在少量核偏移和空泡化现象; S13 组肝细胞开始出现核聚集现象, 空泡化程度进一步增加; S16 和 S19 组肝细胞形态不完整, 存在核聚集甚至出现核溶解, 空泡化加剧甚至成片相连。随饲料淀粉水平升高, 鳊鱼空腹血糖含量呈上升趋势, 但各处理组间并不存在显著差异。S13 组血清中谷丙转氨酶和谷草转氨酶的活性最低。与对照组(S7)相比, 其余各处理组肝脏中 *glut2* 的相对表达量显著下降。S16 组和 S19 组肝脏中 *gck* 的 mRNA 水平显著低于 S7、S10 和 S13 组, 但 *pk* 的相对表达量不受饲料淀粉水平影响。与对照组相比, S13 组和 S16 组肝脏中 *g6pca1* 的相对表达量显著升高, 但各处理组肝脏 *g6pca2* 的 mRNA 水平无显著差异。肝脏中 *gys1* 的表达不受饲料淀粉水平显著影响, 但 S16 和 S19 组的糖原含量显著高于对照组。与对照组相比, 肝脏中抗氧化性能相关指标(超氧化物歧化酶活性和还原性谷胱甘肽含量)在 S13 组达到最大值, 而后显著下降。综上, 鳊鱼饲料中最适淀粉水平应保持在 13%以下。

关键词: 鳊鱼; 淀粉; 生长性能; 糖代谢; 组织学

Quantification of the optimum starch level in the diet of juvenile mandarin fish *Siniperca chuati*

Xi-Feng Liu¹, Hai-Yue Tan¹, Hong-Kang Liu¹, Min Zhao², Xu-Liang Zhai³, Yang Xue³, Li Luo^{1*},
Yong-Jun Chen^{1*}

(1. Key Laboratory of Freshwater Fish Resources and Reproductive Development of Ministry of Education, College of Fisheries, Southwest University, Chongqing 400716; 2. Shandong New Hope Liuhe Group Co., Ltd., Qingdao 266061; 3. Chongqing Fisheries Technology Extension Station, Chongqing 400400)

Abstract: This study was performed to evaluate the effects of dietary starch levels on growth, feed utilization, body composition, hepatic glucose metabolism and liver histology of mandarin fish, and thus determine its optimal inclusion level. Utilizing cassava starch as the carbohydrate source, five isonitrogenous (crude protein: 47%) and isolipidic (8.5%) experimental diets were prepared with 7%~19% starch, which were referred to as diets S7, S10, S13, S16 and S19, respectively. Four replicate group of juvenile mandarin fish with an initial body weight of 37.5 g were fed each experimental diet for 8 weeks. The results showed that the growth performance (final body weight, specific growth rate and weight gain rate) and feed efficiency of mandarin fish significantly increased with the increase of dietary starch from 7% to 13% and then levelled off. Feed intake was not affected by dietary starch levels. HE staining showed that a small amount of eccentric nuclei and vacuolization were observed in the hepatocytes of the S7 and S10 fish. The amount of vacuolization was further increased, and nuclear aggregation was observed in the hepatocytes of the S13 fish. The hepatocytes of the S16 and S19 fish was not intact with serious nuclear deviation, nuclear aggregation or even nuclear dissolution, and the degree of vacuolization was aggravated with pieces of vacuoles. The fasting blood glucose level of mandarin fish trend to increase with an increase of dietary starch levels, but the differences were not significant among treatments. The activities of alanine aminotransferase and aspartate aminotransferase were lowest in the serum of the S13 fish. The mRNA level of *glut2* in the liver of the S7 fish was significantly higher than those of the other treatments. The mRNA levels of *gck* in the liver of the S16 and S19 fish were significantly lower than those of the other treatments, but the expression of *pk* was not affected by dietary starch levels. Compared with the control, the relative expression of *g6pca1* in the liver of the S13 and S16 fish was significantly up-regulated, but the expression of *g6pca2* was not affected by dietary treatments. The expression of *gys1* in the liver was not significantly affected by dietary starch levels, but glycogen concentration was markedly higher in the S16 and S19 fish than in the control. Compared with the control, the highest values of antioxidant defense indicators such as the activity of superoxide dismutase and reduced glutathione level were evidenced in the liver of the S13 fish, and decreased with further increase of dietary starch levels. Taken together, the upper limit of dietary starch was about 13% in the diet of juvenile mandarin fish.

Key words : Mandarin fish; Starch; Growth performance; Glucose metabolism; Histology

鳊鱼营养和驯化研究

张进^{1,2}

(1.浙江省淡水水产研究所, 浙江 湖州 ; 2. 宁波大学海洋学院, 浙江 宁波)

摘要: 用蛋白质含量分别为 66.85%、61.46%、56.23%、51.09%、46.16% 的五种配合饲料投喂鳊鱼幼鱼, 对照组饲喂活鱼, 鱼体重平均 2.79g, 试验共进行 35d, 结束时各组鱼平均尾增重分别为 9.37g、10.15g、9.47g、8.37g、7.38g 和 6.81g, 饲料系数分别为 0.94、0.78、0.84、0.94、1.18 和 3.14。结果表明鳊鱼在幼鱼阶段人工饲料中最佳蛋白质添加量约为 61.46%。用脂肪含量分别为 6.5%、8.3%、11% 和 13.4% 的饲料投喂鳊鱼幼鱼, 其中含有一定量的动物脂肪, 含量分别为 0, 0.9%, 2.3%, 3.5%, 鱼的体重平均为 10.90g, 试验共进行 35d, 结果四个组鱼的尾增重分别为 29.17g, 31.69g, 31.63g, 29.25g, 饲料系数分别为 1.39, 1.28, 1.28, 1.36, 试验结果表明鳊鱼饲料中脂肪的最佳添加量分别为 8.3%~11%, 而且动物脂肪对鳊鱼具有诱食作用。采用不同驯养方法对鳊鱼进行驯养对比试验, 三种驯养方法分别为第一组(快速驯饲、软颗粒饲料)、第二组(常规驯饲、软颗粒饲料)、第三组(常规驯饲、硬颗粒饲料), 第一组以饥饿→活饵→活饵加死饵→死饵加软颗粒饲料→软颗粒饲料的方式逐步过渡驯化, 第二组以冲水刺激投喂活饵→活饵加死饵→死饵加冰鲜饵→冰鲜饵加软颗粒饲料→软颗粒饲料的方式逐步过渡, 第三组以冲水刺激投喂活饵→活饵加死饵→死饵加冰鲜饵→冰鲜饵加硬颗粒饲料→硬颗粒饲料的方式逐步过渡。试验用鳊鱼平均体重为 1.5g, 三组鱼驯化率分别为 82.1%, 91.2%, 66.5%, 试验得出结论, 不同的驯养方法对鳊鱼幼鱼的成活率有着显著的影响, 使用常规方法投喂软颗粒饲料驯养鳊鱼的成活率最高。

关键词: 蛋白质; 脂肪; 驯化

Research on the nutrition and domestication of mandarin fish

Zhang Jin^{1, 2}

(1. Zhejiang Freshwater Fisheries Research Institute, Huzhou, Zhejiang, China; 2. College of Oceanography, Ningbo University, Ningbo, Zhejiang, China)

Abstract: The juvenile mandarin fish were fed with five kinds of compound feeds with protein content of 66.85%, 61.46%, 56.23%, 51.09% and 46.16%, and the control group was fed live fish, with an average fish weight of 2.79g, the experiment was carried out for 35 days, and the average tail weight gain of each group was 9.37g, 10.15g, 9.47g, 8.37g, 7.38g and 6.81g at the end of the period, and the feed coefficients were 0.94, 0.78, 0.84, 0.94, 1.18 and 3.14. The results showed that the optimal protein addition in artificial feed at the juvenile stage was about 61.46%. With fat content of 6.5%, 8.3%, 11% and 13.4% of the feed fed mandarin fish juveniles, which contained a certain amount of animal fat, the content was 0, 0.9%, 2.3%, 3.5%, the average weight of the fish was 10.90g, the experiment was carried out for a total of 35 days, the results of the tail weight gain of the four groups of fish were 29.17g, 31.69g, 31.63g, 29.25g, feed coefficients were 1.39, 1.28, 1.28, 1.36, the test results showed that the optimal amount of fat added in the mandarin fish feed was 8.3%~11%, and animal fat had a predistendency effect on mandarin fish. The three domestication methods were the first group (rapid domestication, soft pellet feed), the second group (conventional domestication, soft pellet feed), the third group (conventional domestication, hard pellet feed), the first group was gradually domesticated by starvation→live bait→live bait plus dead bait→dead bait plus soft pellet feed→soft pellet feed, and the second group was gradually transitioned by flushing to stimulate feeding live bait→live bait plus dead bait→dead bait plus chilled bait→chilled bait plus soft pellet feed→soft pellet feed. The third group gradually transitioned to the method of flushing stimulation by feeding live bait→live bait plus dead bait→dead bait plus chilled bait→chilled bait plus hard pellet feed→hard pellet feed. The average weight of the mandarin fish was 1.5g, and the domestication rates of the three groups were 82.1%, 91.2% and 66.5%, respectively.

Key words: protein; Fat; domestication

花鲈 (*Lateolabrax maculatus*) 血管内皮生长因子 b 的分子特征 及其在降低脂肪沉积中的潜在作用

苏宁宁, 郑钧, 张关荣, 关俊锋, 高欣, 程微奕, 徐超, 谢帝芝, 李远友*

(华南农业大学海洋学院, 广州, 510642)

摘要: 血管内皮生长因子 B (VEGFB) 是 VEGF 家族的成员, 在哺乳动物中表现出有限的血管生成活性, 但在脂质代谢方面发挥了意想不到的作用。然而, 它在鱼类脂质代谢中的作用尚不清楚。本课题组在花鲈 (*Lateolabrax maculatus*) 中克隆到 *vegfb* 基因, 它编码 254 个氨基酸, 肽链具有 Vegf 家族的典型特征, 且与其他脊椎动物的同源性很高。Vegfb 基因在花鲈的肝脏中表达水平最高, 其次是鳃、肠和脂肪组织。养殖试验结果表明, 高脂饲料投喂显著降低了花鲈肝脏 *vegfb* 基因的表达水平, 并增加了肝脏脂质沉积。体外肝细胞实验中, 利用棕榈油+油酸处理或干扰 *vegfb* 表达均显著提高甘油三酯和胆固醇的含量, 促进肝细胞脂滴的沉积, 显著上调脂肪生成相关基因的表达水平 (*c/ebpα*、*plin2* 和 *dgat1*); 过表达 *vegfb* 则产生相反的效果, 下调脂肪酸转运和脂肪生成相关基因的表达水平并减少脂肪沉积 ($P < 0.05$)。以上结果表明, 在花鲈肝细胞中 Vegfb 可能通过调节脂肪酸转运和脂肪生成相关基因从而在降低脂质沉积中发挥重要作用。

关键词: 血管内皮生长因子 B, 花鲈, 分子特征, 表达谱, 脂肪生成

通讯作者: 李远友, E-Mail: yyli16@scau.edu.cn

基金项目: 国家自然科学基金项目 (32273148)

Molecular characterization of vascular endothelial growth factor b from spotted sea bass (*Lateolabrax maculatus*) and its potential roles in decreasing lipid deposition

Ningning Su, Jun Zheng, Guanrong Zhang, Junfeng Guan, Xin Gao, Zhiyi Cheng, Chao Xu,
Dizhi Xie, Yuanyou Li*

College of Marine Science, South China Agricultural University, Guangzhou 510642

Abstract: Vascular endothelial growth factor B (VEGFB) is a member of VEGF family, which shows limited angiogenic activity in mammals, but plays an unexpected role in lipid metabolism. However, its role in fish lipid metabolism is still unclear. Our research group cloned *vegfb* gene from *Lateolabrax maculatus*, which encodes 254 amino acids. The peptide chain has the typical characteristics of Vegf family and has high homology with other vertebrates. The expression level of *vegfb* in the liver of *L. japonicus* was the highest, followed by gill, intestine and adipose tissue. The results of feeding experiment showed that high-fat feed significantly reduced the expression level of *vegfb* in the liver of *L. japonicus* and increased the lipid deposition in the liver. *In vitro* hepatocyte experiments, palm oil + oleic acid treatment or interfering *vegfb* expression significantly increased the contents of triglycerides and cholesterol, promoted the deposition of lipid droplets in hepatocytes, and significantly increased the expression levels of lipogenesis-related genes (*c/ebpa*, *plin2* and *dgat1*). Overexpression of *vegfb* had the opposite effect, down-regulating the expression level of genes related to fatty acid transport and lipogenesis and reducing fat deposition ($P < 0.05$). These results indicate that Vegfb may play an important role in reducing lipid deposition by regulating fatty acid transport and lipogenesis related genes in the hepatocytes of *L. japonicus*.

Key words: Vascular endothelial growth factor B, *Lateolabrax maculatus*, molecular characterization, expression profile, adipogenesis

黄颡鱼铁代谢相关基因的克隆及其对不同铁源的响应

徐鹏程¹, 宋长春¹, 谭肖英¹, 赵涛¹, 仲崇超¹, 徐杰杰¹, 宋玉峰¹, 罗智^{1,2*}

(1.华中农业大学, 分子营养学实验室, 湖北武汉 430070; 2.青岛海洋科学与技术试点国家实验室, 海洋渔业科学与食物产出过程功能实验室, 山东青岛 266237)

摘要:【目的】本研究旨在对黄颡鱼 (*Pelteobagrus fulvidraco*) 铁代谢相关基因进行鉴定, 并探究相关基因在各组织中对饲料中不同铁源的响应。【方法】在本研究中, 我们对铁代谢关键基因 (*tf*、*tfr1*、*hp*、*fpn1*、*ho1*、*ho2*、*tfr2*、*hju*、*hepcidin*、*fth*、*ftl*、*ftm*、*irp1*、*irp2* 和 *hif2 α*) 进行克隆, 得到其全长 cDNA 序列。随后对其保守结构域、同源性进行分析, 构建进化树, 并探究了铁代谢相关基因在各组织中的表达差异。此外, 黄颡鱼 (2.50 ± 0.01 g) 被随机饲喂 5 种含不同铁源的饲料 (硫酸亚铁, 甘氨酸亚铁, 硫酸亚铁, 柠檬酸铁, 纳米氧化铁), 养殖实验持续 10 周。【结果】我们发现, 铁代谢相关基因在结构上与哺乳动物具有类似的功能结构域, 表明黄颡鱼在铁代谢机制上可能与哺乳动物类似。同时, 我们发现铁代谢相关基因在黄颡鱼各组织中均有表达, 但组织间表达水平存在差异。在养殖实验中我们发现, 相较于其他铁源, 甘氨酸亚铁和纳米氧化铁作为铁源可以提高黄颡鱼心脏, 脑, 肾脏和鳃中的铁含量, 表现出较好的利用率。同时, 不同铁源的添加能够影响铁代谢相关基因在各组织中的表达。【结论】本研究对黄颡鱼铁代谢相关基因进行了鉴定, 并且通过饲料中添加不同铁源的养殖实验发现, 甘氨酸亚铁与纳米氧化铁作为铁源会提高黄颡鱼组织中的铁含量, 这将为提高饲料中微量元素的高效利用提供一定的参考。

关键词: 铁代谢; 分子表征; 组织表达分布; 饲料铁源; 黄颡鱼

资助项目: 国家自然科学基金重点国际(地区)合作研究项目 (32220103013), 国家重点研发计划 (2018YFD0900400)

报告作者: 罗智, E-Mail: luozhi99@mail.hzau.edu.cn

Characterization of fifteen key genes involved in iron metabolism and their Responses to dietary iron sources in yellow catfish *Pelteobagrus fulvidraco*

Peng-cheng Xu¹, Chang-chun Song¹, Xiao-ying Tan¹, Tao Zhao¹, Chong-chao Zhong¹, Jie-jie Xu¹, Yu-feng Song¹, Zhi Luo^{1,2*}

(¹Laboratory of Molecular Nutrition, Huazhong Agricultural University, Wuhan 430070;

²Laboratory for Marine Fisheries Science and Food Production Processes, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266237.)

Abstract: [Objective] This experiment was conducted to identify iron metabolism-related genes in yellow catfish (*Pelteobagrus fulvidraco*) and to explore their responses to dietary iron sources in different tissues. [Methods] The full-length cDNA sequences of fifteen iron metabolism-relevant genes (*tf*, *tfr1*, *hp*, *fpn1*, *ho1*, *ho2*, *tfr2*, *hju*, *hepcidin*, *fth*, *ftl*, *ftm*, *irp1*, *irp2* and *hif2a*.) were obtained from yellow catfish. Then, the conserved domains and homology were analyzed, the phylogenetic tree was constructed, and the expression of iron metabolism-related genes in various tissues were explored. Yellow catfish (2.50 ± 0.01 g) were randomly fed five diets containing different iron sources (ferrous sulfate, ferrous bisglycinate, ferrous chloride, ferric citrate, and ferric oxide nanoparticles) for 10 weeks. [Results] We found that iron metabolism-related genes had similar functional domains with mammals, indicating that the mechanism of iron metabolism in yellow catfish may be similar to mammals. Meantime, we found that iron metabolism-related genes were expressed in various tissues of yellow catfish, but the expression levels were different among tissues. We found that yellow catfish fed the ferrous bisglycinate and ferric oxide nanoparticles diets had higher iron content in heart, brain, kidney and gill compared with other iron sources, showing better utilization. Meantime, different dietary iron sources addition affected their mRNA expression differentially in various tissues. [Conclusions] In summary, this study identified the genes related to iron metabolism in yellow catfish, and found that ferrous bisglycinate and ferric oxide nanoparticles diets increased the iron content in yellow catfish tissues. This study will provide a reference for improving the efficient use of trace elements in feed.

Keywords: Iron metabolism; Molecular characterization; Tissue mRNA expression; Dietary iron sources; *Pelteobagrus fulvidraco*

肌醇在调节草鱼皮肤免疫反应中的作用

王美琪¹, 李双安¹, 冯琳^{1, 2, 3}, 吴培^{1, 2}, 刘杨^{1, 2, 3}, 姜俊^{1, 2, 3}, 周小秋^{1, 2, 3*}, 姜维丹^{1, 2, 3*}

(1. 四川农业大学, 成都 611130; 2. 鱼类营养与安全生产四川省高校重点实验室, 成都 611130; 3. 动物抗病营养教育部重点实验室, 农业农村部, 四川省重点实验室, 成都 611130)

摘要: 肌醇 (*myo*-inositol, MI) 是细胞膜的重要组成成分, 在跨膜信号转导、离子通道调节、细胞运输等方面发挥重要作用。鱼类皮肤是重要的黏膜免疫器官, 目前关于 MI 对鱼类皮肤影响的研究较少。本试验旨在研究在嗜水气单胞菌攻毒作用下, 饲料中添加 MI 对草鱼皮肤屏障功能的影响。将 540 尾 (221.33 ± 0.84 g) 草鱼随机分为 6 组, 分别投喂含不同水平肌醇 (27.0、137.9、286.8、438.6、587.7、737.3 mg/kg) 的饲料, 试验期为 10 w。生长试验结束后, 对各组进行为期 14 d 的嗜水气单胞菌攻毒。结果表明, 饲料中适宜水平 MI (438.6-737.3 mg/kg): 1) 增加了致密真皮层厚度, 降低了草鱼皮肤发病率。2) MI 可能通过 Nrf2、p38MAPK、MLCK 信号通路提高草鱼皮肤抗氧化能力、抑制过度细胞凋亡、改善紧密连接进而增强皮肤的物理屏障功能。3) 饲料中添加 MI 增加了皮肤抗菌化合物 (ACP、LZ、C3、IgM、C4) 的酶活性和含量, 并提高了皮肤中抗菌肽相关基因 (*leap-2a*、*leap-2b*、*hepcidin*、 β -*defensin-1*、*mucin2*) 的 mRNA 水平, 同时下调了促炎细胞因子 (IL-6、TNF- α 、IL-1 β 、IL-8)、上调抗炎细胞因子 (TGF- β 和 IL-10) 的 mRNA 水平, 从而增强皮肤免疫功能。本试验根据研究结果得出以下结论: 饲料中中添加 MI 通过增强草鱼皮肤屏障功能, 并保护其免受嗜水气单胞菌的感染。本研究有助于 MI 在水生动物中的应用提供理论依据。

关键词: 肌醇; 草鱼; 皮肤; 物理屏障; 免疫屏障

资助项目: 国家自然科学基金项目 (31972810); 四川省自然科学基金 (2022NSFSC0006) 和中国科学院自然科学基金委员会 (CARS-45) 的资助

通信作者: 周小秋, 姜维丹; E-Mail: zhouxq@sicau.edu.cn, WDJiang@sicau.edu.cn;

氯化钠缓解吉富罗非鱼冬季低温环境下的氧化应激反应

黄东宇¹, 梁化亮¹, 张璐², 陈效儒², 王用黎², 任鸣春^{1*}

(1. 中国水产科学研究院淡水渔业研究中心, 农业农村部稻渔综合种养生态重点实验室, 江苏 无锡 214081; 2. 通威农业发展有限公司, 农业农村部水产畜禽营养与健康养殖重点实验室, 水产健康养殖四川省重点实验室, 四川 成都 610093)

摘要: 本研究开展为期6周的养殖实验, 旨在研究饲料中补充氯化钠对生理、代谢和应激反应的影响。结果表明: (1) 除0.2%氯化钠(0.2S)添加组的最终体重、增重率、特定生长率和饲料转化率优于对照组外, 其他氯化钠添加组(0.05S、0.1S和0.15S)与对照组相比无显著差异; (2) 低温应激实验结果表明, 0.1S和0.15S饲料组的存活率明显高于对照组; (3) 转录结果表明, 鳃部富集的途径主要是能量代谢和细胞凋亡途径, 肝脏富集的途径主要是氨基酸代谢和碳水化合物代谢; (4) 血浆生化指标结果显示, 与对照组相比, 0.15S饲料组显著提高血浆葡萄糖(GLU)、总甘油三酯(TG)含量、Na⁺和K⁺离子浓度, 降低了血浆谷丙转氨酶(ALT)活性。此外, 0.1S饲料组增加了血浆白蛋白(ALB)含量和Cl⁻离子浓度; 0.1S和0.15S饲料组显著降低Na⁺/K⁺-ATP酶的活性。抗氧化酶活性结果显示, 0.1S和0.15S饲料组显著提高总超氧化物歧化酶(T-SOD)活性。基因表达结果显示, 与对照组相比, 0.1S和0.15S饲料组显著上调*gys*、*hsp70*、*mlcp*、*mlc*、*actin*、*tmt*的mRNA表达, 下调*akt*、*gk*和*erk*的mRNA表达。根据回归分析, 饲料中氯化钠的最佳添加含量为0.10%-0.13%, 可以促进能量调节, 改善免疫反应, 增强吉富罗非鱼(GIFT)的抗寒能力。

关键词: 氯化钠; 氧化应激; 生理反应; 冬季低温; 吉富罗非鱼

Sodium chloride alleviates oxidative stress induced by extreme winter cold in genetically improved farmed tilapia (GIFT; *Oreochromis niloticus*)

Dongyu Huang¹, Hualiang Liang¹, Lu Zhang², Xiaoru Chen², Yongli Wang², Mingchun Ren^{1*}

(1. Key Laboratory of Integrated Rice-Fish Farming Ecology, Ministry of Agriculture and Rural Affairs, Freshwater Fisheries Research Center, Chinese Academy of Fishery Sciences, Wuxi 214081, PR China; 2. Tongwei Agricultural Development Co., LTD., Key laboratory of nutrition and healthy culture of aquatic, livestock and poultry, ministry of agriculture and rural affairs, Healthy Aquaculture Key Laboratory of Sichuan Province, Chengdu 610093, PR China)

Abstract: A 6-week trial was designed to investigate the effects of dietary sodium chloride supplementation on physiological, metabolic, and molecular stress response parameters. The findings showed that (1) there were no significant differences between sodium chloride supplementation groups (0.05S, 0.1S, and 0.15S) and the control group ($P > 0.05$), except for the 0.2S diet, which showed better final body weight, weight gain rate, specific growth rate, and feed conversion ratio than the control group ($P < 0.05$). (2) The hypothermic stress experiment results showed that the survival rates in the 0.1S and 0.15S diets were significantly higher than the control group ($P < 0.05$). (3) Transcription results showed that these enriched pathways in the gill were mainly energy metabolism and apoptosis pathways, while the major enrichment pathways in the liver were mainly amino acid metabolism and carbohydrate metabolism. (4) The plasma parameter results showed, compared to the control group, the 0.15S diet significantly increased the plasma GLU, TG contents, and Na^+ and K^+ concentrations and decreased the plasma ALT activity ($P < 0.05$). In addition, the 0.1S diet increased the plasma ALB content and Cl^- concentration ($P < 0.05$). The gill Na^+/K^+ -ATPase activity decreased markedly when the fish were fed the 0.1S and 0.15S diets ($P < 0.05$). The antioxidant enzyme activity results showed that the 0.1S and 0.15S diets significantly increased the T-SOD activities ($P < 0.05$). Gene expression results showed that compared to the control group, the 0.1S and 0.15S diets up-regulated the expression of *gys*, *hsp70*, *mlep*, *mlc*, *myosin*, *tnt* mRNA, and down-regulated the *akt*, *gk*, and *erk* mRNA expression. Based on the regression analysis, the optimum dietary sodium chloride levels range from 0.10% to 0.13% of the diet, which could facilitate energy regulation, improve the immune response, and ultimately strengthen the cold resistance of GIFT.

Key words: Sodium chloride; Oxidative stress; Physiological response; Winter cold; Genetically improved farmed tilapia (GIFT)

尼罗罗非鱼对高脂饲料摄入的适应机制研究

陈翠英, 谭森月, 魏嘉敏, 李锐鑫, 王树启*

(汕头大学理学院海洋生物研究所, 汕头市, 515063)

摘要: 水产养殖业中高脂低蛋白饲料的广泛使用严重损害了鱼类的肝脏健康。研究表明, 鱼类有多种机制来适应高脂饲料的摄入, 但关于脂肪组织在鱼类适应高脂饲料中的作用研究较少。为此, 本研究评估了尼罗罗非鱼 (~18g) 摄食脂肪水平为 6% (NFD) 或 12% (HFD) 的饲料 6、8 和 10 周后的肝胰腺和脂肪组织的生理生化反应及糖脂代谢相关基因表达水平的变化。结果发现, 罗非鱼在摄食 HFD 饲料 6 周后, 肝体比、血清和肝胰腺的 TG 和 NEFA 及肝胰腺脂滴含量均明显高于 NFD 组 ($P < 0.05$)。血清 AST 和 ALT 以及肝胰腺 MDA 含量也同样在摄食 HFD 后第 6 周就出现极显著的增加 ($P < 0.05$)。但随着饲养时间增加至第 10 周时, 以上血清和肝胰腺脂质代谢及损伤指标均呈现逐渐下降的趋势, 而腹脂率、血清与肝胰腺的葡萄糖含量则出现明显升高的趋势 ($P < 0.05$)。有趣的是, 在摄食 HFD 饲料 6 周后, 脂肪组织细胞主要以肥大的方式出现明显的扩增, 尤其是在第 8 周更为显著, 直到第 10 周才以增生为主, 而 NFD 组的脂肪组织细胞则在第 10 周才出现明显的扩增, 前期以增生为主, 后期则以肥大为主要扩增方式。此外, qPCR 结果显示, 相比 NFD 组, 摄食 HFD 饲料 6 周后肝胰腺脂质合成关键基因(*acca*, *fas*, *dgat1*, *vegfa*), 葡萄糖代谢关键基因(*pfk-1*, *g6pase*, *g6pd*, *glut2*) 以及炎症因子 (*tnf β* , *il-1 β*) 的表达明显上调了。除了糖异生、糖酵解及脂质分解 (*lpl*, *hsl*, *cpt1*, *fabp1*) 相关基因的表达随着摄食 HFD 时间的延长而明显升高, 而肝胰腺的脂质合成和炎症因子的表达水平则出现明显的下调 ($P < 0.05$), 相反, 脂肪组织脂代谢相关基因 (*hsl*, *ppary*, *atgl*, *adipor2*), 炎症因子以及糖代谢相关基因的表达则呈现先升高后下降的趋势, 而细胞增殖与分化相关基因 (*c/ebp γ* , *srebp1*) 的表达则明显上调了 ($P < 0.05$)。以上结果表明, 尼罗罗非鱼幼鱼摄食的过量脂肪优先储存在肝胰腺中, 而 HFD 的摄入明显诱导了腹腔脂肪组织的发育, 并可能以此缓解了由 HFD 引起的肝胰腺脂质过度沉积而造成的损伤。此外, 肝胰腺糖异生和糖酵解的增加也可能是尼罗罗非鱼适应长期 HFD 摄入的一种机制。

关键词: 尼罗罗非鱼, 高脂饲料, 腹腔脂肪, 肝胰腺, 糖脂代谢

*通讯作者: 王树启, E-Mail: sqw@stu.eud.cn; 基金项目: 广东省现代农业产业技术体系淡水鱼产业创新团队项目 (2019KJ150); 国家自然科学基金面上项目 (32473178)。

Studies on the mechanisms by which Nile tilapia (*Oreochromis niloticus*) adapt to the high-fat diet

Cuiying Chen, Senyue Tan, Jiamin Wei, Ruixin Li, Shuqi Wang*

(Marine Biology Institute of Shantou University, Shantou, Guangdong 515063, PR China)

Abstract: Previous studies have shown that fish have multiple mechanisms to adapt to high-fat diet (HFD), but little is known about the role of adipose tissue in adaptation to HFD for fish. Here, the physiological and biochemical responses of the hepatopancreas and adipose tissues, and the expression of genes related to glycolipid metabolism were analyzed in Nile tilapia juveniles (~18 g) after a feeding trial conducted with two lipid levels diets (6% and 12% lipid, named NFD and HFD, respectively) for 6-10 weeks. After 6 weeks on a HFD, hepatosomatic index, the contents of TG and NEFA in serum and hepatopancreas and hepatopancreatic lipid droplets were significantly increased when compared to the NFD group ($P < 0.05$). Serum AST and ALT activities, as well as hepatopancreatic MDA levels were also significantly elevated at 6-week HFD ($P < 0.05$). However, as the feeding time increased to 10 weeks, the serum and hepatopancreatic lipid contents and injury indices were gradually decreased, whereas mesenteric fat index and serum and hepatopancreatic glucose contents exhibited increased patterns ($P < 0.05$). Interestingly, after 6 weeks of HFD, a significant expansion of mesenteric adipocytes mainly caused by hypertrophy was observed in tilapia, which was more pronounced especially at 8-week, and not predominantly hyperplasia until 10-week HFD. However, this was not the case for fish fed the NFD, with expansion dominated by hyperplasia early at 6-week and later expansion primarily through hypertrophy. Furthermore, the RT-qPCR results showed that the expression of lipid synthesis (*acca*, *fas*, *dgat1*), glucose metabolism (*pfk-1*, *g6pd*, *glut2*), and inflammatory factors (*tnf β* , *il-1 β*) were significantly upregulated in hepatopancreas at 6-week HFD ($P < 0.05$). The expression of genes associated with gluconeogenesis, glycolysis and lipolysis (*lpl*, *hsl*, *cpt1* and *fabp1*) was markedly elevated, while the expression of inflammatory factors was significantly reduced in hepatopancreas with the prolonged consumption of the HFD ($P < 0.05$). In contrast, the expression of genes related to lipid metabolism (*hsl*, *ppar γ* , *atgl*, *adipor2*), inflammation and glucose metabolism in mesenteric adipose tissue was firstly increased at 8-week and then decreased at 10-week HFD, whereas the expression of genes related to cell proliferation and differentiation (*c/ebp γ* , *srebp1*) were significantly up-regulated ($P < 0.05$). The above results indicated that the excess lipid consumed by juvenile Nile tilapia is preferentially accumulated in the hepatopancreas, and HFD intake obviously induces the development of mesenteric adipose tissue, which may in turn alleviate the damage caused by HFD-induced excessive lipid deposition in hepatopancreas. Additionally, increased hepatopancreatic gluconeogenesis and glycolysis may also be a mechanism by which Nile tilapia adapt to a long-term HFD.

Key words: Nile tilapia; HFD; Mesenteric adipose tissue; Hepatopancreas; glucose and lipid metabolism

水产动物饲源性损伤：证据与挑战

蔡春芳^{1,2*}, 何海龙^{1,2}, 叶伟豪^{1,2}, 叶元土^{1,2}

(1.江苏省水产动物营养重点实验室, 江苏 苏州 215123; 2. 苏州大学生命科学学院, 江苏 苏州)

摘要:【目的】为了明确饲料质量对水产养殖绿色发展的影响, 开发低碳饲料, 【方法】开展了文献研究并在江苏地区进行了实地调查走访, 在此基础上采用鱼类营养与饲料学常规研究方法进行了实验研究。【结果】调查走访中发现, 投喂价格较低的饲料时鱼类发生出血、肠炎、脂肪肝、绿肝、胆汁渗漏、死亡的概率高; 相同的饲料投喂量较大时鱼类容易出现白便、出血、肠炎、诺卡氏菌病、胆汁渗漏及暴发性死亡。上述调研结果与渔技人员发表的研究报告相支持。用抗生素、胆汁酸拌料投喂, 并/或降低投喂量, 可缓解病情。实验研究发现饲料中可溶性膳食纤维含量越高, 鱼类越容易发生吐料、绿便、白便、肠炎、绿肝、胆汁渗漏、出血、肝脂肪变性、肠道菌群和胆汁酸稳态失调、抗应激能力下降和死亡, 但个体差异较大。在南美白对虾 (*Litopenaeus vannamei*)、牛蛙 (*Rana catesbeiana*) 养殖中也可见类似现象。在商业饲料配方的基础上提高动物蛋白和油脂水平, 银鲫 (*Carassius auratus gibelio*) 和草鱼 (*Ctenopharyngodon idellus*) 的生长性能和健康状态得到改善, 吨鱼产品的饲料碳足迹和成本显著下降 ($P < 0.05$)。【结论】膳食纤维可能是防控各类水产疾病和降低吨鱼产品饲料碳足迹的重要抓手, 应研究制定饲料中膳食纤维限量标准, 且在膳食纤维生理效应研究中应注意个体差异。

关键词: 饲料; 鱼病; 调查; 碳足迹; 膳食纤维

Feeding induced damage in aquatic animals: evidences and challenges

Chunfang Cai^{1,2*}, Hailong He^{1,2}, Weihao Ye^{1,2}, Yuantu Ye^{1,2}

(1. Key Laboratory of Aquatic Nutrition of Jiangsu Province, Suzhou China 215123; 2. School of Life Sciences, Soochow University, Suzhou China 215123)

Abstract: [Objective] This study aims to elucidate the impact of feed quality on sustainable aquaculture and to provide reference for the development of low-carbon footprint feed. [Methods] We conducted field investigations in Jiangsu Province and literature reviews, followed by experiments using conventional research methods in fish nutrition and feed science. [Results] Field investigations revealed that feeding fish with lower-cost feed increased the likelihood of bleeding, enteritis, fatty liver, green liver syndrome, bile leakage, and mortality. With higher feeding volumes of the same feed, fish were more prone to white stool, bleeding, enteritis, *Nocardia* infection, bile leakage, and death. These findings align with published reports by fishery technicians. Treatment with antibiotics and bile acids, and/or reducing feed quantity, was effective in alleviating these conditions. Experimental studies revealed that high levels of soluble dietary fiber in feed increased the likelihood of vomiting, green stool, white stool, enteritis, green liver, bile leakage, bleeding, hepatic steatosis, imbalances in gut microbiota and bile acid homeostasis, reduced stress tolerance, and mortality, though individual differences were significant. Similar issues were also observed in *Litopenaeus vannamei* and *Rana catesbeiana*. Increasing animal protein and oil in commercial feed formulas improved growth performance and health in *Carassius auratus gibelio* and *Ctenopharyngodon idellus*, and significantly reduced the carbon footprint and cost per ton of fish ($P < 0.05$). [Conclusion] Dietary fiber may play a crucial role in preventing various aquatic diseases and reducing the carbon footprint of feed per ton of fish. Further research should focus on establishing dietary fiber limit standards in feed, with attention to individual variation in physiological responses to dietary fiber.

Key words: Feed; Fish disease; Investigation; Carbon footprint; dietary fiber

四种饲料诱食剂对中华绒螯蟹幼蟹生长、食欲及消化吸收的 比较研究

李雯¹, 李二超^{1*}, 王松¹, 王晓丹¹, 陈立侨^{1*}

(1. 华东师范大学生命科学院, 上海 200241)

摘要:【目的】饲料诱食剂能增强食欲, 增加进食量, 促进消化吸收, 从而促进生长。本研究旨在探究四种饲料诱食剂对中华绒螯蟹幼蟹生长、食欲及消化吸收的影响。【方法】在有效剂量范围内, 每种诱食剂以两个浓度添加, 共形成八种饲料和对照饲料 (Ctrl)。诱食剂的种类及剂量分别为 2%和 4%的鱿鱼膏 (S1、S2)、0.5%和 1%的谷氨酸 (G1、G2)、0.05%和 0.1%的核苷酸 (N1、N2) 以及 0.04%和 0.08%的二甲基- β -丙酸噻亭 (D1、D2)。进行 20 次 (6 轮) 的饲料选择行为试验和为期 8 周的养殖试验。【结果】四种诱食剂均显著刺激了食欲, 提高了 1 小时摄食量, 并增加了特定生长率和增重。饲料选择行为试验的结果与养殖试验一致。在最佳浓度下, N1、D2、S2 和 G2 的效果从高到低依次排序。此外, 本研究还揭示了食欲相关基因参与调控摄食行为的可能过程。诱食剂提高了幼蟹的饲料利用率和粗蛋白、粗脂肪含量。值得注意的是, 诱食剂增强了消化吸收酶的活性, 其中 N1 效果最佳。相关性分析结果显示, 特定生长率和增重与摄食量、基因表达和酶活性显著相关。【结论】饲料诱食剂可以通过调节食欲基因的表达, 增强食欲, 引发摄食行为, 最终增加摄食量。此外, 饲料诱食剂还可以通过增强消化吸收酶的活性, 促进对摄入的营养物质的消化吸收, 改善营养物质的利用和沉积, 最终促进生长。其中, 0.05%的核苷酸效果最佳。

关键词: 饲料诱食剂; 生长性能; 食欲; 消化; 吸收

Comparative effects of four feed attractants on growth, appetite, digestion and absorption in juvenile Chinese mitten crab (*Eriocheir sinensis*)

Wen Li¹, Erchao Li^{1*}, Song Wang¹, Xiaodan Wang¹, Liqiao Chen^{1*}

(1. School of Life Sciences, East China Normal University, Shanghai China 200241)

Abstract: [Objective] Feed attractants can enhance appetite, increase food intake, and promote digestion and absorption, thereby improving growth. This study aims to investigate the effects of four feed attractants on the growth, appetite, digestion and absorption of juvenile Chinese mitten crab (*Eriocheir sinensis*). [Methods] Within the effective dosage range, two concentrations of each feed attractant were added, yielding eight diets and a control diet (Ctrl) without attractants. The attractants included 2.00% and 4.00% squid paste (S1, S2), 0.50% and 1.00% glutamic acid (G1, G2), 0.05% and 0.10% nucleotides (N1, N2), and 0.04% and 0.08% dimethyl-beta-propiethetin (D1, D2). A feed choice behavior test (20 times, six rounds) and an eight-week culture experiment were carried out. [Results] All four types of feed attractants demonstrated significant appetite-stimulating effects, enhancing 1-h food intake and increasing the specific growth rate and weight gain. The results of the feed choice behavior experiment were consistent with those of the culture experiment. Among the four attractants, N1, D2, S2, and G2 had effects ranging from high to low at the best concentrations. In addition, this study revealed that appetite-related genes are involved in regulating feeding behavior. Feed attractant supplementation increased feed utilization and crude protein and lipid levels in whole crabs. Notably, feed attractants increased the activity of digestive and absorptive enzymes, with N1 exhibiting the most pronounced effect. Correlation analysis revealed that the specific growth rate and weight gain are associated with food intake, gene expression and enzyme activity, as mentioned above. [Conclusion] Dietary supplementation with feed attractants can regulate appetite gene expression to enhance appetite, trigger eating behavior, and ultimately increase food consumption. This study indicated that feed attractants can enhance the activity of digestion and absorption enzymes, facilitate the digestion and absorption of ingested nutrients, improve the utilization and deposition of nutrients, and ultimately promote growth. The findings indicate that a concentration of 0.05% nucleotides is most effective as a feed attractant.

Key words: Feed attractant; Growth performance; Appetite; Digestion; Absorption

饲料 SFA/MUFA 比对罗非鱼生长性能、肌肉品质和脂质代谢的影响

莫子颖, 黄小平, 关俊锋, 徐超, 李远友, 谢帝芝*

(华南农业大学海洋学院 广东 广州 510642)

摘要: 饲料饱和 (SFA) 与单不饱和脂肪酸 (MUFA) 在节约 LC-PUFA 方面也具有重要作用。为探讨罗非鱼对饲料 SFA/MUFA 的适宜需求比, 本试验以豆油、茶油和猪油为脂肪源配制成 4 种等氮 (30%) 等脂 (7%) 饲料 (T1-T4, 其 SFA/MUFA 比分别为 1/3、1/2、1/1、3/2), 于池塘网箱中养殖罗非鱼幼鱼 (初始体重~5.0 g) 9 周。结果显示, 各饲料组鱼的生长性能 (增重率、特定生长率、饵料系数和存活率)、全鱼常规营养成分以及血清低密度脂蛋白 (LDL)、总抗氧化能力 (T-AOC) 和丙二醛 (MDA) 含量均无显著差异 ($P > 0.05$); 但血清总脂 (TG) 和总胆固醇 (T-CHO) 含量, 以及肝脏和肌肉脂肪水平随着饲料 SFA/MUFA 比升高而增加 ($P < 0.05$)。在脂肪代谢方面, 相比于其它饲料组, T2 组鱼肝脏和肌肉 LC-PUFA 水平最高, 但各组鱼肝脏 LC-PUFA 合成关键酶基因 (*fads2, elovl5, srebp1, ppara*) mRNA 表达水平均无显著差异 ($P > 0.05$), 胞质 NAD⁺/NADH 比值随着饲料 SFA/MUFA 比显著下降 ($P < 0.05$); 然而, 随着饲料 SFA/MUFA 比升高, 肌肉脂肪酸合成 (*fas, acc*) 相关基因表达水平显著上升, 脂肪酸 β 氧化 (*aco-xl, ppar-a*) 呈先下降后上升趋势 ($P < 0.05$)。在肌肉质地方面, 相比于 T3 和 T4 组, T1 和 T2 组鱼肌肉硬度、咀嚼性和剪切力等质构特性显著提升 ($P < 0.05$)。综上所述, 当饲料 SFA/MUFA 添加比为 1/2 时, 既可通过促进组织脂肪酸 β -氧化, 间接提升 LC-PUFA 沉积水平, 又可改善肌肉质构特性, 从而提升养殖罗非鱼肌肉品质。

关键词: 罗非鱼; 饲料 SFA/MUFA; 生长性能; 肌肉品质; 脂质代谢

通讯作者: 谢帝芝, 副研究员, E-Mail: xiedizhi@scau.edu.cn

基金项目: 广东省自然科学基金-青年提升项目 (2024A1515030246)

Effects of dietary SFA/MUFA ratio on growth performance, muscle quality and lipid metabolism of tilapia

Ziying Mo, Xiaoping Huang, Junfeng Guan, Xu Chao, Yuanyou Li, Dizhi Xie*

(College of marine sciences, South china agricultural university, Guangzhou, Guangdong 510642)

Abstract: Dietary saturated (SFA) and monounsaturated fatty acids (MUFA) also play a crucial role in the “n-3 LC-PUFA sparing”. To investigate the optimal ratio of SFA/MUFA required by tilapia for feed, this experiment used soybean oil, tea oil, and pig oil as fat sources to prepare four isonitrogenous (30 %) and isolipidic (7 %) diets (T1-T4 with SFA/MUFA ratios of 1/3, 1/2, 1/1, and 3/2, respectively) and cultured tilapia juveniles (initial body weight ~5.0 g) in pond cages for 9 weeks. The results showed that there were no significant differences in the growth performance (growth rate, specific growth rate, feed coefficient and survival rate), whole fish proximate composition, and serum low-density lipoprotein (LDL), total antioxidant capacity (T-AOC) and malondialdehyde (MDA) contents among the four groups ($P > 0.05$). However, the total serum lipids (TG) and total cholesterol (T-CHO) levels, as well as liver and muscle crude lipid levels, increased with the increase of the dietary SFA/MUFA ratio ($P < 0.05$). In terms of tissue fatty acid composition and lipid metabolism, the liver and muscle LC-PUFA levels of fish in T2 group was the highest ($P < 0.05$), but the mRNA expression levels of hepatic key enzyme genes (*fads2*, *elovl5*, *srebp1*, *ppara*) for LC-PUFA biosynthesis showed no significant difference among the four groups ($P > 0.05$). The cytosolic NAD⁺/NADH ratio decreased significantly with the dietary SFA/MUFA ratio ($P < 0.05$). However, with an increase in the dietary SFA/MUFA ratio, there was a significant upregulation of muscle mRNA expression levels for genes associated with fatty acid synthesis (*fas*, *acc*), and β -oxidation (*aco-xl*, *cpt-1*, *ppar-a*) exhibiting a subsequent downward and then upward trend respectively ($P < 0.05$). In terms of muscle texture, compared with the T3 and T4 groups, the T1 and T2 groups showed significantly high hardness, chewiness, and shear force ($P < 0.05$). In summary, a dietary SFA/MUFA addition ratio of 1/2 can indirectly enhance LC-PUFA deposition levels by promoting tissue fatty acid β -oxidation and improve muscle texture characteristics to enhance the muscle quality of farmed tilapia.

Key words: Tilapia; dietary SFA/MUFA; growth performance; Muscle quality; Lipid metabolism

饲料蛋氨酸水平对黄鳢幼鳢生长性能、肝肠健康、肌肉品质及氨基酸代谢的影响

陈圣娣^{1,2,3}, 梁立文^{1,2,3}, 周秋白^{1,2,3*}

(1. 江西农业大学动物科学技术学院, 江西 南昌 330045; 2. 江西农业大学特种水产研究所, 江西 南昌 330045; 3. 南昌市特色水生生物营养生理与健康养殖重点实验室, 江西 南昌 330045)

摘要: 【目的】本试验旨在研究黄鳢 (*Monopterus albus*) 幼鳢对饲料蛋氨酸的适宜需求量, 以为黄鳢配合饲料的精准配制提供理论依据。【方法】配制 6 组蛋氨酸实测值为 0.97%、1.17%、1.37%、1.77%、2.57%、4.17% 的等氮等能饲料, 分别命名为 M1、M2、M3、M4、M5、M6, 饲喂初始体重为 11.40 ± 0.01 g 的幼鳢 60 d。养殖试验结束后分析幼鳢生长性能、肝肠健康和肌肉品质相关指标, 根据分析结果对蛋氨酸缺乏组 (M1 组)、生长最佳组 (M2 组)、蛋氨酸过量组 (M6 组) 幼鳢肝脏进行转录组与代谢组联合分析, 进一步探究饲料蛋氨酸水平对幼鳢氨基酸代谢的影响。【结果】(1) 随饲料蛋氨酸水平的升高, 幼鳢生长性能呈先升高后下降趋势, M2 组增重率 (WGR)、特定生长率 (SGR) 显著高于 M1、M5、M6 组, M3 组饲料系数 (FCR) 显著低于 M6 组, 蛋白质效率 (PER)、蛋白质沉积率 (PRR) 显著高于 M1、M5、M6 组 ($P < 0.05$)。 (2) M3 组肝脏谷丙转氨酶 (GPT)、谷草转氨酶 (GOT) 活性显著高于 M1 组, 血氨 (Sa) 显著低于 M6 组 ($P < 0.05$)。M4 组血清 GPT、GOT 显著低于 M1 组 ($P < 0.05$)。M4 组肝脏过氧化氢酶 (CAT)、超氧化物歧化酶 (SOD)、谷胱甘肽过氧化物酶 (GSH-Px) 活性及还原性谷胱甘肽 (GSH) 含量显著高于 M1 组。M3 组肝脏丙二醛 (MDA) 含量显著低于 M1 组, 蛋白质羰基 (CPO) 含量显著低于 M5、M6 组 ($P < 0.05$)。 (3) M2 组前肠固有层厚度、绒毛高度、微绒毛长度显著大于 M1、M5、M6 组 ($P < 0.05$)。M1 组肝细胞界限模糊, 细胞核偏移, M5、M6 组肝细胞空泡增多。 (4) M3 组前肠蛋白酶及前肠脂肪酶活性显著高于 M1、M6 组 ($P < 0.05$)。M3 组全鱼、肌肉、肝脏粗蛋白质含量显著高于 M1、M6 组, 肌肉硬度显著高于其余组 ($P < 0.05$)。 (5) M2 组与 M1 组相比, 富集到的氨基酸代谢相关通路为谷胱甘肽代谢、甘氨酸、丝氨酸和苏氨酸代谢、缬氨酸、亮氨酸和异亮氨酸降解、mTOR 信号通路、蛋白质的消化吸收。其中 *hras*、*ulk*、*aldh* 及 *idh1* 基因上调, 代谢物苏氨酸、氧化型谷胱甘肽增加, 亮氨酸减少。M6 组与 M2 组相比, 富集到的氨基酸代谢相关通路为蛋白质的消化和吸收、半胱氨酸和甲硫氨酸代谢、谷胱甘肽代谢、胰岛素抵抗、胰岛素分泌、 β -丙氨酸代谢、精氨酸和脯氨酸代谢。其中 *gck*、*anpep*、*ldh* 等基因上调, *slc38a2*、*slc16a10*、*g6pc*、*pepck*、*sams*、*odc1* 等基因下调; 代谢物 6-磷酸葡萄糖、O-磷酸-L-丝氨酸、S-谷硫酰基-L-半胱氨酸、S-磺基-L-半胱氨酸、L-半胱氨酰甘氨酸、氧化型谷胱甘肽增加; 苏氨酸、苯丙氨酸、肌酸减少。【结论】(1) 以 WGR、SGR、FCR、PRR、PER 为评价指标, 综合生化指标与抗氧化能力, 得出幼鳢的适宜蛋氨酸需求为 1.25%-1.51% (占饲料蛋白质 2.49%-3.02%)。 (2) 转录组与代谢组联合分析发现, 蛋氨酸缺乏可能提高了幼鳢对苏氨酸的利用, 降低了对亮氨酸的利用, 降低抗氧化能力。过量蛋氨酸可能影响了幼鳢对氨基酸的转运, 产生胰岛素抵抗, 降低抗氧化能力。谷胱甘肽代谢通路可能是其中的

关键通路。

关键词：幼鳊；蛋氨酸；生长性能；肝肠健康；肌肉品质；氨基酸代谢

资助项目：国家现代农业产业技术体系专项资金(CARS-46)资助
通讯作者：周秋白，E-Mail: zhouqiubai@163.com

The effect of dietary methionine levels on growth performance, liver and intestinal health and amino acid metabolism of juvenile swamp eels (*Monopterus albus*)

(Shengdi Chen^{1 2 3}, LiWen Liang^{1 2 3}, Qiubai Zhou^{1 2 3*})

(1. College of Animal Science and Technology, Jiangxi Agricultural University, Nanchang China 330045; 2. Institute of Special Fisheries, Jiangxi Agricultural University, Nanchang China 330045; 3. Key Laboratory of Featured Hydrobios Nutritional Physiology and Healthy Breeding, Nanchang China 330045)

Abstract: [Objective] The purpose of this experiment was to investigate the appropriate dietary methionine requirements for juvenile swamp eels (*Monopterus albus*) in order to provide a theoretical basis for the accurate formulation of swamp eels compound feed. [Methods] Six groups of isonitrogenous and isoenergetic feeds with measured methionine values of 0.97%, 1.17%, 1.37%, 1.77%, 2.57% and 4.17%, designated M1, M2, M3, M4, M5 and M6 were fed to juvenile eels with an initial body weight of 11.40 ± 0.01 g for 60 days. After the feeding trial, the growth performance, liver and intestinal health and flesh quality of juvenile swamp eels were evaluated. Based on the evaluation results, the livers of juvenile swamp eels from the methionine deficiency group (M1), the optimal growth group (M2) and the methionine excess group (M6) were subjected to combined transcriptomic and metabolomic analyzes to further investigate the effects of dietary methionine levels on amino acid metabolism of juvenile swamp eels. [Results] (1) As dietary methionine levels increased, the growth performance of juvenile swamp eels first increased and then decreased. The weight gain rate (WGR) and specific growth rate (SGR) of the M2 group were significantly higher than those of the M1, M5 and M6 groups. The feed conversion ratio (FCR) of the M3 group was significantly lower than that of the M6 group, and the protein efficiency ratio (PER) and protein retention rate (PRR) were significantly higher than those of the M1, M5 and M6 groups ($P < 0.05$). (2) The activities of glutamate-pyruvate transaminase (GPT) and glutamate-oxaloacetic transaminase (GOT) in the liver of the M3 group were significantly higher than those in the M1 group, and blood ammonia (Sa) was significantly lower than that in the M6 group. group ($P < 0.05$). Serum GPT and GOT were significantly lower in the M4 group than in the M1 group ($P < 0.05$). The activities of liver catalase (CAT), superoxide dismutase (SOD), glutathione peroxidase (GSH-Px) and reduced glutathione (GSH) content were significantly higher in the M4 group than in the M1 group. The content of malondialdehyde (MDA) in the liver of the M3 group was significantly lower than that of the M1 group, and the content of protein carbonyl (CPO) was significantly lower than that of the M5 and M6 groups ($P < 0.05$). (3) The lamina propria thickness (MT), villus height (VH), and microvilli length (MH) of the foregut were significantly higher in the M2 group than in the M1, M5, and M6 groups ($P < 0.05$). The border of liver cells in the M1 group was blurred and the nucleus was displaced. The vacuoles of liver cells in groups M5 and M6 increased. (4) The

activities of foregut protease and foregut lipase were significantly higher in the M3 group than in the M1 and M6 groups ($P < 0.05$). The crude protein content of whole fish, muscles and liver in the M3 group was significantly higher than in the M1 and M6 groups, and the muscle hardness was significantly higher than in the other groups ($P < 0.05$). (5) The amino acid metabolism pathways enriched by M2 compared to M1 were glutathione metabolism, valine, leucine, and isoleucine degradation, mTOR signaling pathway, and glycine, serine, and threonine metabolism. Among them, the genes *hras*, *ulk* and *idh1* were upregulated and the metabolite oxidized glutathione and threonine were increased. The amino acid metabolism pathways enriched by M6 compared to M2 were protein digestion and absorption, cysteine and methionine metabolism, glutathione metabolism, insulin resistance, insulin secretion, arginine and proline metabolism. Among them, genes such as *gck*, *anpep* and *ldh* were upregulated and genes such as *slc38a2*, *slc16a10*, *g6pc*, *pepck*, *sams* and *odc1* were downregulated; Metabolites 6-phosphate glucose, O-phosphate-L-serine, S-glutamyl-L-cysteine, S-sulfo-L-cysteine, L-cysteinylglycine and oxidized glutathione increased. Threonine, phenylalanine and creatine decreased. [Conclusion] (1) Considering WGR, SGR, FCR, PRR and PER as evaluation indices, comprehensive biochemical indices and antioxidant capacity, the appropriate methionine requirement of juvenile swamp eels was 1.25% to 1.51% (2.49% to 3.02% of feed protein). (2) Combined transcriptome and metabolome analysis revealed that methionine deficiency can increase threonine utilization, decrease leucine utilization, and reduce antioxidant capacity in juvenile swamp eels. Excess methionine can impair the transport of amino acids in young swamp eels, leading to insulin resistance and a reduction in antioxidant capacity. The glutathione pathway may be the key pathway.

Key words: Juvenile Swamp Eels; Methionine; Growth Performance; Liver and Intestinal Health; Amino Acid Metabolism

饲料蛋白质水平对以棉籽浓缩蛋白为主要蛋白质来源的凡纳滨对虾生长性能、免疫反应、消化能力、肠道菌群和转录组的影响

王红明¹, 章双^{1,2,3*}

(1. 广东海洋大学, 水产学院, 广东 湛江 524088; 2. 中国湛江, 农业部华南水产畜禽饲料科技重点实验室; 3. 广东省水产动物精准营养与高效饲料工程技术研究中心, 中国湛江)

摘要: 【目的】本研究旨在探讨饲料蛋白水平对以棉籽浓缩蛋白为主要蛋白源的凡纳滨对虾生长性能、免疫反应、消化能力、肠道菌群和转录组的影响。【方法】以 CPC 为主要蛋白来源, 配制蛋白水平分别为 32%、36%、40%、44% 和 48% 的五种等脂饲料(分别命名为 CPC32、CPC36、CPC40、CPC44 和 CPC48 组) 饲养凡纳滨对虾(初始体重: 0.42±0.01 克) 8 周。

【结果】实验结束后发现: CPC40 组的凡纳滨对虾的终末体重 (final body weight, FBW)、增重率 (weight gain rate, WGR)、特定生长率 (specific growth rate, SGR) 和饲料系数 (feed coefficient ratio, FCR) 达到了最大值。以增重率为判据进行分析得出, 当饲料中蛋白水平为 40.01% 时, 凡纳滨对虾获得最佳生长性能。随着蛋白水平的升高, 凡纳滨对虾肌肉中精氨酸含量也随之升高, 且在 CPC48 组中达到最大值。副溶血弧菌 (*Vibrio parahaemolyticus*) 感染后, CPC48 组的凡纳滨对虾感染弧菌后在 72 小时 (hpi) 内的累积死亡率显著高于 CPC32 组和 CPC36 组 ($P < 0.05$)。与 CPC40 组相比, CPC32 组的超氧化物歧化酶 (superoxide dismutase, SOD)、酚氧化酶 (phenol oxidase, PO) 和过氧化氢酶 (hydrogen peroxidase, CAT) 的活性显著降低 ($P < 0.05$)。此外, 与 CPC40 组相比, CPC32 组对应的免疫相关酶的基因表达也都呈现出相同的趋势。CPC32 组的胰蛋白酶和淀粉酶的活性显著低于 CPC40 组 ($P < 0.05$)。肠道菌群分析结果显示, CPC48 组和 CPC32 组间菌群的 α -多样性有显著差异。变形菌门 (Proteobacteria) 的相对丰度在所有组别中没有显著差异 ($P > 0.05$)。此外, 就拟杆菌门 (Bacteroidetes) 的相对丰度而言, CPC32 组的相对丰度显著高于其余各组 ($P < 0.05$)。在属的水平上, 与 CPC40 组相比, 其余组的发光杆菌属 (*Photobacterium*) 的丰度显著升高。与 CPC40 相比, 在预测丰度排名前 10 位的通路中, CPC36 组中无显著差异; CPC32、CPC44 和 CPC48 组中复制和修复 (replication and repair) 丰度显著降低; CPC44 和 CPC48 组中碳水化合物代谢 (Carbohydrate Metabolism) 显著升高 ($P < 0.05$)。转录组分析显示, 与 CPC40 组相比, CPC32 和 CPC48 组分别有 543 (334 个上调, 209 个下调) 和 968 (150 个上调, 818 个下调) 差异基因 (Differentially expressed genes, DEGs)。这些 DEGs 在 IL-17 信号通路 (IL-17 signaling pathway)、内质网中的蛋白加工 (protein processing in the endoplasmic reticulum)、朊病毒病 (Prion disease)、甲状腺激素合成 (Thyroid hormone synthesis)、流体剪切应力 (Fluid shear stress) 和动脉粥样硬化 (atherosclerosis) 中显著富集, HSP90B1 基因参与其中。此外, HSP90B1 和 HSP90AA1 基因的表达量在 CPC32 和 CPC48 组显著上调。相关性分析表明, HSP90B1 基因与发光杆菌属有显著的正相关性。【结论】综上所述, CPC

蛋白水平为 40.01%是最佳的，过高或过低的 CPC 蛋白水平会降低凡纳滨对虾的免疫力和消化率，改变肠道微生态的结构和功能，诱发应激蛋白 HSP90B1 基因的表达，增加肠道有害细菌的丰度。

关键词：凡纳滨对虾；生长性能；免疫反应；消化能力；肠道菌群；转录组

Effects of dietary protein levels on growth performance, immune response, digestibility, intestinal flora and transcriptome of *Litopenaeus vannamei* fed cottonseed protein concentrate as the main protein source

Hongming Wang¹, Shuang Zhang^{1,2,3*}

(¹ College of Fisheries, Guangdong Ocean University, Zhanjiang, China; ² Key Laboratory of Aquatic, Livestock and Poultry Feed Science and Technology in South China, Ministry of Agriculture, Zhanjiang, China; ³ Aquatic Animals Precision Nutrition and High Efficiency Feed Engineering Research Center of Guangdong Province, Zhanjiang, China)

Abstract: The aim of this study was to reveal the effect of different protein levels (32% (CPC32), 36% (CPC36), 40% (CPC40), 44% (CPC44), and 48% (CPC48)) on the growth and health of *Litopenaeus vannamei*, using cottonseed protein concentrate (CPC) as the main protein source. The results showed that the final body weight (FBW), weight gain rate (WGR), specific growth rate (SGR) and feed coefficient ratio (FCR) of *L. vannamei* in CPC40 group reached the maximum values. Using WGR as a criterion, it was concluded that the optimum growth performance of *L. vannamei* shrimp was obtained at a protein level of 40.01% in the diet. The cumulative mortality of *Vibrio parahaemolyticus* infection within 72 hours was significantly higher in CPC48 than in CPC32 and CPC36 groups. In terms of hepatopancreas biochemistry, CPC40 group significantly increased the antioxidant enzyme activities and gene expression of shrimp. Trypsin and amylase activities were significantly increased in the CPC40 group compared to the CPC32 and CPC48 groups. Meanwhile, different protein levels significantly affected intestinal flora diversity, and the CPC40 group was able to reduce the abundance of harmful bacteria in the gut at the phylum and genus levels. Sequencing and quantitative analyses showed that the expression of HSP90B1 and HSP90AA1 genes was significantly up-regulated in the CPC32 and CPC48 groups compared with the CPC40 group. Correlation analysis showed that the HSP90B1 gene was significantly positively correlated with *Photobacterium*. In conclusion, the best growth performance of shrimp was achieved at a protein level of 40.01% when CPC was used as the main protein source. The results suggest that the optimal protein level in the diet may influence metabolic and immune pathways by regulating the synergistic effects of the JUN and HSP90B1 genes, as well as Bacteroidetes and *Photobacterium*. This regulation may lead to a decrease in the abundance of harmful intestinal bacteria, enhancing immunity and digestion, and ultimately improving the growth performance of shrimp.

Keywords: *Litopenaeus vannamei*; growth performance; immune response; digestibility; intestinal flora; transcriptome

饲料磷脂水平对中华鲟 (*Acipenser sinensis*) 幼鱼生长性能、抗氧化力及脂肪代谢的影响研究

张聃炆¹, 胡亚成^{2,3}, 陈京华¹, 隋超^{1,3}, 姜伟³, 李庆飞^{1*}

(1. 青岛农业大学海洋科学与工程学院, 山东 青岛 266109; 2. 中国海洋大学海水养殖重点实验室(教育部)、水产动物营养与饲料重点实验室(农业农村部), 山东 青岛 266003; 3. 中国长江三峡集团有限公司中华鲟研究所, 湖北 宜昌 443100)

摘要:【目的】本实验以中华鲟幼鱼 (12.27 ± 0.03 g) 为研究对象, 研究饲料中不同磷脂水平对其生长性能、抗氧化能力和脂肪代谢的影响。【方法】以鱼油、大豆油和大豆磷脂为脂肪源, 通过调整豆油和大豆磷脂的比例, 制备 5 种磷脂含量分别为 1.26%、3.29%、4.34%、5.93%和 7.02%的等氮等脂的实验饲料, 投喂在室内流水系统养殖的中华鲟幼鱼, 每个处理组 3 个重复, 养殖实验为期 8 周。【结果】随着饲料磷脂水平的升高, 中华鲟幼鱼的特定生长率 (SGR) 呈先上升后下降趋势, 折线模型拟合确定饲料中适宜磷脂水平为 5.93%。较高磷脂水平的饲料 (5.93%和 7.02%) 能够显著降低中华鲟幼鱼肝脏的脂肪含量 ($P < 0.05$)。中华鲟幼鱼肝脏特定脂肪酸的比例与饲料脂肪酸比例呈线性相关 ($P < 0.05$), 而肌肉脂肪酸组成的组间差异不显著 ($P > 0.05$)。EPA 和 DHA 较其他种类脂肪酸更倾向积累在肌肉组织中。消化酶和抗氧化酶的活性随着饲料磷脂水平的增加而线性增加 ($P < 0.001$)。饲料中添加磷脂能够显著增强中华鲟幼鱼肝脏抗氧化基因的表达, 高磷脂水平实验组 (7.02%) 谷胱甘肽过氧化氢酶 (GSH-Px) 基因表达量较对照组高约 8 倍 ($P < 0.001$)。磷脂能够显著诱导与脂质分解相关的基因表达, 并抑制脂肪合成相关基因的转录 ($P < 0.001$)。【结论】基于生长性能、抗氧化能力和肝脏生化指标, 中华鲟幼鱼饲料中最适磷脂水平为 5.93% (大豆卵磷脂为磷脂源)。

关键词: 磷脂; 生长; 抗氧化力; 脂代谢; 中华鲟

Effects of dietary phospholipids on growth performance, antioxidant capacity, and lipid metabolism of juvenile Chinese sturgeon (*Acipenser sinensis*), a critically endangered sturgeon in the Yangtze River

Danyang Zhang¹, Yacheng Hu^{2,3}, Jinghua Chen¹, Chao Sui^{1,3}, Wei Jiang³, Qingfei Li^{1*}

(1. School of Marine Science and Engineering, Qingdao Agricultural University, Qingdao, Shandong China 266109; 2. Key Laboratory of Mariculture (Ministry of Education), and Key Laboratory of Aquaculture Nutrition and Feed (Ministry of Agriculture and Rural Affairs), Ocean University of China, Qingdao China 266003; 3. Institute of Chinese Sturgeon, China Three Gorges Corporation, Yichang China 443100)

Abstract: This study aimed to investigate the effects of dietary phospholipids (PLs) on growth performance, antioxidant capacity, and lipid metabolism of juvenile Chinese sturgeon (*Acipenser sinensis*). Juvenile sturgeon, with an initial body weight of 12.27 ± 0.03 g, were fed five diets containing graded levels of PLs (1.26%, 3.29%, 4.34%, 5.93%, and 7.02%) in triplicate for 56 days. All experimental diets were formulated to be isonitrogenous (55%) and isolipidic (10%). Results indicated that specific growth rate increased from 2.21 to 2.89 with elevated levels of dietary PLs. The optimum PLs level for juvenile Chinese sturgeon was estimated to be 5.93% of diet according to the broken-line regression analysis of the specific growth rate against dietary PLs levels. Diets containing higher levels of PLs (5.93% and 7.02% of diet) significantly reduced the lipid content of whole body and liver by around 30% in juvenile sturgeon compared to the control group ($P < 0.05$). The proportions of specific fatty acids present in the liver lipid were linearly correlated with their percentages in dietary lipid ($P < 0.05$), whereas muscle fatty acid composition remained unaffected across different treatments ($P > 0.05$). EPA and DHA were preferentially accumulated into the muscle tissue. Activities of digestive enzymes and antioxidant enzymes were linearly increased with incremental dietary PLs levels ($P < 0.001$). Inclusion of PLs in diet significantly enhanced the expression of antioxidant genes with the transcription of *GSH-Px* in the liver of fish fed 7.02% PLs of diet being approximately 8-fold greater than in those fish fed diet without PL addition ($P < 0.001$). Dietary PLs significantly induced the gene expression related to lipid catabolism, and suppressed the transcription of genes involved in lipogenesis ($P < 0.001$). Based on growth performance, antioxidant capacity, and liver biochemical parameters, inclusion of 5.93% PLs (soy lecithin preparation) in the diets is recommend for juvenile Chinese sturgeon.

Keyword: Phospholipids, growth, antioxidant capacity, lipid metabolism, Chinese sturgeon

饲料中碳水化合物和脂肪水平对翘嘴鳊生长性能、肝脏组织学、抗氧化能力以及肌肉质构的影响

韩志豪¹, 张尼荷¹, 龚堃^{1,2}, 孙泽强¹, 刘圣超¹, 黄旭雄^{1,2}, 陈乃松^{1,2}, 李松林^{1,2*}
(1. 上海海洋大学 农业农村部鱼类营养与环境生态研究中心, 上海 201306; 2. 上海海洋大学 水产科学国家级实验教学示范中心, 上海 201306;)

摘要:【目的】本研究旨在探究饲料中碳水化合物和脂肪水平对翘嘴鳊生长性能、肝脏组织学、抗氧化能力以及肌肉质构的影响。【方法】采用 3×3 正交试验设计, 配制梯度碳水化合物(4%、8%和 12%)和粗脂肪(8%、12%和 16%)水平的 9 种等氮(粗蛋白含量 52%)实验饲料。将 945 尾体重相近(55g)的翘嘴鳊随机分配到 27 个养殖桶, 每个实验处理设置 3 个重复, 每天 2 次定量投喂, 实验周期 10 周。【结果】饲料碳水化合物和脂肪水平的变化对翘嘴鳊的存活率和生长性能没有明显影响($P > 0.05$)。随着饲料中脂肪水平的升高, 全鱼、肝脏和肌肉的脂肪含量均显著升高($P < 0.05$), 且饲料碳水化合物含量的升高显著提高了肝脏脂肪的含量($P < 0.05$)。肝糖原含量随着饲料碳水化合物水平的升高而明显增加($P < 0.05$)。肝脏抗氧化能力方面, 丙二醛(MDA)含量随饲料脂肪或碳水化合物含量的增加而显著提高($P < 0.05$), 过氧化氢酶活性则呈相反趋势($P < 0.05$)。超氧化物歧化酶活性随着饲料脂肪含量的升高而明显提高($P < 0.05$), 但随着饲料碳水化合物含量的增加, 超氧化物歧化酶活性先降低后提高($P < 0.05$)。此外, 肌肉硬度随饲料脂肪和碳水化合物含量的增加显著下降($P < 0.05$)。肌肉的咀嚼性、胶粘性和剪切力仅受饲料脂肪水平的影响, 并随饲料脂肪水平的增加而显著降低($P < 0.05$)。【结论】综合考虑营养学评价指标以及浮性膨化饲料加工要求, 翘嘴鳊饲料中碳水化合物和脂肪的适宜水平分别为 8%和 12%。

关键词: 翘嘴鳊; 碳水化合物; 脂肪; 生长, 肝脏健康, 肌肉质构

Effects of dietary carbohydrate and lipid levels on growth performance, hepatic histology and antioxidant capacity, and flesh texture of mandarin fish (*Siniperca chuatsi*)

Zhihao Han¹, Nihe Zhang¹, Ye Gong¹, Zeqiang Sun¹, Shengchao Liu¹, Xuxiong Huang^{1,2}, Naisong Chen¹, Songlin Li^{1,2*}

(1. Research Centre of the Ministry of Agriculture and Rural Affairs on Environmental Ecology and Fish Nutrition, Shanghai Ocean University, Shanghai China 201306; 2. National Demonstration Center on Experiment Teaching of Fisheries Science, Shanghai Ocean University, Shanghai China 201306)

Abstract: [Objective] The aim of this experiment was to investigate the effects of dietary carbohydrate and lipid levels on growth performance, hepatic histology and antioxidant capacity, and flesh texture of mandarin fish (*Siniperca chuatsi*). [Methods] In this study, nine isonitrogenous experimental diets containing graded level of carbohydrates (4%, 8% and 12%) and crude lipid (8%, 12%, and 16%) were formulated in a 3 × 3 factorial design. 945 mandarin fish with similar body weight (55g) were randomly assigned into 27 tanks and the experiment diets were fed to triplicate tanks twice daily for 10 weeks. [Results] Results showed that different dietary treatments did not significantly affect survival rate and growth performance of mandarin fish ($P > 0.05$). The lipid content of whole body, liver and muscle all significantly increased with increasing levels of dietary lipid ($P < 0.05$), while only liver lipid content was significantly increased with the increased of carbohydrate level ($P < 0.05$). Hepatic glycogen content increased significantly with increasing dietary carbohydrate level ($P < 0.05$). As to liver antioxidant capacity, malondialdehyde content increased significantly with increasing dietary lipid or carbohydrate content and catalase activity showed an opposite trend ($P < 0.05$). Superoxide dismutase activity increased significantly with increasing levels of dietary lipid but decreased first and then increased with increasing dietary carbohydrate level ($P < 0.05$). Additionally, the increase of both dietary lipid and carbohydrate levels resulted in a significant reduction in muscle hardness ($P < 0.05$). Muscle chewiness, gumminess and shear force were only affected by dietary lipid levels and decreased significantly with increasing dietary lipid levels ($P < 0.05$). [Conclusion] Taking into account the nutritional evaluation indexes and manufacture of floating extruded aquafeeds, the appropriate dietary carbohydrate and lipid level for mandarin fish were 8% and 12%, respectively.

Key words: *Siniperca chuatsi*; Carbohydrate; Lipid; Growth; Liver health; Muscle texture

饲料中添加肌醇对克氏原螯虾幼虾生长，蜕皮性能和蜕皮激素信号通路的影响

普畅畅¹，刘苑艺¹，王冰珂³，王爱民²，张春暖^{1*}

1 河南科技大学动物科技学院水产环境与动物安全实验室，河南洛阳，471023；2 盐城工学院海洋与生物工程学院水产动物营养与饲料研究所，江苏盐城，224051；3 河南省水产科学研究院，河南郑州，450044；

摘要：肌醇是甲壳类动物的必需营养素。然而，克氏原螯虾幼虾对肌醇的最佳需求量及其参与机体生长和营养调节的机制尚不清楚。本研究旨在研究饲料中添加肌醇对克氏原螯虾幼虾生长、蜕皮性能和蜕皮激素信号通路的影响。本实验挑选均重为 6.39 ± 0.05 g、健康且大小一致的克氏原螯虾幼虾共 360 尾，随机平均分为 6 组，分别饲喂添加 0 mg/kg（对照组）、500 mg/kg、1000 mg/kg、2000 mg/kg、3000 mg/kg、4000 mg/kg 肌醇的 6 种等氮等能饲料，每组 3 个重复，每个重复 20 尾虾，养殖周期为 6 周。随着肌醇水平的升高，克氏原螯虾的末重、增重率和蜕皮率呈现先升高后降低的趋势，在添加量为 1000 mg/kg 时，生长性能最好。以 EIF 为内参基因，随着肌醇添加量的增加，克氏原螯虾蜕皮相关基因维甲酸 X 受体 (RXR)、蜕皮激素受体 (ECR) 和蜕皮激素诱导蛋白-75 (E75) 基因表达量先增加后降低，当肌醇添加量为 1000 mg/kg 时，E75、ECR 和 RXR 基因表达水平显著高于其它实验组，蜕皮抑制激素 (MIH) 基因表达量与 ECR、E75 和 RXR 相反 ($P < 0.05$)。此外，膳食肌醇能够增强消化酶活性并诱导 GH-IGF 生长轴相关基因的表达，促进克氏原螯虾营养物质的消化和吸收。并且，膳食肌醇降低了血清脂质分子水平 (TG、TC) 并增加了血清抗氧化能力 (SOD、CAT、GPX 和 POD)。总之，本文的结果表明，在饲料中补充 1000 mg/kg 的肌醇时，可以通过提高消化酶活性、促进蜕皮相关基因及 GH-IGF 生长轴相关基因的表达，更有利于克氏原螯虾幼虾的生长。

关键词：肌醇；生长性能；蜕皮；基因表达；克氏原螯虾

基金项目：国家自然科学基金(中国，32002405)；江苏省种业振兴“揭榜挂帅”项目 (JBGS (2021) 032)

通讯作者：张春暖 (1987-)，女，博士，副教授；E-Mail: zhangchunnuan12@163.com

The effects of dietary myo-inositol on growth, ecdysis performance, and ecdysone signaling pathway in juvenile freshwater crayfish, *Procambarus clarkii*

Changchang Pu¹, Yuanyi Liu¹, Bingke Wang³, Aimin Wang², Chunnuan Zhang^{1*}

1. Laboratory of Aquatic Environment and Animal Safety, College of Animal Science and Technology, Henan University of Science and Technology, Luoyang, Henan, 471023, China; 2. Institute of Aquatic Animal Nutrition and Feed, College of Marine and Bioengineering, Yancheng Institute of Technology, Yancheng, Jiangsu, 224051, China; 3. Henan Academy of Fishery Sciences, Zhengzhou 450044, China

Abstract: Myo-inositol (MI) is an essential nutrient for crustaceans. However, the optimal MI requirement of juvenile freshwater crayfish and the mechanisms that regulate growth and nutrition are unknown. This experiment aimed to study the effect of inositol addition on the growth, ecdysis performance, and ecdysone signaling pathway of juvenile freshwater crayfish (*Procambarus clarkii*). Then, six diets were prepared by adding 0 mg/kg (control group), 500 mg/kg, 1000 mg/kg, 2000 mg/kg, 3000 mg/kg, and 4000 mg/kg MI to the basal diet. A total of 360 juvenile freshwater crayfish were cultured for six weeks, in three parallel groups and their average body weight was (6.39 ± 0.05) g. The results showed that the final weight, weight gain rate, and specific growth rate in 500 mg/kg and 1000 mg/kg were significantly higher than that in 0 mg/kg, and the growth performance in 1000 mg/kg was the best. With EIF as the reference gene, the expression of the ecdysis-related genes retinoic acid X receptor (RXR), ecdysone receptor (ECR), and ecdysone inducible protein-75 (E75) increased first and then decreased with the increase of MI addition. When the amount of MI was 1000 mg/kg, the gene expression levels of E75, ECR, and RXR were significantly higher than those of other experimental groups, and the gene expression level of molt inhibitory hormone (MIH) was opposite to that of ECR, E75, and RXR. Also, dietary MI enhanced digestive enzyme activity and induced the expression of genes related to the GH-IGF growth axis to promote the digestion and absorption of nutrients in freshwater crayfish. Furthermore, dietary MI reduced serum lipid molecule levels and increased serum antioxidant capacity. In conclusion, the results presented here indicate that when 1000 mg/kg MI is supplemented into the diet, it can improve the activity of digestive enzymes, promote the expression of ecdysis-related genes and GH-IGF growth axis genes, and is more conducive to the growth of juvenile freshwater crayfish.

Keywords: Myo-inositol; Growth performance; Ecdysis; Gene expression; *Procambarus clarkii*

维生素 E 对鳊生长性能及血清生化指标的影响

陈琪琪¹, 王文洁¹, 周达¹, 翟旭亮², 薛洋², 汪福保⁴, 陈拥军¹, 刘海平¹, 赵敏^{1*},
罗莉^{1*}

(1. 西南大学水产学院, 西部(重庆)科学城种质创制大科学中心, 淡水鱼类资源与生殖发育教育部重点实验室, 重庆 400715; 2. 重庆市水产技术推广总站, 重庆 400400; 3. 佛山市南海区杰大饲料有限公司, 广东 佛山 528211)

摘要: 为探究日粮中不同维生素 E 含量对鳊生长性能及抗氧化能力的影响, 本实验在基础日粮中分别添加 0 (E0)、100 (E1)、200 (E2)、300 (E3)、400 (E4)、500 (E5) mg/kg 维生素 E, 配制成 6 组等氮等脂的实验饲料, 分别投饲初始体重 44.02 ± 0.4 g 的鳊 56 天, 期间每天 10 点饱食投饲 1 次。结果显示: (1) 鳊的终末体重 (FW)、增重率 (WGR)、特定生长率 (SGR) 均随饲料中维生素 E 添加水平的提高呈先升高后降低的趋势, 其中 E3 组最高 ($P < 0.05$), 与 E0 组相比, FW 升高了 13.02%, WGR 升高了 23.30%, SGR 升高了 13.50%; 饲料系数 (FCR) 随维生素 E 含量的增加呈先减后增趋势, 其中 E3 组最低 ($P < 0.05$), 较 E0 组降低了 15.28%; (2) 随饲料中维生素 E 含量的增加, 血清中甘油三酯、总胆固醇和低密度脂蛋白的含量均呈降低趋势, 其中 E5 组甘油三酯和总胆固醇的含量最低 ($P < 0.05$), 甘油三酯含量较 E0 组降低了 36.63%, 总胆固醇含量较 E0 组降低了 20.73%, E4 组低密度脂蛋白的含量最低 ($P < 0.05$), 较 E0 组降低了 46.23%; 高密度脂蛋白含量随饲料中维生素 E 含量的增加呈上升趋势, E5 组较 E0 组升高了 7.75% ($P < 0.05$); (3) 血清中谷丙转氨酶和谷草转氨酶活性均随饲料中维生素 E 含量的增加而降低, 其中 E5 组活性最低 ($P < 0.05$), 较 E0 组, 谷丙转氨酶活性降低了 35.45%, 谷草转氨酶活性降低了 26.67%; (4) 血清中总超氧化物歧化酶 (T-SOD) 和过氧化氢酶 (CAT) 活性随饲料中维生素 E 含量的增加均呈先增后减的趋势, 其中 E3 组最高 ($P < 0.05$), 与 E0 组相比, SOD 升高了 23.31%, CAT 升高了 27.92%; 丙二醇含量随饲料中维生素 E 含量的增加呈先减后增趋势, 其中 E2 组最低, 较 E0 组降低了 19.61% ($P < 0.05$)。综上所述, 当日粮中添加 300mg/kg 维生素 E 时, 能够显著提高鳊的生长性能及抗氧化能力; 日粮中维生素 E 水平的增加, 能够增强鳊脂代谢能力, 改善肝脏健康。

关键词: 鳊; 维生素 E; 生长性能; 血清生化指标

资助项目: 新希望六和集团有限公司项目, 重庆市生态渔产业技术体系项目, 重庆市水产科技创新联盟项目

通讯作者: 赵敏, EMail: 1062773230@qq.com 罗莉, E-Mail: luoli1972@163.com

Effects of Dietary Vitamin E on Growth Performance and Serum Biochemical Indexes of *Siniperca chuatsi*

Abstract: In order to explore the effects of different vitamin E contents in diets on growth performance and antioxidant capacity of *Siniperca chuatsi*, the experiment added 0 (E0), 100 (E1), 200 (E2), 300 (E3), 400 (E4) and 500 (E5) mg/kg vitamin E to the basal diet to prepare 6 groups of iso-nitrogenous and iso-lipidic experimental diets. *Siniperca chuatsi* with an initial body weight of 44.02 ± 0.4 g was fed once at 10 o'clock every day for 56 days. The results show: (1) With the increase of dietary vitamin E supplemental level, the final body weight (FW), weight gain rate (WGR) and specific growth rate (SGR) were firstly increased and then decreased, and the highest values were found in E3 group ($P < 0.05$). Compared with E0 group, FW and WGR were increased by 13.02% and 23.30% respectively. SGR increased by 13.50%. Feed conversion ratio (FCR) firstly decreased and then increased with the increase of vitamin E content, and the lowest was found in E3 group ($P < 0.05$), which was 15.28% lower than that in E0 group. (2) With the increase of dietary vitamin E content, the contents of triglyceride, total cholesterol and low density lipoprotein in serum showed a decreasing trend, and the contents of triglyceride and total cholesterol in E5 group were the lowest ($P < 0.05$). Compared with E0 group, the contents of triglyceride and total cholesterol in E5 group were decreased by 36.63% and 20.73% respectively. The content of low density lipoprotein in E4 group was the lowest ($P < 0.05$), which was decreased by 46.23% compared with E0 group. High-density lipoprotein content was increased with the increase of dietary vitamin E content, and it was increased by 7.75% ($P < 0.05$) in E5 group compared with E0 group. (3) The activities of serum alanine aminotransferase and aspartate aminotransferase were decreased with the increase of dietary vitamin E content, and the activity of E5 group was the lowest ($P < 0.05$). Compared with E0 group, alanine aminotransferase and aspartate aminotransferase activities were decreased by 35.45% and 26.67%; (4) The activities of total superoxide dismutase (T-SOD) and catalase (CAT) in serum were firstly increased and then decreased with the increase of dietary vitamin E content, and the highest level was found in E3 group ($P < 0.05$). Compared with E0 group, SOD was increased by 23.31% and CAT was increased by 27.92%; With the increase of dietary vitamin E content, the propylene glycol content firstly decreased and then increased, and the E2 group was the lowest, which was decreased by 19.61% ($P < 0.05$) compared with E0 group. In conclusion, supplementation of 300mg/kg vitamin E in daily diet can significantly improve the growth performance and antioxidant capacity of *Siniperca chuatsi*; The increase of vitamin E level in daily diet can enhance the metabolism ability of *Siniperca chuatsi* and improve liver health.

Keywords: *Siniperca chuatsi*; vitamin E; Growth Performance; Serum Biochemical Indexes

线粒体柠檬酸穿梭：缓解高脂饲料诱导鱼类代谢紊乱的潜在调控靶标

王俊贤，张彦宇，钱玓呈，钱焱凡，金安慧，王麦，骆源，乔芳，张美玲，陈立侨，
杜震宇*

（华东师范大学生命科学学院水生动物营养与环境健康实验室，上海，200241）

摘要：线粒体柠檬酸穿梭是依赖于溶质运载家族 25 成员 A1（Slc25a1）将线粒体柠檬酸转运至胞质的过程，在糖酵解、脂质合成和蛋白质乙酰化中发挥重要调控作用。研究发现，Slc25a1 高表达与高脂饮食诱导的肥胖密切相关，而抑制 Slc25a1 能否缓解营养过载诱导的代谢紊乱尚不清楚。为此，本研究分别在斑马鱼和罗非鱼中，构建 Slc25a1 生化抑制和敲降模型，探究抑制 Slc25a1 对高脂饲料诱导的代谢紊乱的缓解作用。结果发现，抑制线粒体柠檬酸穿梭可缓解 HFD 诱导的肥胖、肝脂肪变性和胰岛素抵抗。抑制 Slc25a1 改变了肝脏蛋白乙酰化模式，降低细胞质乙酰化水平，而提高线粒体乙酰化水平。在 HFD 背景下，抑制 Slc25a1 可通过提高 Cpt1a 的乙酰化水平促进脂肪酸 β -氧化，降低肝脏 TG 积累。此外，抑制 Slc25a1 引发乙酰化诱导的 Pdhe1 α 失活，导致葡萄糖氧化分解代谢降低，并伴随着肝脏组织对葡萄糖摄取和储存的增加。研究还发现，在 HFD 营养背景下抑制 Slc25a1 激活了 SIRT1/PGC1 α 通路，促进线粒体增殖并增强氧化磷酸化以产生能量。综上所述，本研究发现依赖 Slc25a1 的柠檬酸穿梭通过调控非组蛋白乙酰化在 HFD 诱导的肝脂沉积和高血糖的发展中发挥重要调控作用，为开发缓解高脂饲料诱导的代谢紊乱的精准饲料配方提供新的见解。

关键词：线粒体柠檬酸穿梭；代谢紊乱；营养代谢；蛋白乙酰化

资助项目：国家重点研发计划“海洋农业与淡水渔业科技创新”专项：鱼类优质生产的精准营养调控机制与技术（2023YFD2400603）

通讯作者：杜震宇，E-Mail: zydu@bio.ecnu.edu.cn

Inhibition of mitochondrial citrate shuttle alleviates metabolic syndromes induced by high-fat diet

Jun-Xian Wang, Yan-Yu Zhang, Yu-Cheng Qian, Yi-Fan Qian, An-Hui Jin, Mai Wang, Yuan Luo, Fang Qiao, Mei-Ling Zhang, Li-Qiao Chen, Zhen-Yu Du*

(Laboratory of Aquaculture Nutrition and Environmental Health (LANEH), School of Life Sciences, East China Normal University, Shanghai, China)

Abstract: The mitochondrial citrate shuttle, which relies on the solute carrier family 25 member 1 (SLC25A1), plays a pivotal role in transporting citrate from the mitochondria to the cytoplasm. This shuttle supports glycolysis, lipid biosynthesis, and protein acetylation. Previous research has primarily focused on Slc25a1 in pathological models, particularly high-fat diet (HFD)-induced obesity. However, the impact of Slc25a1 inhibition on nutrient metabolism under HFD remains unclear. To address this gap, we used zebrafish and Nile tilapia to evaluate the effects of inhibiting Slc25a1. In zebrafish, we administered Slc25a1-specific inhibitors (CTPI-2) for four weeks, while Nile tilapia received intraperitoneal injections of dsRNA to knockdown slc25a1b for seven days. Inhibition of the mitochondrial citrate shuttle effectively protected zebrafish from HFD-induced obesity, hepatic steatosis, and insulin resistance. Notably, glucose tolerance was unaffected. Inhibition of Slc25a1 altered hepatic protein acetylation patterns, with decreased cytoplasmic acetylation and increased mitochondrial acetylation. Under HFD conditions, Slc25a1 inhibition promoted fatty acid oxidation and reduced hepatic triglyceride accumulation by deacetylating Cpt1a. Additionally, Slc25a1 inhibition triggered acetylation-induced inactivation of Pdhe1 α , leading to a reduction in glucose oxidative catabolism. This was accompanied by enhanced glucose uptake and storage in zebrafish livers. Furthermore, Slc25a1 inhibition under HFD conditions activated the SIRT1/PGC1 α pathway, promoting mitochondrial proliferation and enhancing oxidative phosphorylation for energy production. Our findings provide new insights into the role of non-histone protein acetylation via the mitochondrial citrate shuttle in the development of hepatic lipid deposition and hyperglycemia caused by HFD.

Keywords: Mitochondrial citrate shuttle; Metabolic syndromes; Nutrient metabolism; Protein acetylation

蝎源抗菌肽 (IsCT) 改善生长中期草鱼肠道物理屏障⁵

张崇¹, 胡启宇¹, 冯琳^{1,2,3}, 吴培^{1,2,3}, 刘杨^{1,2,3}, 周小秋^{1,2,3*}, 姜维丹^{1,2,3*}

(1. 四川农业大学动物营养研究所, 四川 成都 611130; 2. 四川农业大学动物营养研究所, 鱼类营养与安全生产, 四川省大学重点实验室, 四川 成都 611130; 3. 四川农业大学动物营养研究所, 教育部动物抗病营养重点实验室, 四川 成都 611130)

摘要:【目的】蝎源抗菌肽是从 Isalo 蝎子中分离出来的一种 α -螺旋型细胞毒性的线性抗菌肽, 是一种有效的免疫刺激剂, 不仅能广谱抗菌, 且不易产生耐药性。在饲料全面禁抗背景下, 寻找抗生素的替代物对于草鱼的健康养殖至关重要。本试验旨在探究蝎源抗菌肽(IsCT)与草鱼肠道物理屏障之间的联系, 涉及草鱼肠道的抗氧化活性、细胞凋亡和顶端连接复合物(AJC)。【方法】将 540 尾草鱼 (136.88 ± 0.36 g) 随机分为 6 个处理组, 分别饲喂不同 IsCT 含量 (0、0.6、1.2、1.8、2.4 和 3.0 mg/kg) 的 6 种饲料, 试验为期 60 d, 生长试验结束后进行 6 d 的嗜水气单胞菌攻毒试验。【结果】结果表明: 1) 添加 1.8 mg/kg IsCT 显著降低了草鱼肠道活性氧 (ROS)、蛋白质羰基 (PC) 和丙二醛 (MDA) 含量, 并且显著增加了总抗氧化能力 (T-AOC)、铜锌超氧化物歧化酶 (CuZnSOD) 以及谷胱甘肽过氧化物酶 (GPx) 等抗氧化酶的活性及 mRNA 水平 ($P < 0.05$), 这可能与 Kelch 样 ECH 相关蛋白 (Keap) /核因子 E2 相关因子 2 (Nrf2) 信号通路有关; 2) 1.8 mg/kg IsCT 减少了肠道 DNA 的片段化, 并通过线粒体途径 (Bcl-2/Apaf-1/caspase-9/caspase-3) 和死亡受体途径 (FasL/caspase-8/caspase-3, -7) 缓解细胞凋亡, 这个过程受到 c-Jun 氨基末端激酶 (JNK) 信号通路调节; 3) IsCT 改善了草鱼肠道 AJC 屏障, 这可能与小 Rho GTP 酶蛋白 (RhoA) / Rho 相关激酶 (ROCK) 信号通路调节的紧密连接 (TJ) 和粘附连接 (AJ) 完整性增强有关。【结论】以上结果表明, IsCT 可以增强草鱼肠道物理屏障, 涉及肠上皮细胞 (IEC) 和顶端连接复合体 (AJC) 完整性的维持。以肠道中 ROS 和 PC 含量作为标识确定草鱼饲料中 IsCT 的适宜添加水平分别为 1.78 和 1.77 mg/kg。本研究对鱼类的健康养殖具有重要意义, 为抗菌肽改善肠道健康提供了部分理论依据。

关键词: 草鱼; 蝎源抗菌肽; 肠上皮细胞; 顶端连接复合体; 紧密连接; 粘附连接

资助项目: 国家自然科学基金项目 (31922086)、国家重点研发计划 (2019YFD0900200, 2018YFD0900400)
通讯作者: 周小秋, E-Mail: zhouxq@sicau.edu.cn; 姜维丹, E-Mail: WDJiang@sicau.edu.cn

新型水凝胶日粮对中华绒螯蟹生长、消化和营养物质表观消化率的影响

赵涵婧, 王曦, 曹秀飞, 储小雨, 周靖宇, 黄洋洋, 郭慧星, 华浩坤, 刘文斌, 蒋广震*
(南京农业大学动物科技学院, 江苏省水产动物营养重点实验室, 江苏 南京 210095)

摘要:【目的】目前中华绒螯蟹商品日粮虽然营养充足, 种类丰富, 但日粮溃散快、中华绒螯蟹摄食不便以及性腺成熟慢等都制约了其更好的发展。多数研究者将解决问题的中心聚焦到改善日粮配方上, 忽略了日粮物理性质对中华绒螯蟹的影响。本试验制备了一种新型海藻酸钠-氯化钙水凝胶日粮 (SAH), 以研究这种软颗粒质地的水凝胶日粮对中华绒螯蟹生长和消化的影响。【方法】(1) 养殖试验: 设计了三种不同质地的日粮, 即颗粒日粮 (PEF)、幼鱼杂鱼 (JMF) 和水凝胶日粮 (SAH:SA12.5%), 进行为期 8 周的试验探究对生长和消化的影响。(2) 表观消化率试验: 选择了五组不同含量海藻酸钠的水凝胶日粮 (SAH1 (SA8.33%)、SAH2 (SA9.09%)、SAH3 (SA10%)、SAH4 (SA11.01%)、SAH5 (SA12.5%)), 并将颗粒日粮作为对照组 (CON), 探究中华绒螯蟹对这种水凝胶日粮的吸收利用能力。【结果】养殖试验的结果发现, 三组日粮的生长性能没有出现显著差异 ($P<0.05$)。对肝胰腺中消化酶活性分析发现, SAH 组与 JMF 组相比胰蛋白酶活性显著增加 ($P<0.05$), 而脂肪酶, α 淀粉酶和纤维素酶活性没有出现显著差异 ($P<0.05$); 对肠道中有关消化相关的基于分析发现, SAH 组 *crtb1*、*tryp*、*il*、*espt*、*pm1* 和 *pm2* 基因表达显著上调 ($P<0.05$)。在表观消化率试验中, 中华绒螯蟹对六种日粮的干物质的表观消化率为 47.35%-78.95%; 粗蛋白的表观消化率为 62.68%-83.64%; 粗脂肪的表观消化率为 91.83%-98%; 总氨基酸的表观消化率为 65.94%-84.45%。发现 SAH3 和 SAH5 组在干物质、粗蛋白、粗脂肪、总磷和总氨基酸中的表观消化率显著高于对照组 ($P<0.05$)。【结论】综上所述, SAH 日粮在对中华绒螯蟹生长没有负面影响的前提下, 改善了中华绒螯蟹的消化性能, 其消化酶和表观消化率都有着显著的提高。

关键词: 中华绒螯蟹, 水凝胶日粮, 生长性能, 消化, 表观消化率

Effects of new hydrogel diet on growth and apparent digestibility of *Eriocheir sinensis*

Hanjing Zhao, Xi Wang, Xiufei Cao, Xiaoyu Chu, Jingyu Zhou, Huixing Guo, Haokun Hua,
Wenbin Liu, Guangzhen Jiang*

(Key Laboratory of Aquatic Nutrition and Feed Science of Jiangsu Province, College of Animal Science and Technology, Nanjing Agricultural University, No.1 Weigang Road, Nanjing 210095, People's Republic of China)

Abstract : [Objective] Currently, although the commercial diet of *E. sinensis* is nutritious and diverse, the rapid dispersion of the diet, inconvenient feeding of *E. sinensis*, and slow gonadal maturation all hinder their better development. Most researchers focus on improving the dietary formula to address the issue, neglecting the impact of the physical properties of the diet on *E. sinensis*. In this experiment, a new type of sodium alginate calcium chloride hydrogel diet (SAH) was prepared to study the effect of this soft particle texture hydrogel diet on the growth and digestion of *E. sinensis*. [Methods] (1) Breeding experiment: Three diets with different textures were designed, pellet diet (PEF), juvenile miscellaneous fish (JMF) and hydrogel diet (SAH: SA12.5%). The experiment lasted for 8 weeks to explore the effects on growth and digestion. (2) Apparent digestibility test: five groups of hydrogel diets with different contents of sodium alginate (SAH1 (SA8.33%), SAH2 (SA9.09%), SAH3 (SA10%), SAH4 (SA11.01%), and SAH5 (SA12.5%) were selected, and the pellet diet was used as the control group (CON) to explore the absorption and utilization ability of *E. sinensis* to this hydrogel feed. [Results] The results of the breeding experiment showed that there was no significant difference in growth performance among the three groups of diets ($P<0.05$). Analysis of digestive enzyme activity in the hepatopancreas revealed that the SAH group showed a significant increase in trypsin activity compared to JMF ($P<0.05$), while there were no significant differences in lipase, α -amylase, and cellulase activities ($P<0.05$); Based on the analysis of digestion related genes in the intestine, it was found that the expression of *crtb1*, *tryp*, *il*, *espt*, *pm1*, and *pm2* genes was significantly upregulated in the SAH group ($P<0.05$). In the apparent digestibility test, the apparent digestibility of dry matter in six diets by *E. sinensis* ranged from 47.35% to 78.95%; The apparent digestibility of crude protein ranges from 62.68% to 83.64%; The apparent digestibility of crude lipid is 91.83% to 98%; The apparent digestibility of TAA ranges from 65.94% to 84.45%. The apparent digestibility of dry matter, crude protein, crude fat, total P, and TAA in SAH3 and SAH5 groups was significantly higher than that in the CON ($P<0.05$). [Conclusion] In summary, SAH diet improved the digestive performance of *E. sinensis* without negative effects on their growth, with significant improvements in digestive enzymes and apparent digestibility.

Key words : *Eriocheir sinensis*, Hydrogel diet, Growth performance , digestion, apparent digestibility

养殖鱼类越冬前精准投喂策略研究：以草鱼为例

武文一^{1,2}, 吉红^{2*}

(1. 河南牧业经济学院动物科技学院, 河南 郑州 450046; 2. 西北农林科技大学动物科技学院, 陕西 杨凌 712100)

摘要:【目的】为探讨越冬前鱼类精准投喂策略,【方法】采用双因子分析法(3×2),对初始质量 27.55 ± 1.57 g的草鱼越冬前投喂6种不同蛋白质和脂肪水平的饲料;包括28%、31%、34%蛋白水平和4%、8%脂肪水平进行4周的试验;同时继续设计添加高不饱和脂肪酸(n-3 HUFA)的四组饲料,分别是:31%蛋白4%脂肪组、31%蛋白8%脂肪组、31%蛋白8%脂肪组(含0.52% n-3 HUFA)和31%蛋白8%脂肪组(含1.04% n-3 HUFA),进而探讨n-3 HUFA越冬前强化功能。【结果】结果表明,越冬前强化31%蛋白、4%脂肪水平饲料对草鱼越冬后体重损失有显著抑制作用($P<0.05$),同时显著提高了越冬后草鱼血清代谢物中TP、GLU和TG含量。对肝胰脏和肌肉越冬前后脂肪酸模式分析发现,越冬前强化31%蛋白、4%脂肪水平饲料对机体脂肪酸比例变化产生影响最小,显示该处理组能有效降低越冬期间脂肪酸比例发生剧烈变化的同时,继而降低氧化应激。提高饲料脂肪或是添加n-3 HUFA显著提高了脂肪酸比例模式的变化,提高了机体脂肪动员及代谢,造成氧化应激,不利于越冬。

【结论】综上所述:越冬前强化饲料中含有31%蛋白和4%脂肪对草鱼安全越冬作用最为明显,结果最佳;而n-3 HUFA强化饲料不仅无益反而有不利作用。

关键词: 越冬; 草鱼; 蛋白和脂肪; n-3 HUFA

Research on precise feeding strategy of breeding fish before overwintering: Take grass carp as an example

Wenyi Wu^{1,2}, Hong Ji^{2*}

(1. College of Animal Science and Technology, Henan Institute of Animal Husbandry and Economy, Zhengzhou Henan, 450046; 2. College of Animal Science and Technology, Northwest A & F University, Yangling Shaanxi, 712100)

Abstract: [Objective] To explore the precise feeding strategy of fish before overwintering, [Methods] Using the two-factor analysis method (3×2), grass carp with an initial mass of 27.55 ± 1.57 g were fed six different protein and lipid levels before overwintering, including 28%, 31%, 34% protein levels and 4%, 8% lipid levels for 4 weeks; and the design of four groups with high unsaturated fatty acid (n-3 HUFA), including 31% protein 4% lipid, 31% protein 8% lipid, 31% protein 8% lipid (0.52% n-3 HUFA) and 31% protein 8% lipid (1.04% n-3 HUFA), to explore the strengthening function of n-3 HUFA before overwintering. [Results] The results showed that the diet of 31% protein and 4% lipid before overwintering ($P<0.05$), and significantly increased the TP, GLU and TG content in the serum metabolites after overwintering. The analysis of fatty acid patterns before and after overwintering of hepatopancreas and muscle found that the diet of 31% protein and 4% lipid before overwintering had the least impact on the change of fatty acid ratio, which showed that the treatment group could effectively reduce the drastic change of fatty acid ratio during overwintering, and then reduce the oxidative stress. Increasing feed lipid or adding n-3 HUFA levels significantly increased the change of fatty acid ratio pattern ($P<0.05$), improved the body lipid mobilization and metabolism, and then caused oxidative stress, which is not conducive to overwintering. [Conclusion] In conclusion: 31% protein and 4% lipid are the most obvious effects and the best results, while the n-3 HUFA fortified feed is not beneficial but unfavorable.

Key words: Overwintering; Grass carp; Protein and lipid; n-3 HUFA

营养感知分子 UBXD8 调控缢蛏高不饱和脂肪酸（HUFA）合成的作用及机制

冉照收^{1*}, 廖凯, 徐继林¹

(1. 贝类营养与免疫研究实验室, 宁波大学海洋学院, 浙江宁波 315211)

摘要: 现有研究表明, 海洋软体动物高不饱和脂肪酸 (HUFA) 合成能力低, 饵料 HUFA 为其正常生长发育所必须。然而, 目前关于洋软体动物如何感知饵料 HUFA 水平, 反馈调控自身 HUFA 合成尚不清楚。我们前期以缢蛏为研究对象, 首次证实海洋软体动物具备完整的 HUFA 合成通路。在此基础上, 本文揭示了 HUFA 感知分子 UBXD8 在缢蛏 HUFA 合成中的调控作用及机制。结果发现, 缢蛏 UBXD8 具有脊椎动物 UBXD8 保守的功能结构域, 并在肠组织表达量最高, 提示其可能反馈调控缢蛏 HUFA 合成; 进一步, 体外纯化缢蛏 UBXD8 蛋白, 与不同脂肪酸共孵育, 经非变性胶凝胶电泳发现, 其特异性与不饱和脂肪酸发生多聚化反应, 且随着不饱和程度和碳链长度、及脂肪酸浓度增加而增强, 提示其可能通过感知 HUFA 水平调控 HUFA 合成; 随后, 经 RNA 干扰发现, 敲降缢蛏 UBXD8 引起 HUFA 合成相关基因 (Fad 和 Elovl) 表达变化、及缢蛏 HUFA 组成变化, 提示其可能通过 INSIG-SREBP 轴介导 Fad 和 Elovl 表达、进而调控 HUFA 合成。综上, 本研究结果表明, UBXD8 可能通过感知 HUFA 水平调控缢蛏 HUFA 合成、从而维持 HUFA 稳态。本文可为研发基于营养感知的提高海洋软体动物、乃至其它水产经济动物 HUFA 合成能力方法提供指导和借鉴。

关键词: 高不饱和脂肪酸; 调控; 海洋软体动物

The regulatory role and mechanism of nutrient-sensor UBXD8 in HUFA synthesis of *Sinonovacula constricta*

Zhaoshou Ran*, Kai Liao, Jilin Xu

(Laboratory of Nutrition and Immunology of Shellfish, School of marine science, Ningbo University, Ningbo, Zhejiang, China 315211)

Abstract: Current research indicates that marine mollusks have a low ability to synthesize highly unsaturated fatty acids (HUFA), making dietary HUFA essential for their normal growth and development. However, it is still unclear how marine mollusks sense dietary HUFA levels and then feedback-regulate their own HUFA synthesis. In our previous studies using *Sinonovacula constricta* as a model organism, we were the first to confirm that marine mollusks possess a complete HUFA synthesis pathway. Based on this, the present study reveals the regulatory role and mechanism of the HUFA-sensing molecule UBXD8 in the HUFA synthesis of *S. constricta*. The results show that *S. constricta* UBXD8 has conserved functional domains similar to that of vertebrate UBXD8 and is most highly expressed in intestinal tissue, suggesting it may feedback-regulate HUFA synthesis in *S. constricta*. Furthermore, after purifying the UBXD8 protein *in vitro* and co-incubating it with different fatty acids, we found through non-denaturing gel electrophoresis that it specifically underwent polymerization reactions with unsaturated fatty acids. This polymerization increased with the degree of unsaturation, carbon chain length, and fatty acid concentration, indicating that UBXD8 may regulate HUFA synthesis by sensing HUFA levels. Subsequently, RNA interference experiments revealed that knocking down UBXD8 in *S. constricta* resulted in changes in the expression of HUFA synthesis-related genes (Fad and Elovl) and alterations in HUFA composition, suggesting that UBXD8 may mediate the expression of Fad and Elovl through the INSIG-SREBP pathway, thereby regulating HUFA synthesis. In summary, our findings suggest that UBXD8 may regulate HUFA synthesis in *S. constricta* by sensing HUFA levels, thereby maintaining HUFA homeostasis. This study provides guidance and insights for developing methods to enhance the HUFA synthesis capability of marine mollusks and other economically important aquatic animals based on nutrient sensing.

Key words: highly unsaturated fatty acids; regulation; marine mollusks

鱼类食物成瘾的分子机制及其在鳊鱼驯食饲料中的作用

何珊*, 卢宏亮¹, 缪云亮², 李映岑³

1.华中农业大学水产学院, 湖北武汉 430070

摘要: 鳊鱼驯食饲料后易出现厌食返口, 深入研究鳊鱼稳定驯食饲料的分子机理, 对于鳊鱼饲料配方优化及饲料高效利用品种培育, 最终解决鳊鱼人工饲料可控养殖问题具有重要意义。食物成瘾与药物成瘾具有相同的神经生物学机制, 本文研究了食物成瘾介导的鳊鱼稳定驯食饲料机理。细胞水平研究发现, 赖氨酸引起鳊鱼食物成瘾的信号途径是激活 *c-fos*, 升高 *oprml*, 增加 *drd1*, 同时减少 *drd2*, 最后诱导 *agrp* 的转录。而高糖刺激鳊鱼脑细胞后, *agrp*、*drd1* 和 *oprml* 基因表达量显著下降, AgRP 和 c-Fos 蛋白的表达下降。活体水平研究发现, 斑马鱼投喂添加赖氨酸的饲料后摄食次数增加, 投喂高糖饲料后摄食次数减少, 而且 30 天后进行食物选择实验发现, 赖氨酸强化后的斑马鱼对赖氨酸饲料具有偏好, 会更多地选择添加赖氨酸的饲料, 在赖氨酸强化的斑马鱼中提前注射食物成瘾通路抑制剂, 可消除赖氨酸引起的食物成瘾。反之, 斑马鱼投喂高糖饲料 30 天后, 并不能引起食物成瘾, 对高糖饲料未发生偏好。赖氨酸添加饲料投喂斑马鱼引起的赖氨酸成瘾, 伴随着食欲基因及成瘾基因表达的上升, 而高糖添加饲料投喂的斑马鱼中相关基因无显著差异; 同时赖氨酸成瘾的斑马鱼中组蛋白 H3K4me3 和 H3K79me3 表达量显著上升, 而高糖饲料投喂并未成瘾的斑马鱼中 H3K4me3 和 H3K79me3 表达量显著下降。本文阐明了鱼类的食物成瘾信号通路, 发现添加赖氨酸的饲料, 会引起食物成瘾, 组蛋白 H3K4 甲基化作为上游调节因子激活了食物成瘾信号途径, 而短期高糖饲料投喂不能引起食物成瘾。此外, 本文通过比较不同驯食能力的鳊鱼脑组织中食物成瘾 *penk* 基因表达量来探究 *penk* 基因与鳊鱼食性驯化的关系, 发现易驯食鳊鱼脑组织 *penk* mRNA 的表达量显著高于难驯食鳊鱼。通过分子标记开发, 从鳊鱼难易驯群体中共筛选出了 4 个驯食相关 SNP 位点, 性状关联分析发现 *penk*-C 位点与驯食性状呈中度正相关, 成功开发了鳊鱼驯食饲料性状相关食物成瘾基因 SNP 标记。

关键词: 鳊鱼; 食物成瘾; 饲料驯化; 分子标记

资助项目: 国家自然科学基金 (32172951);

*通讯作者, 何珊, 副高级, 主要从事鱼类功能基因组、营养基因组及鳊鱼饲料利用遗传改良相关研究。E-mail:heshan@mail.hzau.edu.cn

珍珠龙胆石斑鱼(*Epinephelus fuscoguttatus*♀×*E. lanceolatus*♂)

SUMO1、SUMO2 和 UBC9 基因克隆及序列分析

陈强^{1,2,3}, 钱家豪^{1,2,3}, 刘泓宇^{1,2,3*}, 谭北平^{1,2,3}, 董晓慧^{1,2,3}, 迟淑艳^{1,2,3},
杨奇慧^{1,2,3}, 章双^{1,2,3}, 邓君明^{1,2,3}, 殷彬^{1,2,3}

(1. 广东海洋大学, 水产学院, 水产动物营养与饲料实验室, 广东 湛江 524088; 2. 广东省水产动物精准营养与高效饲料工程技术研究中心, 广东 湛江 524088; 3. 农业部华南水产与畜禽饲料重点实验室, 广东 湛江 524088)

摘要: SUMOylation 修饰可以通过增强级联反应来增强和促进鱼细胞的葡萄糖代谢。【目的】本实验以杂交石斑鱼(*Epinephelus fuscoguttatus*♀×*E.*)为研究对象, 对 SUMO1、SUMO2 和 UBC9 基因进行分子克隆和序列分析。同时测定杂交石斑鱼不同组织中 SUMO1、SUMO2 和 UBC9 的表达。【方法】本研究采用 RACE-PCR 方法获得杂交石斑鱼 SUMO1、SUMO2 和 UBC9 基因的全长 cDNA 序列。【结果】杂种石斑鱼 SUMO1 与尼罗罗非鱼和草鱼 SUMO1 的同源性分别为 98%和 91%, 与 SUMO2 的同源性分别为 96%和 93%, 与 UBC9 的同源性为 94%; 功能位点和保守结构域分析表明, 杂交石斑 SUMO1 和 SUMO2 在 c 端具有保守的双氨酸重复序列和泛素样折叠超家族, UBC9 具有保守的 Cys93 和保守的泛素样连接酶 E2 催化超家族结构域。【结论】组织表达谱显示, SUMO1、SUMO2 和 UBC9 在杂交石斑鱼的脑组织和心脏组织中表达量较高, 在肌肉组织中表达量最低。

关键词: SUMOylation, 分子克隆, 葡萄糖代谢, 珍珠龙胆石斑鱼

Molecular cloning and sequence analysis of the SUMO1, SUMO2 and UBC9 genes of the hybrid grouper (*Epinephelus fuscoguttatus* ♀ × *E. lanceolatus* ♂)

Qiang Chen^{1,2,3}, Jiahao Qian^{1,2,3}, Hongyu Liu^{1,2,3*}, Beiping Tan^{1,2,3}, Xiaohui Dong^{1,2,3}, Shuyan Chi^{1,2,3}, Qihui Yang^{1,2,3}, Shuang Zhang^{1,2,3}, Bin Yin^{1,2,3}

1. Laboratory of Aquatic Animal Nutrition and Feed, Fisheries College, Guangdong Ocean University, Zhanjiang 524025, P.R. China; 2. Aquatic Animals Precision Nutrition and High Efficiency Feed Engineering Research Centre of Guangdong Province, Zhanjiang, Guangdong, China; 3. Key Laboratory of Aquatic, Livestock and Poultry Feed Science and Technology in South China, Ministry of Agriculture, Zhanjiang 524025, P.R. China

Abstract: SUMOylation modifications could enhance and promote glucose metabolism in fish cells through enhanced cascade reactions. [Objective] Molecular cloning and sequence analysis of SUMO1, SUMO2 and UBC9 genes were carried out in this experiment using the hybrid grouper (*Epinephelus fuscoguttatus* ♀ × *E. lanceolatus* ♂). [Methods] The expression of SUMO1, SUMO2 and UBC9 in different tissues of the hybrid grouper was also determined. [Results] In this study, the full-length cDNA sequences of SUMO1, SUMO2 and UBC9 genes of hybrid grouper were obtained by RACE-PCR. The homology analysis showed that hybrid grouper SUMO1 was 98% and 91% similar to Nile tilapia and grass carp SUMO1, 96% and 93% to SUMO2 and 94% to UBC9; the functional site and conserved structural domain analysis showed that hybrid grouper SUMO1 and SUMO2 had conserved double glycine repeats and ubiquitin-like folding superfamily at the C-terminus UBC9 has a conserved Cys93 and a conserved ubiquitin-like ligase E2 catalytic superfamily domain. [Conclusion] Tissue expression profiles showed that SUMO1, SUMO2 and UBC9 were more highly expressed in brain and heart tissue and least expressed in muscle in hybrid grouper.

Keywords: SUMOylation, Molecular cloning, Glucose metabolism, Hybrid grouper (*Epinephelus fuscoguttatus* ♀ × *E. lanceolatus* ♂)

基金项目：广东省普通高校重点科研项目（2024ZDZX2085）、广东省现代化海洋牧场适养品种核心技术攻关项目（2024-MRB-00-001）、国家海水鱼产业技术体系(CARS-47)

通讯作者：刘泓宇，教授，博士生导师，E-Mail: liuhyu@gdou.edu.cn

棕榈油在红鳍东方鲀饲料中的应用：生长、体成分、肌肉质构和脂质代谢

范昱含¹, 熊海燕², 刘家豪², 刘国旭², 马强², 卫育良², 梁萌青², 徐后国^{2*}

(1. 上海海洋大学水产与生命科学学院, 上海 沪城环路 999 号 201306; 2. 中国水产科学院黄海水产研究所, 山东 青岛 266071)

摘要:【目的】棕榈油产量高, 价格低, 棕榈酸和油酸含量丰富, 是水产饲料行业极具发展潜力的鱼油替代脂肪源。本研究旨在探究红鳍东方鲀饲料中棕榈油替代鱼油对其生长、体成分、肌肉质构、脂肪酸组成、脂质代谢等方面的影响, 从而为红鳍东方鲀饲料中适宜脂肪源的开发提供新思路。【方法】通过为期 8 周的养殖实验, 全面评估棕榈油替代红鳍东方鲀饲料中鱼油的可行性。对照组饲料 (FO 组) 以 8% 的海洋鱼油为主要外加脂肪源, 而实验组饲料中的外加鱼油则被商品棕榈油以 25%、50%、75% 和 100% 的水平替代作为脂肪源, 分别标记为 25PO 组、50PO 组、75PO 组和 100PO 组。本实验选取初始体重为 (15.0±0.04g) 的一批红鳍东方鲀幼鱼为实验对象, 每处理组 3 个重复, 每桶 30 尾红鳍东方鲀幼鱼, 每天饱食投喂两次。【结果】用棕榈油替代鱼油对红鳍东方鲀的生长和摄食没有负面影响, 但 PO100 组的增重相比于对照组下降了 17.3%。棕榈油对鱼类的粗成分和肌肉质构没有显著影响。饲料中棕榈油对肌肉脂肪酸组成的影响不显著, 仅在 100PO 组中 DHA 和 EPA 显著降低。与肌肉相比, 肝脏和肠道脂肪酸组成受到饲料的影响更为明显。在肠道中, 用棕榈油替代 50% 以上的鱼油会显著下调过氧化物酶体脂肪酸 β-氧化和甘油三酯水解相关基因的表达, 同时上调胆固醇生物合成相关基因的表达。在肝脏中, 替代 75% 以上的鱼油也会显著上调胆固醇的合成。【结论】棕榈油可以替代红鳍东方鲀饲料中 75% 的外加海水鱼油, 并且不会对红鳍东方鲀的生长性能、饲料利用率、肌肉成分和肌肉质构产生不利影响。

关键词: 脂质营养; 红鳍东方鲀; 脂肪源; 原料替代; 肌肉质构

Efficacy of Palm Oil Application in Tiger Puffer Diets: Growth, Body Composition, Muscle Texture, and Lipid Metabolism

Yuhan Fan¹, Haiyan Xiong², Jiahao Liu², Guoxu Liu², Qiang Ma², Yuliang Wei²,
Mengqing Liang², Houguo Xu^{2*}

(1.College of Fisheries and Life Sciences, Shanghai Ocean University, 999 Huchenghuan Road, Shanghai 201306, China; 2.State Key Laboratory of Mariculture Biobreeding and Sustainable Goods, Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, 106 Nanjing Road, Qingdao 266071, China)

Abstract: [Objective] Palm oil, with its higher production, lower prices, and higher levels of palmitic acid and oleic acid, may have great potential for use in the aquafeed industry. This study explores the effects of palm oil as a substitute for fish oil in tiger puffer feeds on its growth, body composition, muscle texture, fatty acid composition, and lipid metabolism, thereby providing new insights into the development of novel lipid sources for the feed of tiger puffer. [Methods] In this study, with an 8-week feeding experiment, the efficacy of palm oil as a substitute for fish oil in tiger puffer feeds was comprehensively evaluated. The control diets (FO group) contained 8% marine fish oil as the main lipid source, while in the treatment diets, the added marine fish oil was replaced with palm oil at 25%,50%,75%, and 100%, respectively, which was named 25PO, 50PO, 75PO, and 100PO, respectively. Juvenile tiger puffers with an initial weight of 15.0 ± 0.04 g were used, with three replicate tanks of 30 juvenile fish tiger puffer for each dietary group. [Results] The fish oil replacement by palm oil did not have an adverse effect on fish growth and feeding, but the weight gain decreased by 17.3% in group PO100. Palm oil had no significant effects on fish proximate composition and muscle texture. The effects of dietary palm oil on muscle fatty acid composition were not significant, with DHA and EPA significantly lowered only in the 100PO group. In contrast, the changes in liver and intestinal fatty acid compositions in response to diets were more significant than those in the muscle. In the intestine, the replacement of more than 50% fish oil by palm oil significantly downregulated the gene expression associated with peroxisomal fatty acid β -oxidation and triglyceride hydrolysis, while upregulated the expression of cholesterol biosynthetic genes. In the liver, the replacement of more than 75% fish oil also significantly upregulated the cholesterol synthesis. [Conclusion] In conclusion, palm oil can replace 75% of added marine fish oil in tiger puffer diets and does not adversely affect the growth performance, feed utilization, muscle composition, and muscle texture.

Keywords: Lipid nutrition; Pufferfish; Lipid source; Alternative ingredient; Muscle texture

组氨酸在调控大口黑鲈生长、营养代谢、免疫能力中具有重要作用

梁化亮¹, 黄东宇¹, 张璐², 任鸣春^{1*}

(1.中国水产科学研究院, 淡水渔业研究中心, 农业农村部稻渔综合种养生态重点实验室, 江苏 无锡 214081; 2. 通威农业发展有限公司, 农业农村部水产畜禽营养与健康养殖重点实验室, 水产健康养殖四川省重点实验室, 四川 成都 610093)

摘要:为探讨大口黑鲈 (*Micropterus salmoides*) 幼鱼饲料组氨酸适宜需求量及饲料组氨酸水平对其营养代谢、免疫调控的影响进行为期 56 天的养殖实验。试验选用平均初始体重约 12.33 g 的黑鲈 360 尾, 在 18 个 1m*1m*1m 的试验网箱中投喂 6 个不同组氨酸水平的饲料, 组氨酸水平分别为 0.71%、0.89%、1.08%、1.26%、1.48%和 1.67%。实验结果表明: (1) 饲料中适宜的组氨酸水平可提高大口黑鲈的生长性能和蛋白质合成。根据特定生长率和饲料转化率。基于特定生长率和饵料系数, 采用二次回归模型分析, 大口黑鲈幼鱼适宜的饲料组氨酸需求为 1.26% (饲料蛋白质的 2.68%); (2) 大口黑鲈可以通过 AAR 信号通路感知饲料组氨酸水平, 表现为随着饲料组氨酸水平的升高, AAR 信号通路核心基因 GCN2、eIF2 α 、CHOP、ATF4 和 REDD1 下调。饲料组氨酸水平提高可通过调节 PPAR α 、CPT1、L-FABP、PGC1 α 、PPAR γ 、FAS、ACC、SREBP1 和 ELOVL2 等 PPAR α 和 PPAR γ 信号通路基因表达, 降低全身和肝脏脂质含量。肝油红 O 染色阳性面积比和血清 TC 含量的降低也支持了这一结果; (3) 饲料组氨酸缺乏可通过调控 Nrf2、PEPK、IRE1 和 NF- κ B 信号通路来削弱肠道抗氧化能力, 诱发肠道内质网应激, 进而引起炎症反应、细胞凋亡和坏死, 降低大口黑鲈的免疫能力。基于 MDA 和 T-SOD 结果, 通过二次回归分析确定大口黑鲈幼鱼适宜的饲料组氨酸需求为 1.30%-1.45% (饲料蛋白质的 2.77%-3.09%)。

关键词: 大口黑鲈; 组氨酸; 营养需求; 营养代谢; 免疫调控

Histidine plays an important role in regulating the growth, nutritional metabolism and immunity of largemouth bass (*Micropterus salmoides*)

Hualiang Liang¹, Dongyu Huang¹, Lu Zhang², Mingchun Ren^{1*}

(1. Key Laboratory of Mariculture (Ministry of Education) and Key Laboratory of Aquaculture Nutrition and Feed (Ministry of Agriculture and Rural Affairs), Ocean University of China, Qingdao China 266003; 2. Laboratory for Marine Fisheries Science and Food Production Processes, Qingdao National Laboratory for Marine Science and Technology, Qingdao China 266237)

Abstract: This 56-day research aimed to evaluate the recommended histidine requirement and the influence of dietary histidine levels on nutrient metabolism and immune regulation in largemouth bass (*Micropterus salmoides*). A feeding trial was conducted with 360 largemouth bass of about 12.33 g mean initial weight that were fed with six graded levels of histidine in 18 experimental cages (1m*1m*1m), which were 0.71%, 0.89%, 1.08%, 1.26%, 1.48% and 1.67%, respectively. The results showed that (1) the appropriate dietary histidine level could improve the growth performance and protein synthesis. According to the specific growth rate and feed conversion rate, the recommended histidine requirement of juvenile largemouth bass was 1.26% of the diet (2.68% of dietary protein) by regression lines calculated using a quadratic model; (2) Dietary histidine levels could be sensed by the AAR signaling pathway, representing as down-regulation of core genes of AAR signaling pathway with the increased dietary histidine levels, including GCN2, eIF2 α , CHOP, ATF4 and REDD1. Increased dietary histidine levels decreased the lipid content of the whole body and the liver by regulating gene expressions of PPAR α and PPAR γ signaling pathway, including PPAR α , CPT1, L-FABP, PGC1 α , PPAR γ , FAS, ACC, SREBP1 and ELOVL2. These findings were also supported by the decrease of positive area ratio of hepatic oil red O staining and the TC content of plasma; (3) Histidine deficiency can weaken the intestinal antioxidant capacity and induce intestinal endoplasmic reticulum stress, which further leads to an inflammatory response, apoptosis, and necroptosis and decreases the immune capacity of largemouth bass via regulating Nrf2 signaling pathway, PEPK signaling pathway, IRE1 signaling pathway and NF- κ B signaling pathway. Based on the results of MDA and T-SOD, the appropriate dietary histidine requirements of juvenile largemouth bass are 1.30%-1.45% of the diet (2.77%-3.09% dietary protein) as determined by quadratic regression analysis.

Key words: Largemouth bass (*Micropterus salmoides*); Histidine; Nutrient requirement; Nutrition metabolism; Immunoregulation

资助项目：国家终点研发计划项目（2018YFD0900400）、国家特色淡水鱼产业技术体系（CARS-46）

通讯作者：任鸣春，E-Mail: renmc@ffrc.cn

专题二

营养与品质

不同年龄长吻鮠肌肉营养品质及挥发性风味物质比较分析

马英¹, 侯梦丹¹, 高胡君¹, 秦凤¹, 张云秀¹, 刘陈¹, 秦志勇¹, 魏震², 郑维², 熊银林², 翟旭亮³, 薛洋³, 徐凤³, 叶华¹, 罗辉¹

(1.西南大学水产学院, 淡水鱼类资源与生殖发育教育部重点实验室, 重庆 402460; 2.四川省珍稀特有鱼类保护与利用中心, 四川 611200; 3.重庆市水产技术推广总站, 重庆 401147)

摘要: 为研究不同年龄长吻鮠肌肉营养品质和挥发性风味之间的差异, 以人工养殖的 2 龄、3 龄、4 龄长吻鮠为研究对象, 分别对其基本营养成分、氨基酸、脂肪酸、矿物质和挥发性风味物质进行测定和分析。结果表明, 4 龄和 2 龄肌肉粗蛋白和灰分显著高于 3 龄, 但各龄肌肉间粗脂肪和灰分无显著性差异。各龄肌肉均测得 18 种氨基酸, 包含必需氨基酸 7 种, 半必需氨基酸 3 种, 非必需氨基酸 8 种。呈味氨基酸以谷氨酸、天冬氨酸为主, 必需氨基酸中赖氨酸、亮氨酸含量最高。其中苏氨酸、缬氨酸、丙氨酸、胱氨酸和牛磺酸含量各龄间存在显著差异, 其余氨基酸差异不显著。长吻鮠肌肉中必需氨基酸与氨基酸总量比值与 WHO/FAO 模式推荐的标准 (0.4) 相近, 必需氨基酸与非必需氨基酸比值高于 WHO/FAO 推荐值 (0.6)。4 龄和 3 龄肌肉必需氨基酸指数均为 0.87, 高于 2 龄肌肉。综合氨基酸评分 (AAS) 和化学评分 (CS) 揭示缬氨酸为长吻鮠肌肉中第一限制性氨基酸。脂肪酸测定结果显示, 除木蜡酸外, 其余脂肪酸各龄间均无显著差异。各龄长吻鮠肌肉中不饱和脂肪酸总量高于饱和脂肪酸, 多不饱和脂肪酸与饱和脂肪酸比值符合健康膳食推荐比值。长吻鮠肌肉中 n-3 PUFAs/ n-6 PUFAs 比值均较为理想, DHA 和 EPA 含量丰富。矿物质种类齐全, 但各龄间均无显著差异, 微量元素中锌、铁含量较高。三个年龄段肌肉中共检测出 40 种挥发性风味物质, 4 龄和 3 龄肌肉的风味优于 2 龄肌肉。研究表明, 各龄长吻鮠肌肉均具有较高的食用价值, 其中, 4 龄长吻鮠肌肉的鲜味程度和营养价值最佳, 具有更高的水产市场消费潜力。该研究为长吻鮠营养需求的进一步研究, 食品加工和居民膳食选择提供了参考依据。

关键词: 不同年龄; 长吻鮠; 肌肉; 基本营养成分; 挥发性风味物质

资助项目: 国家重点研发计划项目(2022YFD2400903)

通讯作者: 罗辉, E-Mail: luohui2629@126.com

Comparative analysis of nutritional quality and volatile flavor compounds in the muscles of *Leiocassis longirostris* at different ages

Ying Ma¹, Mengdan Hou¹, Hujun Gao¹, Feng Qin¹, Yunxiu Zhang¹, Chen Liu¹, Zhiyong Qin¹, Zhen Wei², Wei Zheng², Yinlin Xiong², Xuliang Zhai³, Yang Xue³, Feng Xu³, Hua Ye¹, Hui Luo¹
(1. Key Laboratory of Freshwater fish resources and reproductive development(Ministry of Education), College of Fisheries, Southwest University, Chongqing 402460; 2. Center for Conservation and Utilization of Rare and Endemic Fishes in Sichuan, Sichuan 611200; 3. Chongqing Alliance for Aquatic Science and Technology Innovation, Chongqing 401147)

Abstract: In order to study the differences in the nutritional quality and volatile flavor of *Leiocassis longirostris* at different ages, the basic nutrients, amino acids, fatty acids, minerals and volatile flavor substances of artificially cultured 2-year-old, 3-year-old and 4-year-old *L. longirostris* were determined and analyzed. The results showed that the crude protein and ash content of muscles of 4-year-old and 2-year-old *L. longirostris* were significantly higher than those of 3-year-old *L. longirostris*, but there were no significant differences in crude fat and ash among the muscles of different ages. 18 kinds of amino acids were measured in the muscles of different ages, including 7 essential amino acids, 3 semi-essential amino acids and 8 non-essential amino acids. The flavor amino acids were mainly glutamic acid and aspartic acid, and the contents of lysine and leucine were the highest among the essential amino acids. Among them, the contents of threonine, valine, alanine, cystine and taurine were significantly different among the different ages, while the differences of other amino acids were not significant. The ratio of essential amino acids to total amino acids in the muscles of *L. longirostris* was close to the standard recommended by the WHO/FAO model (0.4), and the ratio of essential amino acids to non-essential amino acids was higher than the value recommended by WHO/FAO (0.6). The essential amino acid index of both 4-year-old and 3-year-old muscle was 0.87, which was higher than that of 2-year-old muscle. The comprehensive amino acid score (AAS) and chemical score (CS) revealed that valine was the first limiting amino acid in the muscles of *L. longirostris*. The results of fatty acid determination showed that except for lignoceric acid, there was no significant difference in the remaining fatty acids among different ages. The total amount of unsaturated fatty acids in the muscles of *L. longirostris* of all ages was higher than that of saturated fatty acids, and the ratio of polyunsaturated fatty acids to saturated fatty acids met the recommended ratio of a healthy diet. The ratios of n-3 PUFAs/ n-6 PUFAs in the muscle of *L. longirostris* were all more favorable, and the content of DHA and EPA was rich. There were a full range of minerals, but there was no significant difference among the ages. The content of zinc and iron in trace elements was high. A total of 40 volatile flavor substances

were detected in the muscles of the three age groups, and the flavor of the muscles of 4-year-old and 3-year-old was better than that of the muscles of 2-year-old. The study has shown that the muscles of *L. longirostris* of all ages have high edible value, among which the umami degree and nutritional value of the muscles of 4-year-old *L. longirostris* are the best, and have higher consumption potential in the aquatic market. This study provides a reference for further research on the nutritional needs of *L. longirostris*, food processing and residents' dietary choices.

Key words: different ages; *Leiocassis longirostris*; muscle; basic nutrients; volatile flavor substances

不同锌源对鳊生长、肌肉品质、抗氧化及免疫能力的影响

晏晓露¹, 王文洁¹, 陈雨霜¹, 周达¹, 古殿超², 汪福保³, 翟旭亮⁴, 薛洋⁴, 陈拥军¹,
刘海平^{1*}, 罗莉^{1*}

(1.西南大学水产学院, 西部(重庆)科学城种质创制大科学中心, 淡水鱼类资源与生殖发育教育部重点实验室, 重庆 400715; 2.湖南德邦生物科技股份有限公司, 湖南 常宁 421500; 3.重庆市水产技术推广总站, 重庆 400400; 4.佛山市南海区杰大饲料有限公司, 广东 佛山 528211)

摘要: 为了探究饲料中添加不同锌源对鳊(*Siniperca chuatsi*)生长性能、肌肉品质, 抗氧化及免疫能力的影响, 以鳊基础饲料为对照组(CON), 分别添加 40mg/kg 硫酸锌($ZnSO_4$)、大米蛋白氨基酸螯合锌、大豆蛋白氨基酸螯合锌, 蛋氨酸锌(1:1)和蛋氨酸锌 (2:1)。选取初始体重为(67.46±2.02)g 的鳊 270 尾, 随机分为 6 组, 每组 3 个重复, 每个重复 15 尾, 进行 49d 生长试验。结果表明, 与对照组相比, 5 种锌源均促进鳊生长和饲料转化, 其中蛋氨酸锌(2:1)效果最显著($P<0.05$), 其次是蛋氨酸锌(1:1)、大豆蛋白氨基酸螯合锌、大米蛋白氨基酸螯合锌, 硫酸锌作用效果最差; 该组肌肉硬度、粘性、弹性、内聚性、胶着性、咀嚼性、回复性显著增加($P<0.05$); 背肌的肌纤维更细, 排列更为紧密; 肌肉 Zn 沉积率和胶原蛋白显著升高($P<0.05$); 血浆和肠道 CuZn-SOD、T-SOD、T-AOC 显著提高($P<0.05$), MDA 显著降低($P<0.05$); 肠道 *cuzn-sod*、*nrf2*、*gpx1* 和 *keap1b* mRNA 表达量显著上调($P<0.05$); 肠道肌层厚度、绒毛数量、分支绒毛数量均显著提高($P<0.05$); 血浆 LPS、D-LA 含量显著降低($P<0.05$); 肠道胰蛋白酶、脂肪酶、淀粉酶、Na⁺-K⁺-ATP 酶均显著升高($P<0.05$); IgM 含量显著升高, *il-1β*、*tnf-α* 表达量均显著下调($P<0.05$); *tgf-β1a* 表达量显著上调 ($P>0.05$)。综上, 蛋氨酸锌(2:1) 具有促进鳊生长性能和微量元素沉积, 提高消化吸收、抗氧化和免疫能力, 改善肌肉品质的作用。

关键词: 鳊; 蛋氨酸锌; 抗氧化; 免疫; 肌肉品质

资助项目: 重庆市水产科技联盟

通信作者: 刘海平, luihappy@163.com; 罗莉, E-mail: luoli1972@163.com

Effects of different zinc sources on growth, muscle quality, antioxidant and immune capacity of Mandarin fish (*Siniperca chuatsi*)

Xiaolu Yan¹, Wenjie Wang¹, Yushang Chen¹, Da Zhou¹, Dianchao Gu², Fubao Wang³, Xuliang Zhai⁴, Yang Xue⁴, Yongjun Chen¹, Li Luo^{1*}

(1. Key Laboratory of Freshwater Fish Resources and Reproductive Development of Ministry of Education, College of Fisheries, Southwest University, Chongqing China 400716; 2. Hunan Depon Biotechnology Co., Ltd, Changning China 421500; 3. Foshan Nanhai Jieda Feed Co., Ltd, Foshan China 528211; 4. Chongqing Fisheries Technology Extension Station, Chongqing China 400400)

Abstract: To investigate the effects of various zinc sources in feed on the growth performance, muscle quality, antioxidant capacity, and immune function of *Siniperca chuatsi*, the basic feed for *Siniperca chuatsi* served as the control group (CON). The experimental groups included 40 mg/kg zinc sulfate (ZnSO₄), zinc chelated with rice protein amino acid, zinc chelated with soy protein amino acid, zinc methionine (1:1) and zinc methionine (2:1). A total of 270 mandarin fish, with an initial weight of (67.46±2.02) g, were selected and randomly divided into six groups. Each group consisted of three replicates, with each replicate containing 15 fish. A growth test was conducted over a period of 49 days. The results showed that compared with the control group, all five zinc sources promoted the growth and feed conversion of *Siniperca chuatsi*, among which zinc methionine (2:1) had the most significant effect ($P<0.05$), followed by zinc methionine (1:1), soy protein Amino acid chelated zinc, rice protein amino acid chelated zinc, and zinc sulfate have the worst effect; the muscle hardness, viscosity, elasticity, cohesiveness, gumminess, chewiness, and resilience of this group all were significantly increased ($P<0.05$); the muscle fibers of the back muscles are thinner and more closely arranged; the Zn deposition rate and collagen of muscle are significantly increased ($P<0.05$); CuZn-superoxide dismutase (CuZn-SOD), total superoxide dismutase (T-SOD), and total antioxidant capacity (T-AOC) in plasma and intestine are also significantly increased ($P<0.05$), while malondialdehyde (MDA) levels are significantly decreased ($P<0.05$); the mRNA expression levels of intestinal *cuzn-sod*, *nrf2*, *gpx1* and *keap1b* are significantly increased ($P<0.05$); the thickness of the intestinal muscle layer, the number of villi, and the number of branched villi were all significantly increased ($P<0.05$); the levels of LPS and D-LA in plasma were significantly decreased ($P<0.05$); the levels of intestinal trypsin, lipase, amylase, and Na⁺-K⁺-ATPase were significantly elevated ($P<0.05$); IgM content increased significantly, and the expression levels of *il-1β* and *tnf-α* were significantly down-regulated ($P<0.05$); the mRNA expression level of *tgf-β1a* was significantly up-regulated ($P<0.05$). In summary, zinc methionine (2:1) can promote the growth performance and trace element deposition of mandarin fish, improve digestion and absorption, antioxidant and immune capabilities, and improve muscle quality. In conclusion, zinc methionine (2:1) has the positive effects of promoting the growth performance and deposition of trace elements, improving digestion and absorption, antioxidant and immune ability, and improving muscle quality in *Siniperca chuatsi*.

Keywords: *Siniperca chuatsi*; Zinc methionine; Antioxidant; Immunity; Muscle quality

从抑制到激活:胍基乙酸对草鱼成肌细胞增殖和分化的双重作用

许芝耀¹, 姜维丹^{1,2,3}, 吴培^{1,2,3}, 刘杨^{1,2,3}, 任红梅^{1,2,3}, 金小璇^{1,2,3}, 冯琳^{1,2,3*}, 周小秋^{1,2,3*}

1. 四川农业大学动物营养研究所, 成都, 611130; 2. 鱼类营养与安全生产重点实验室, 成都, 611130; 3. 动物抗病营养农业部、教育部、四川省重点实验室, 成都, 611130

摘要:【目的】本研究以草鱼成肌细胞为研究模型, 探讨胍基乙酸(GAA)对草鱼成肌细胞增殖分化的影响机制。【方法】本实验选用0、5、10和20mMGAA分别去探究其对成肌细胞活力, 迁移, 增殖和分化的影响。【结果】首先, 试验首次发现草鱼成肌细胞能够进行GAA的合成和代谢。其次, 通过CCK8和EDU⁺实验发现随着GAA浓度升高, 细胞增殖率降低($P < 0.05$)。进一步研究发现: 与对照组相比, GAA显著抑制了Wnt3a和PGSK-3 β 的蛋白水平, 降低了PGSK-3 β 的免疫荧光强度($P < 0.05$)。同时, 通过荧光共定位发现, GAA显著抑制 β -连环蛋白从细胞质向细胞核的迁移($P < 0.05$)。在草鱼成肌细胞分化期, 相较于对照组, GAA显著提高了肌管的长度和直径, 同时提高了草鱼肌管的融合效率($P < 0.05$); 显著提高诱导分化7d时MyoD1和MYHC的蛋白水平($P < 0.05$); 并显著提高了成肌细胞分化为肌管时Wnt3a和PGSK-3 β 的蛋白水平、 β -catenin的入核率以及 β -catenin与MyoD1的蛋白互作($P < 0.05$)。【结论】综上所述, GAA在草鱼成肌细胞增殖过程中抑制Wnt/ β -catenin信号通路, 而在草鱼成肌细胞分化过程中激活Wnt/ β -catenin信号通路。本实验揭示了GAA在草鱼成肌细胞不同生长阶段具有不同的作用, 为GAA在畜牧业提供更多理论依据。

关键词: 胍基乙酸, 草鱼成肌细胞, β -连环蛋白, MyoD1

通讯作者: 周小秋, 教授, 博士生导师; 冯琳, 教授, 博士生导师; E-mail:

zhouxq@sicau.edu.cn (周小秋); fenglin@sicau.edu.cn (冯琳)

基金项目: 国家现代农业产业技术体系(CARS-45); 国家自然科学基金(U23A20250)。

大口黑鲈高度不饱和脂肪酸合成特性及关键基因功能表征⁶

孙守向¹, 孙丽慧¹, 李倩¹, 陈建明^{1*}, 郭建林^{1*}

(浙江省淡水水产研究所健康淡水养殖农业与农村重点实验室, 浙江湖州, 313000)

摘要: 【目的】饲料中鱼油水平的下降导致大口黑鲈鱼体高度不饱和脂肪酸 (HUFA) 水平低下, 显著降低其营养品质, 提高内源性 LC-PUFA 合成被认为是解决该问题的有效途径, 本研究旨在探明大口黑鲈 HUFA 合成特性, 为其营养调控策略开发提供基础研究。【方法】本研究通过给予 HUFA (HD) 或不含 HUFA (NHD) 的饲料来验证大口黑鲈的内源性 HUFA 合成能力, 通过生物信息学挖掘大口黑鲈内源性 HUFA 合成的相关基因及进化分化机制, 借助体外原代细胞基因敲降及酵母异源表达实验揭示 HUFA 合成相关基因的功能特性。【结果】结果显示, 大口黑鲈能够利用 C18 多不饱和脂肪酸 (PUFA) 作为前体物质内源地合成 HUFA, 尽管 NHD 饲料影响了其生长性能和肝脏健康。同时鉴定了大口黑鲈的 HUFA 生物合成相关基因, 包括两种脂肪酸脱饱和酶 (*fads2a* 和 *fads2b*) 和三种脂肪酸延长酶 (*elov15*、*elov14a* 和 *elov14l*)。生物信息学分析证实了大口黑鲈 HUFA 合成相关基因的进化保守性, 并揭示了 *fads2s* 基因独特的进化分化机制。功能验证实验证实了 *Fads2a* 具有 $\Delta 4, \Delta 5, \Delta 8$ 去饱和酶活性, 而 *Fads2b* 则具有 $\Delta 5, \Delta 6, \Delta 8$ 去饱和酶活性。*Elov15* 主要参与 C18 和 C20 PUFA 的延长过程, 而 *Elov14a* 和 *Elov14l* 则涉及 C18, C22 及更长链 PUFA (>C24) 的延长。【结论】总体而言, 本研究表征了大口黑鲈的 HUFA 合成关键基因及功能特征, 构建了大口黑鲈完整的 HUFA 合成通路, 从而加深了对淡水肉食性鱼类中 HUFA 合成特性及其进化机制的理解。

关键词: 大口黑鲈; 高度不饱和脂肪酸; 脂肪酸去饱和酶; 脂肪酸延长酶; 功能特性

资助项目: 中国博士后科学基金面上项目 (项目编号 2024M752872)、浙江省“尖兵”“领雁”科技计划项目 (2024C02012)

通讯作者, 郭建林, E-mail: wavej1@aliyun.com; 陈建明, E-mail: aqua_labjm@163.com

Characterisation of Endogenous Highly Unsaturated Fatty Acids Synthesis and Key Enzyme Functions in Largemouth Bass (*Micropterus salmoides*)

Shouxiang Sun¹, Lihui Sun¹, Qian Li¹, Jianming Chen^{1,*}, Jianlin Guo^{1,*}

(1. Agriculture and Rural Affairs Key Laboratory of Healthy Freshwater Aquaculture, Zhejiang Institute of Freshwater Fisheries, Huzhou, Zhejiang, China)

Abstract: [Objective] The decrease in fish oil levels in feed leads to low levels of highly unsaturated fatty acids (HUFA) in largemouth bass, significantly reducing their nutritional quality. Enhancing endogenous HUFA synthesis is considered an effective solution to this problem. This study aims to elucidate the characteristics of HUFA synthesis in largemouth bass, providing foundational research for the development of nutritional regulation strategies. [Methods] This study validated the endogenous HUFA synthesis capability of largemouth bass by administering diets either enriched with HUFA (High HUFA Diet, HD) or devoid of HUFA (Non-HUFA Diet, NHD). Bioinformatics was utilized to identify genes related to endogenous HUFA synthesis and to explore their evolutionary divergence mechanisms in largemouth bass. The functional characteristics of HUFA synthesis-related genes were revealed through gene knockdown experiments in vitro using primary cells and heterologous expression assays in yeast. [Results] The results showed that largemouth bass could endogenously synthesis HUFA using C18 polyunsaturated fatty acids (PUFA) as the precursors, although NHD feeding impaired their growth performance and liver health. Furthermore, we characterised the genes potentially involved in HUFA biosynthesis, including two fatty acid desaturases (*fads2a* and *fads2b*) and three fatty acid elongases (*elovl5*, *elovl4a* and *elovl4l*). Bioinformatics analysis confirmed the evolutionary conservation of these genes and revealed the unique evolutionary divergence mechanism of the *fads2s* in largemouth bass. The HUFA biosynthesis-related genes knockdown in primary hepatocyte and yeast heterologous expression confirmed that *Fads2a* has $\Delta 4$, $\Delta 5$, $\Delta 8$ desaturase activities and *Fads2b* $\Delta 5$, $\Delta 6$, $\Delta 8$ desaturase activities. And *Elov15* primarily participated in the elongation of C18 and C20 PUFA, whereas *Elov14a* and *Elov14l* were involved in the elongation of C18, C22 and longer-chain PUFA (> C24). [Conclusion] Overall, we constructed a complete HUFA synthesis pathway in the largemouth bass, thereby enhancing the understanding of the characteristics and evolutionary mechanisms of HUFA synthesis in freshwater carnivorous fish.

Key words: largemouth bass (*Micropterus salmoides*), highly unsaturated fatty acids, fatty acid desaturases, fatty acid elongases, functional characterisation.

大菱鲆幼鱼早期生长阶段的禁食会导致长期的生长抑制及体成分变化

熊海燕^{1,2}, 王迪欣², 范昱含², 张彦娇^{1*}, 马强², 卫育良², 梁萌青², 徐后国^{1,2*}

(1.中国海洋大学水产学院, 山东 青岛 266003; 2.中国水产科学研究院黄海水产研究所, 山东 青岛 266071)

摘要:【目的】在水产养殖活动中, 通过一段时间的禁食再饲喂刺激养殖对象补偿生长的发生已被用作一种经济的生长和体成分控制手段。本实验探讨了不同的“禁食-复喂”模式对大菱鲆幼鱼生长发育的影响。【方法】选取 300 尾初重为 5.54 g 的大菱鲆幼鱼随机分为 5 组, 每个处理组设 3 个重复, 分别以 5 种不同的投喂模式饲养 72 天: 对照组 (CON) 正常饲喂, 不禁食; 其余 4 组分别禁食 3 天、6 天、9 天和 12 天, (在同一天结束禁食) 随后进行 60 天的复喂。在 60 天复喂结束时采集样本评价生长、代谢和体成分并对肝脏进行转录组学分析。

【结果】与对照组相比, 早期禁食 3-12 天导致大菱鲆出现了生长迟缓。这种生长抑制与早期禁食时间密切相关。禁食 12 天组鱼体增重率 (576%) 显著低于对照组 (709%)。早期禁食刺激了复喂后鱼体各组织的脂质积累及肌肉的糖原积累, 但降低了肌肉蛋白质和氨基酸含量。不同饲喂模式对鱼体组织中脂肪酸组成的影响很小。转录组分析证实, 大菱鲆在经历了早期 12 天禁食后尽管接受了 60 天的复喂, 鱼体的肽和蛋白质的生物合成仍然受到了抑制。

【结论】综上所述, 在目前的实验条件下, 并未观察到禁食引起的补偿生长, 而在早期生长阶段禁食会导致大菱鲆幼鱼长期的生长抑制和体成分变化。

关键词: 饥饿; 投喂策略; 营养调控; 能量代谢; 脂质

Early-stage fasting leads to long-term growth inhibition and body composition changes in juvenile turbot *Scophthalmus maximus*

Haiyan Xiong ^{1,2}, Dixin Wang ², Yuhan Fan ², Yanjiao Zhang ^{1*}, Qiang Ma ², Yuliang Wei ², Mengqing Liang ², Houguo Xu ^{1,2*}

(1. Fisheries College, Ocean University of China, Qingdao 266003, China; 2. Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Qingdao 266071, China.)

Abstract: [Objective] Stimulation of compensatory growth by refeeding upon a period of fasting has been used as an economical means of growth and body composition manipulation in aquaculture practices. The present study aimed to evaluate the efficacy of different “fasting-refeeding” patterns in an important aquaculture species, turbot *Scophthalmus maximus*, targeting at an early juvenile stage. [Methods] 300 juvenile turbot (initial weight 5.54 g), were firstly fasted for 3, 6, 9, and 12 days, respectively, before refeed for 60 days. A group with continuous feeding was used as the control group. Each feeding strategy was applied to triplicate tanks (57.0 × 39.0 × 35.0 cm), and each tank was stocked with 20 fish. Sampling and evaluation of growth, metabolism and body composition, as well as transcriptomic analysis of the liver, were conducted at the end of the 60-day refeeding. [Results] Early fasting for 3-12 days resulted in final growth retardation compared to the control group. This growth inhibition was closely correlated to the fasting duration in early stage. The 12-day-fasting group showed significantly lower average weight gain (576%) compared to the control group (709%). The fasting in early days stimulated the lipid accumulation in various tissues and the glycogen accumulation in the muscle of fish after refeeding, but reduced the muscle protein and amino acid contents. The feeding strategy exerted only minor effects on the fatty acid compositions in final fish tissues. The transcriptome analysis confirmed that fasting for 12 days in the early stage still inhibited the peptide and protein biosynthesis even after 60 days of refeeding. [Conclusion] In conclusion, compensatory growth through fasting was not observed under the current experimental conditions. Early fasting leads to long-term growth inhibition and changes of body composition in juvenile turbot.

Key words: Starvation; Feeding regime; Nutritional regulation; Energy mobilization; Lipid

资助项目：山东省泰山学者计划

通讯作者：张彦娇, yanjiaozhang@ouc.edu.cn; 徐后国, E-Mail: xuhg@ysfri.ac.cn

低鱼粉日粮中策略性的添加三种诱食剂来提高大口黑鲈的生长性能、健康状况和肉品质⁷

乐玉华^{1,2}, 胡毅^{2*}, 余莹英^{1*}

(1. 佛山大学, 广东 佛山 528225; 2. 湖南农业大学, 湖南 长沙 410128)

摘要: 为探索柠檬烯、大蒜素和甜菜碱在低鱼粉日粮中对大口黑鲈的诱食作用, 本研究采用饵料球诱食法确定了上述三种诱食剂的最佳诱食浓度, 并分别将其补充至低鱼粉饲料, 通过4周饲养试验, 研究发现柠檬烯、大蒜素和甜菜碱对大口黑鲈具有一定的诱食效果, 其中浓度为0.2%时效果最佳($P<0.05$)。0.2%柠檬烯、大蒜素和甜菜碱可显著提高大口黑鲈末均重、增重率、特定生长率, 降低饲料系数($P<0.05$), 并且促进促食基因表达, 抑制抑食基因表达; 此外, 三种诱食剂均可提高其肠道消化酶活性, 改善其肠道形态, 同时可以提高肝脏抗氧化酶活性, 降低肝细胞空泡化程度; 在肉品质方面, 0.2%柠檬烯、大蒜素和甜菜碱可显著降低大口黑鲈肌肉组加压损失、冷冻损失、冷藏损失($P<0.05$), 并且在不同程度上提高其硬度、弹性、凝聚性、胶着性和回复性及坚实度。同时, 肌肉组织学显示, 诱食剂组肌纤维间缝隙减小, 排列较紧密, 此外, 0.2%柠檬烯和0.2%大蒜素可分别显著提高肌肉 *MyoG*、*Mfy6*、*IGF-1* 和 *IGF-2* 表达水平($P<0.05$)。综上所述, 0.2%柠檬烯、大蒜素和甜菜碱对大口黑鲈具有显著的诱食作用, 可改善其生长性能, 提高消化酶活力和肝脏抗氧化酶活性, 改善肝肠健康, 同时可以通过增强肌肉系水力, 改善肌肉质构特性, 提高肌肉生成相关基因表达量, 改善肌纤维形态改善肉品质。

关键词: 柠檬烯; 大蒜素; 甜菜碱; 生理健康; 肉品质

资助项目: 广东省动物分子设计与精准育种重点实验室(2019年度)(2019B030301010)、广东普通高等院校动物分子设计与精准育种重点实验室项目(2019A1515110068)、广东省重点领域研发项目“中药废弃物资源化利用关键技术研究及示范”(2019B110209005)、国家自然科学基金青年项目(32202911)
通讯作者: 余莹英, E-Mail: Yingying.Yuyuyy999@yeah.net; 胡毅, E-Mail: huyi740322@163.com

Strategically using three feed attractants to improve the growth performance, health status and meat quality of largemouth bass (*Micropterus salmoides*) under a low-fishmeal diet

Yuhua Yue^{1,2}, Yingying Yu^{1*}, Yi Hu^{2*}

(1. Foshan University, Foshan China 528225; 2. Hunan Agricultural University, Changsha China 410128)

Abstract: To explore the attraction effect of limonene, allicin and betaine on largemouth bass in a low fishmeal diet, the best concentration of the above feed attractants was selected by the biting-balls test and supplemented into the low fishmeal diet. Through a four-week feeding trial, it was found that the limonene, allicin and betaine had an evident attractive effect at a concentration of 0.2% on largemouth bass ($P<0.05$). And 0.2% limonene, allicin, and betaine could significantly increase the final average weight, weight gain rate, specific growth rate of largemouth bass and reduce the feed conversion ratio ($P<0.05$), and promote the expression of orexigenic genes and inhibit the expression of anorectic genes. In addition, the three attractants could all increase the activity of intestinal digestive enzymes and improve intestinal morphology. At the same time, they could increase the activities of liver antioxidant enzymes and reducing the degree of hepatocyte vacuolization. In terms of meat quality, 0.2% limonene, allicin, and betaine could significantly reduce the compression loss, freezing loss, and refrigeration loss of largemouth bass muscle tissue ($P<0.05$), and improve hardness, elasticity, cohesiveness, adhesiveness, resilience and firmness to varying degrees. At the same time, muscle histology showed that the gaps between muscle fibers in the attractant groups were reduced and the arrangements were relatively close. In addition, 0.2% limonene and allicin can significantly increase the expression levels of muscle *MyoG*, *Mfy6*, *IGF-1* and *IGF-2* respectively ($P<0.05$). In conclusion, 0.2% limonene, allicin, and betaine have significant attractant effects on largemouth bass. They can improve growth performance, increase digestive enzyme activity and liver antioxidant enzyme activity, and improve liver and intestinal health. At the same time, 0.2% limonene, allicin, and betaine could improve meat quality by enhancing muscle water-holding capacity, improving muscle texture characteristics, increasing the expression of muscle myogenesis related genes, and improve fiber morphology.

Key words: Limonene; Allicin; Betaine; Physiological health; Meat quality

短期低剂量黄曲霉毒素 B1 对草鱼的 Hormesis 效应及毒性损伤评价

李金龙¹, 郭家荣¹, 王佩⁴, 张俊智³, 何志刚¹, 王金龙^{2*}, 胡毅^{3*}

1. 湖南省水产科学研究所, 湖南长沙 410022;
2. 湖南文理学院, 环洞庭湖水产健康养殖及加工湖南省重点实验室, 湖南常德 415000;
3. 湖南农业大学, 水产学院, 湖南长沙 410125;
4. 吉首大学, 生物资源与环境科学学院, 湖南张家界, 416000.

摘要: 本研究旨在评估短期低剂量黄曲霉毒素 B1 对草鱼(*Ctenopharyngodon idellus*)的兴奋作用和毒性损伤。制备 3 种等氮等能黄曲霉毒素 B1 试验饲料: CD(对照, 0 ug/kg)、D1(20 ug/kg)和 D2(500 ug/kg), 并投喂初始平均体重为(15.2±0.1)g 的草鱼幼鱼 56 天。结果表明, 与投喂 CD 组饲料相比, 投喂 D2 组饲料的草鱼增重率和特定生长率显著提高, 饲料系数显著降低, 且体脂含量明显减少(P<0.05)。草鱼血清超氧化物歧化酶含量随着黄曲霉毒素 B1 剂量的增加而显著增加(P<0.05), 但当剂量达到 500ug/kg(D2)时, 草鱼血清超氧化物歧化酶、补体 C3 和免疫球蛋白 M 显著降低(P<0.05), 而丙二醛显著增加(P<0.05)。短期投喂含黄曲霉毒素 B1 的饲料 (D1 和 D2) 后, 草鱼的肝体指数、内脏体指数、血清总胆固醇、甘油三酯和尿素氮含量显著增加(P<0.05), 总胆汁酸分泌显著减少(P<0.05)。肝脏出现空泡增加、组织结构疏松和核转位等结构损伤; 同时, 血清丙氨酸氨基转移酶、天冬氨酸氨基转移酶和碱性磷酸酶等肝功能指标随着黄曲霉毒素 B1 剂量的增加而显著升高(P<0.05)。此外, D2 组草鱼肠道绒毛高度、隐窝深度、绒毛隐窝比和管细胞数以及胰蛋白酶和脂肪酶活性含量均显著高于 CD 组(P<0.05)。综上所述, 短期摄入低剂量黄曲霉毒素 B1(≤500 ug/kg), 草鱼的生长性能和肠道结构和功能产生了一定程度的刺激性增加作用, 但其毒性作用明显, 在 20ug/kg 的剂量下, 草鱼的非特异性免疫系统和肝脏结构和功能显示出明显的毒性损伤。

关键词: 黄曲霉毒素 B1; 草鱼; 生长性能; 非特异性免疫; 组织结构

资助项目: 国家重点研发计划项目(2023YFD2401605); 湖南省重点研发计划(2020NK2016)

*通讯作者, 胡毅, 教授, 主要从事水产动物营养与饲料 E-mail: huyi740322@163.com

Assessment of the hormesis effect and toxic damage of short-term low-dose aflatoxin B1 in Grass Carp (*Ctenopharyngodon idellus*)

Jin-long Li¹, Jia-rong Guo¹, Pei Wang⁴, Jun-zhi Zhang³, Zhi-gang He¹, Jin-long Wang^{2*} and Yi Hu^{3*}

1. Hunan Fisheries Science Institute, Changsha 410022, Hunan, China;

2. Key Laboratory of Health Aquaculture and Product Processing in Dongting Lake Area of Hunan Province, Hunan University of Arts and Science, Changde 415000, Hunan, China;

3. Fisheries College, Hunan Agricultural University, Changsha 410125, Hunan, China;

4. Jishou University, Zhangjiajie 416000, Hunan, China.

Abstract: The present study was conducted to evaluate the hormesis and toxicity of short-term low-dose aflatoxin B1 in grass carp (*Ctenopharyngodon idellus*). Triplicate isonitrogenous and isocaloric aflatoxin B1 diets: CD (control, 0 ug/kg), D1 (20 ug/kg), and D2 (500 ug/kg) were prepared and fed to grass carp with an initial mean body weight of (15.2±0.1) g for 56 days. The results showed that the weight gain rate and specific growth rate of grass carp fed diet D2 were significantly higher, and the feed coefficient and crude fat content of the whole body were significantly lower ($P<0.05$) compared with those fed diet CD. Serum superoxide dismutase content of grass carp fed D1 diet increased significantly ($P<0.05$) with increasing dose of aflatoxin B1, but when the dose reached 500 ug/kg (D2), serum superoxide dismutase, complement C3 and immunoglobulin M of grass carp decreased significantly ($P<0.05$) while malondialdehyde increased significantly ($P<0.05$). After short-term feeding of aflatoxin B1-containing diets (D1 and D2), liver body index, visceral body index, serum total cholesterol, triglyceride and urea nitrogen content of grass carp increased significantly ($P<0.05$), total bile acid secretion decreased significantly ($P<0.05$), and structural damages such as increase in vacuoles, organizational structure loose and nucleus translocation were observed in the liver. Meanwhile, liver function indexes such as serum alanine aminotransferase, aspartate aminotransferase, and alkaline phosphatase increased significantly with the increase of aflatoxin B1 dose ($P<0.05$). In addition, the height of intestinal villi, crypt depth, villus-crypt ratio and tubular cell number, as well as the content of trypsin and lipase activities in the intestine of grass carp in the D2 group were significantly higher than those in the CD group ($P<0.05$). In conclusion, after short-term intake of low doses of aflatoxin B1 (≤ 500 ug/kg), the toxicological damage of aflatoxin B1 was pronounced, although it produced a certain degree of hormesis on the growth performance and intestinal structure and function of grass carp. At a dose of 20 ug/kg, the non-specific immune system and liver structure and function of grass carp showed obvious toxic damage. **Keywords:** Aflatoxin B1; *Ctenopharyngodon idellus*; Growth Performance; Nonspecific Immunity; Organizational structure.

资助项目：国家重点研发计划项目(2023YFD2401605)；湖南省重点研发计划(2020NK2016)

*通讯作者，胡毅，教授，主要从事水产动物营养与饲料 E-mail: huyi740322@163.com

高 SFA/MUFA 比饲料优化鱼油漂洗策略：提升黄河鲤肌肉脂 肪酸营养和质构品质

桑宇航¹, 李新禄¹, 秦超彬², 聂国兴², 徐超¹, 李远友*¹, 谢帝芝*¹

¹华南农业大学海洋学院, 广东 广州 510642;

²河南师范大学水产学院, 河南 新乡 453007

摘要: 鱼油漂洗是一种可有效提升养殖鱼产品 n-3 高不饱和脂肪酸 (LC-PUFA) 含量的投喂策略, 饲料饱和 (SFA) 与单不饱和脂肪酸 (MUFA) 在节约 n-3 LC-PUFA 方面也具有重要作用。为进一步优化鱼油漂洗策略, 本研究在添加 1% 鱼油饲料基础上, 以豆油、菜籽油、棕榈酸单甘脂为脂肪源配成 SFA/MUFA 比分别为 0.6、1.2、1.8 和 2.4 四种等氮 (35%) 等脂 (8%) 饲料 (D1-D4), 于池塘网箱中养殖大规格黄河鲤 (初始体重 \sim 320 g, 前期投喂豆油饲料) 4 周。结果表明, 各饲料组鱼生长性能 (增重率、特定增长率、饲料系数和成活率)、形态指标 (肥满度、肝体比、脏体比和腹脂率等), 以及血清总脂、高密度脂蛋白 (HDL) 和低密度脂蛋白 (LDL) 水平都无显著差异 ($P > 0.05$); 但相比于 D1 和 D2 组, D3 和 D4 组血清总胆固醇水平和 HDL/LDL 显著提升 ($P < 0.05$), 以及肌肉脂肪分解 (*hsl*, *atgl*, *cpt-1*) 与合成 (*ppar γ* , *srebp1*, *fas*) 代谢相关基因表达水平均显著降低 ($P < 0.05$)。在肌肉品质方面, 相比于初始鱼 (n-3 LC-PUFA 和 n-6/n-3 比分别为 1.18 mg/g 和 6.2), 鱼油漂洗组肌肉 n-3 LC-PUFA 含量提升 1.78 \sim 2.24 倍, n-6/n-3 比降低 50.16% \sim 77.14%, 以及硬度、咀嚼性、胶着性和粘黏性等质构指标均得到显著改善 ($P < 0.05$); 此外, 在各鱼油漂洗组中, D3 组 (SFA/MUFA 比为 1.8) 鱼肌肉脂肪酸营养和质构品质进一步提升 ($P < 0.05$)。本研究结果为优化鱼油漂洗策略, 降低水产养殖业对鱼油的依赖提供新见解。

关键词: 鱼油漂洗策略; 饲料 SFA/MUFA 比; 脂肪酸营养; 质构特性; 黄河鲤

Optimizing fish oil-washing strategy with high dietary SFA/MUFA ratio: Enhancing the muscle fatty acid nutrition and textural quality of Yellow River carp

Yuhang Sang¹, Xinlu Li¹, Chaobin Qin², Guoxing Nie², Chao Xu¹,
Yuanyou Li^{*1}, Dizhi Xie^{*1}

¹ College of Marine Sciences, South China Agricultural University, Guangzhou Guangdong 510642;

² College of Fisheries, Henan Normal University, Xinxiang Henan, 453007

Abstract: Fish oil-washing out is an effective feeding strategy for enhancing the content of n-3 polyunsaturated fatty acids (LC-PUFAs) in farmed fish products. Dietary saturated (SFA) and monounsaturated fatty acids (MUFA) also play a crucial role in the “n-3 LC-PUFA sparing”. To further optimize the fish oil-washing out strategy, this study prepared four isonitrogenous (35%) and isolipid (8%) diets containing 1% fish oil with different SFA/MUFA ratios (D1-D4) by using soybean oil, rapeseed oil, and palmitic acid monoglyceride as lipid sources. Using the above four diets fed large-sized yellow river carp (initial weight ~320 g, early feeding soybean oil diets) in pond cages for 4 weeks. The results showed that there were no significant differences in fish growth performance (growth rate, specific growth rate, feed coefficient, and survival rate), morphological indicators (condition factor, hepatosomatic and viscerosomatic index, and abdominal fat ratio), and serum total lipid, high-density lipoprotein (HDL), and low-density lipoprotein (LDL) levels among the four groups ($P > 0.05$). However, comparing to the D1 and D2 groups, the serum total cholesterol level and HDL/LDL ratio were significantly improved in D3 and D4 groups ($P < 0.05$), as well as the expression levels of genes related to muscle lipid catabolism (*hsl*, *atgl*, *cpt-1*) and anabolism (*ppary*, *srebp1*, *fas*) were significantly lower ($P < 0.05$). In terms of muscle quality, the muscular n-3 LC-PUFA contents and n-6/n-3 ratio of fish fed fish oil-washed out diets showed a 1.78-2.24-fold increase and a decrease of 50.16%-77.14%, respectively, compared to the initial fish (1.18 mg/g n-3 LC-PUFA, n-6/n-3 ratio of 6.2). Additionally, the texture parameters (hardness, adhesiveness, and chewiness) were significantly improved in these fish ($P < 0.05$). Furthermore, in the fish oil-washing out groups, the D3 group (SFA/MUFA ratio of 1.8) showed further improvements in the nutritional and textural quality of fish muscle fatty acids ($P < 0.05$). The results provided new insights into optimizing the strategies of fish oil-washing out and reducing the dependence of aquaculture on fish oil sources.

Key words : Fish oil-washing out strategy; Dietary SFA/MUFA ratio; Fatty acid nutrition; Texture quality; Yellow River Carp

通讯作者: 李远友, 教授, E-Mail: yyli16@scau.edu.cn; 谢帝芝, 副研究员, E-Mail: xiedizhi@scau.edu.cn

基金项目: 国家自然科学基金区域创新发展联合基金 (U22A20532)

谷氨酸通过 PPAT 介导的从头合成途径和 ATP 介导的转化途径调节湘云鲫肌肉 IMP 合成的机制研究⁸

左安丽^{1,2}, 郑倩婷¹, 赵大芳¹, 赵峻驰¹, 瞿符发¹, 何志敏¹, 金俊琰², 曹申平^{1*}, 刘臻^{1*}

(1. 湖南省水生动物营养与质量控制重点实验室, 长沙学院生物与化学工程学院, 湖南 长沙 410022; 2. 中国科学院水生生物研究所淡水生态与生物技术国家重点实验室, 湖北 武汉 430072)

摘要: 肌苷酸 (IMP) 在促进鱼肌的鲜味特性形成中起着至关重要的作用。本研究探索了谷氨酸 (Glu) 对湘云鲫 (TCC) 肌肉中 IMP 形成的调控作用及其分子机制。通过在 TCC 饲料和 TCC 肌细胞中补充谷氨酸, 我们观察到体内和体外实验 IMP 含量和磷酸核糖焦磷酸酰胺转移酶 (*ppat*) 的 mRNA 表达均显著升高。通过对 TCC 肌细胞的转录组分析, 发现 Glu 可以激活 IMP 的生物合成途径。随后, 我们从 TCC 中成功克隆了 *ppat* cDNA。序列分析结果显示, TCC 中的 *ppat* mRNA 序列为 1521 bp, 编码 506 个氨基酸。分子对接分析表明, TCC 中谷氨酰胺 (Gln) 与 PPAT 蛋白之间可能存在相互作用。此外, 湘云鲫 PPAT 被干扰后, Glu 促进 IMP 合成的能力受到抑制, 且 Glu 无法激活参与 IMP 从头合成途径相关基因 (*adsl*, *paics*, *atic*) 的表达。此外, 我们发现 Glu 通过转化为 α -酮戊二酸 (α -KG) 促进 ATP 的产生, 进而在 TCC 肌细胞中不依赖激活 *ppat* 促进 IMP 的形成。综上所述, 本研究发现, 添加谷氨酸可以增强 TCC 肌肉和肌肉细胞中 IMP 的形成, 这一过程归因于 PPAT 介导的 IMP 从头合成途径的激活和线粒体衍生的 ATP 的产生。这些发现为氨基酸饲料添加剂在水产养殖中的应用提供了重要意义。

关键词: 谷氨酸; 肌苷酸; ATP; *ppat*; 湘云鲫; IMP 合成途径

资助项目: 国家自然科学基金项目 (32102813, U19A2041)

通讯作者: 曹申平, 刘臻 E-Mail: spcao@ccsu.edu.cn, z20040625@ccsu.edu.cn

Glutamate regulates the PPAT-mediated de novo synthesis and ATP-mediated transformation pathways to boost IMP production in Triploid Crucian Carp

Anli Zuo^{1,2}, Qianting Zheng¹, Dafang Zhao¹, Junchi Zhao¹, Fufa Qu¹, Zhiming He¹, Junyan Jin²,
Shenping Cao^{1*}, Zhen Liu^{1*}

(1 Hunan Provincial Key Laboratory of Nutrition and Quality Control of Aquatic Animals, Department of Biological and Chemical Engineering, Changsha University, Changsha China 410022; 2 State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan China 430072)

Abstract: Inosine monophosphate (IMP) plays a crucial role in promoting umami characteristic of fish muscle. Here, we investigated the contributions of Glu to the formation of IMP in Triploid Crucian Carp (TCC) and the underlying molecular mechanisms. Through supplementary Glu in diets and muscle cells of TCC, we initially observed a significant elevation of IMP content and the mRNA expression of phosphoribosyl pyrophosphate amido transferase (*ppat*) both in *vivo* and in *vitro*. By transcriptome analysis of the TCC muscle cells, Glu was found to activate the IMP biosynthetic pathways. Subsequently, we successfully cloned the *ppat* cDNA from TCC. Sequence analysis revealed that the *ppat* mRNA sequence in TCC was 1521 bp, encoding 506 amino acids. Molecular docking analysis suggested a potential for interaction between glutamine (Gln) and PPAT protein in TCC. Furthermore, the PPAT interference experiment indicated that the capacity of Glu to enhance IMP formation was compromised, and Glu was unable to activate the gene expression involved in the IMP de novo synthesis pathway (*adsl*, *paics*, *atic*) in PPAT knockdown cells. In addition, we found that Glu facilitates increased ATP production through its conversion into α -Ketoglutaric acid (α -KG), subsequently promoting the formation of IMP independently of *ppat* activation in TCC muscle cells. In summary, the study indicated that Glu supplementation enhances IMP formation in TCC muscle and muscle cells, which can be attributed to activation of the PPAT-mediated IMP de novo synthesis pathway and mitochondria-derived ATP production. These findings provide significant implications for the application of amino acid feed additives in aquaculture.

Key words: Glu; IMP; ATP; *ppat*; Triploid Crucian Carp; IMP synthesis pathway

横沙新洲河道优势种鱼类的脂肪酸组成及营养品质评价

谢稷霖^{9,2}, 俞文杰^{1,2}, 宋超^{1,2}, 赵峰¹, 庄平¹

(1.中国水产科学研究院 东海水产研究所, 上海 200090; 2.上海理工大学 环境与建筑学院, 上海 200093)

摘要: 【目的】横沙新洲为上海新生的现代农业产业园区, 其河道中渔业资源丰富, 主要的优势种鱼类有鲃(*Liza haematocheila*)、鲢(*Mugil cephalus*)和黄颡鱼(*Pseudobagrus fulvidraco*)。为探明横沙新洲鱼类优势种的脂肪酸营养品质, 本研究从横沙新洲河道采集样品, 分析其优势种鱼类的脂肪酸营养组成。【方法】采用国标的方法对横沙新洲河道的优势种鱼类的脂肪酸组成进行测定分析。【结果】鲢肌肉中的饱和脂肪酸(SFA)含量最高, 黄颡鱼的最低, 三种鱼类间差异显著($P<0.05$); 黄颡鱼肌肉的单不饱和脂肪酸(MUFA)含量最高, 显著的高于鲃和鲢肌肉中含量; 鲢肌肉的多不饱和脂肪酸(PUFA)含量最低, 显著的低于鲃和黄颡鱼肌肉中含量。SFA 中 C16:0 的含量最高, 其在鲢肌肉中含量最高, 黄颡鱼中最低, 三种鱼类肌肉间差异显著($P<0.05$); MUFA 中 C16:1 和 C18:1n9c 的含量较高, 其中鲃和鲢肌肉中 C16:1 的含量显著高于黄颡鱼肌肉中含量, 黄颡鱼中 C18:1n9c 的含量显著的高于鲃和鲢肌肉中含量($P<0.05$); PUFA 中 EPA、DHA、ALA、ARA、DPA 的含量较高, 在三种鱼类间, EPA、ALA、ARA、n3-PUFA 的含量在鲃中最高, DHA、DPA、n6-PUFA 的含量在黄颡鱼中最高。鲃、鲢和黄颡鱼肌肉中 UFA/SFA 的比值依次为 1.71、1.01 和 2.34, n3-PUFA/n6-PUFA 的比值依次为 1.80、1.30 和 1.31。【结论】鲢以饱和脂肪酸营养为主, 黄颡鱼以单不饱和脂肪酸营养为主, 鲃以 EPA 营养为主, 可见生活在同一水域的鱼类优势种的脂肪酸组成存在明显差异, 这与不同鱼类的自身特性和生态习性相关, 该结果为进一步探明横沙新洲不同鱼类优势种的脂肪酸组成及营养品质差异原因提供依据, 为横沙新洲优势鱼类的开发利用提供指导。

关键词: 横沙新洲; 河道; 优势种; 肌肉; 脂肪酸; 品质评价

资助项目: 上海市科技兴农项目 (2022-02-08-00-12-F01192); 中国水产科学研究院中央级公益性科研院所基本科研业务费专项 (2023TD14)

通讯作者: 赵峰, 研究员, E-mail: zhaof@ecsf.ac.cn; 庄平, 研究员, E-mail: pzhuang@ecsf.ac.cn

基于生长、体成分和抗氧化能力研究饲料中添加川芎水提取物 对鲫鱼体脂和肉质的影响

陈岗富¹, 徐静¹, 杨鹏燕^{1,2}, 苏晓雨¹, 黎杰¹, 徐晓¹, 张会兰¹, 杨奇慧³, 李华涛^{1*}

(1. 内江师范学院生命科学学院, 长江上游鱼类资源与利用四川省重点实验室, 四川 内江 641100; 2. 华中农业大学水产学院, 湖北 武汉 430070; 3. 广东海洋大学水产学院, 广东 湛江 524088)

摘要: 【目的】本研究探讨饲料中添加川芎水提取物(AQE)对异育银鲫(*Carassius auratus gibelio*)体脂和肉质的影响。【方法】选取平均体重(13.05±0.10)g 的鱼 630 尾, 随机分到 21 个 58 cm × 33 cm × 31 cm 的长方体鱼箱中; 实验分为 7 个处理(每个处理 3 个重复鱼箱, 每个重复 30 尾鱼), 分别投喂添加 0%、0.3%、0.6%、0.9%、1.2%、1.5%和 1.8%AEQ 的饲料。结果显示, 投喂 AQE 降低了鲫的增重(WG)、特定生长率和肥满度(CF)以及鱼体脂含量和脂肪沉积率, 提高了其体蛋白含量。此结果说明, AQE 对鱼具有显著的减肥和改善肉质的作用。【结果】投喂 AQE 提高了鲫肝脏脂肪酶以及肠道胰蛋白酶和淀粉酶活性, 但降低了其肠道 Na⁺,K⁺-ATP 酶和 γ-谷氨酰基转移酶活性。此结果说明, AQE 对鲫 WG 的降低可能与其降低了肠道吸收酶活性有关。同时, 饲料中添加 AQE 提高了鲫血浆总蛋白, 降低了血浆总脂、葡萄糖和氨含量。此结果说明, AQE 提高了鱼体脂肪和糖类的利用, 降低了其蛋白质的分解。此外, 投喂 AQE 降低了鲫肝脏丙二醛和肠道过氧化氢含量, 提高了肝脏超氧化物歧化酶(SOD)、过氧化氢酶和谷胱甘肽过氧化物酶以及肠道抗羟自由基和 SOD 活性。【结论】AQE 能改善鱼消化器官的酶性抗氧化剂活性, 以此抑制了其活性氧的产生和脂质氧化。AQE 能通过抑制鱼体吸收酶活性以及改善其营养代谢和抗氧化能力, 降低鱼体的脂肪含量、脂肪沉积, 以及 WG。基于 WG 和 CF 的折线回归分析显示, AQE 用于减肥的适宜添加量为 0.526%和 0.853%。本研究为开发 AQE 具有减肥功能的鱼用饲料添加剂提供了理论依据和科学支撑。

关键词: 川芎提取物; 鲫; 增重; 体成分; 代谢; 抗氧化

基金项目: 四川省科技计划项目(2018JY0214); 内江师范学院青年项目(2022QN31); 大学生创新创业训练计划项目 (X2021061).

通信作者: 李华涛, 教授, 研究方向为动物营养与饲料. E-mail: lihuatao666@163.com

Study the effects of dietary aqueous extract of *Ligusticum Chuanxiong* Hort. on body fat and meat quality based on growth, body composition and antioxidant capacity of crucian carp (*Carassius auratus gibelio*)

CHEN Gangfu¹, XU Jing¹, YANG Pengyan^{1,2}, SU Xiaoyu¹, LI Jie¹, XU Xiao¹, ZHANG Huilan¹, YANG Qihui³, LI Huatao^{1*}

(1. Fishes Conservation and Utilization in the Upper Reaches of the Yangtze River Key Laboratory of Sichuan Province, College of Life Sciences, Neijiang Normal University, Neijiang 641100, China; 2. College of Fisheries, Huazhong Agricultural University, Wuhan 430070, China; 3. College of Fisheries, Guangdong Ocean University, Zhanjiang 524088, China)

Abstract: To investigate the effects of aqueous extract of *Ligusticum chuanxiong* Hort. (AQE) on body fat and meat quality in crucian carp (*Carassius auratus gibelio*), 630 fish with an average body weight of (13.05 ± 0.10) g were randomly divided into 21 cuboid fish boxes of 58 cm × 33 cm × 31 cm. Fish boxes were divided into 7 treatments (3 replicate boxes per treatment, 30 fish per replicate), and fed diets supplemented with 0%, 0.3%, 0.6%, 0.9%, 1.2%, 1.5% and 1.8% AQE, respectively. The results showed that dietary AQE reduced the weight gain, special growth rate, condition factor, fat content and fat deposition rate, and increased the body protein content in crucian carp. These results indicated that AQE has significant weight loss and meat quality improvement effects on fish. In this study, dietary AQE increased the activities of lipase in hepatopancreas as well as of trypsin and amylase in the intestines, but decreased the activities of Na⁺,K⁺-ATPase and γ -glutamyltransferase in the intestines of crucian carp. These results suggested that the decrease in weight gain by AQE may be related to the reduction in activity of absorptive enzyme in the intestines of fish. Meanwhile, dietary AQE increased the content of total protein, and decreased the total glyceride, glucose and ammonia in the plasma of crucian carp. The results indicated that AQE increased the utilization of fat and carbohydrates, and reduced the catabolism of protein in crucian carp. In addition, dietary AQE decreased the malondialdehyde content in hepatopancreas and H₂O₂ content in intestine, and increased the activities of superoxide dismutase (SOD), catalase and glutathione peroxidase in the hepatopancreas as well as anti-hydroxyl radical and SOD in the intestine of crucian carp. The results indicated that AQE could improve the enzymatic antioxidant activity, thereby inhibiting the production of reactive oxygen species and lipid oxidation in the digestive organs of fish. In summary, AQE can reduce the fat content and deposition as well as weight gain by inhibiting the activity of absorption enzymes and improving the nutritional metabolism and antioxidant capacity in fish. The broken-line regression analysis based on WG and CF showed that the appropriate concentration of AQE for weight loss in fish was 0.526% and 0.853% in diets, respectively. This study provides a theoretical basis and scientific support for the development of fish feed additives with weight loss function using AQE.

Keywords: Extract of *Ligusticum chuanxiong*; *Carassius auratus gibelio*; Weight gain; Body composition; Metabolism; Antioxidant

精氨酸对草鱼肌肉能量代谢的影响及其可能作用机制

陈秋燕^{1,2,3}, 马禹龙¹, 冯琳^{1,2,3}, 姜维丹^{1,2,3}, 吴培^{1,2,3}, 刘 杨^{1,2,3}, 周小秋^{1,2,3*}

(1. 四川农业大学动物营养研究所, 四川 成都 611130; 2. 鱼类营养与安全生产四川省高校重点实验室, 四川 成都 611130; 3. 动物抗病营养教育部、农业农村部、四川省重点实验室, 四川 成都 611130)

摘要: 随着消费者对优质水产品需求的不断增加, 鱼类肉质调控在水产养殖中变得尤为重要。能量代谢作为影响肉质的重要因素之一, 可作为肉质的关键调控点。精氨酸是鱼类不可缺少的氨基酸, 可改善肉质。本试验旨在研究精氨酸对草鱼肌肉能量代谢的影响及其可能机制。试验选取初始体重为 661.60 ± 1.00 g 的草鱼 450 尾, 随机分为 6 组 (每组 3 个重复, 每个重复 25 尾): 对照组饲喂基础饲料, 试验组饲喂分别添加 3.5、7.0、10.5、14.0 和 17.5 g/kg 精氨酸的试验饲料, 试验期 63 d。结果表明: 1) 适宜水平精氨酸显著改善了草鱼肌肉肉色 (L 值和 a 值)、pH_{24h} 值和剪切力 ($P < 0.05$), 改善了肌肉理化特性。2) 精氨酸提高草鱼肌肉 pH 值可能通过 ATP 含量和 CK 活性的增加, 提升了磷酸肌酸形式的能量储备; 并通过增强 HK、PK、PDH 与降低 LDH 酶活性来延缓无氧糖酵解的发生, 进而降低肌肉乳酸含量有关 ($P < 0.05$)。3) 10.51-17.51 g/kg 精氨酸可通过上调 Glut4 蛋白表达, 显著提高 GS 活性和肌糖原含量 ($P < 0.05$), 并通过 AMPK/SIRT3/PGC-1 α 通路促进三羧酸循环 (显著提高 CS, Sdha, IDH, Mt-col, mt-nd1 基因和 Aco2 与 cox-IV 蛋白表达 ($P < 0.05$)) 从而提高肌肉对葡萄糖的利用。4) 适宜水平精氨酸可通过显著上调线粒体生物发生、融合和分裂、线粒体自噬相关基因和蛋白 (Lonp1, MFN1, OPA1, Drp1, PGC-1 α , TFAM, Nrf1, Parkin) 的表达从而提高线粒体功能 ($P < 0.05$)。综上, 饲料添加适宜水平精氨酸 (10.51-17.51 g/kg) 可以通过调节草鱼肌肉的能量代谢和线粒体功能进而改善草鱼肌肉品质。研究结果为今后深入研究精氨酸靶向调控草鱼肌肉品质的作用途径提供了一定的理论依据。

关键词: 精氨酸; 草鱼; 能量代谢; 线粒体功能

资助项目: 国家重点研发计划“蓝色粮仓科技创新”重点专项 (2019YFD0900200); 国家现代农业产业技术体系 (CARS-45); 国家自然科学基金面上项目 (31972810)

通讯作者: 周小秋, E-mail: zhouxq@sicau.edu.cn

日粮中黑水虻幼虫几丁质对大口黑鲈生长性能、健康状况和肌肉发育的影响

胡泽超, 夏濛, 吉红*

(西北农林科技大学动物科技学院, 杨凌 712100)

摘要:【目的】旨在评估日粮中黑水虻(*Hermetia illucens*, BSF)幼虫几丁质对大口黑鲈(*Micropterus salmoides*)生长性能、健康状况和肌肉发育的影响。【方法】选取体重为 8.00 ± 0.29 g的大口黑鲈300尾,随机分为5组(每组3个重复,每个重复20尾),配制了含不同水平(0%、0.4%、0.8%、1.2%、1.6%)黑水虻幼虫几丁质(BSFC)的5种实验日粮养殖大口黑鲈56天。【结果】(1)0.4% BSFC显著提高了大口黑鲈的增重率和特定生长率($P < 0.05$),并显著促进了肌肉中C22:1n-9、C24:1n-9的沉积,增加了肌肉总单不饱和脂肪酸含量($P < 0.05$);(2)BSFC显著促进了后肠 β -N-乙酰氨基葡萄糖苷酶的分泌($P < 0.05$);(3)BSFC降低了肌肉和中肠丙二醛(MDA)含量,增强了中肠总超氧化物歧化酶(T-SOD)和过氧化氢酶(CAT)活性($P < 0.05$);1.2%-1.6% BSFC显著促进了血清和肠道溶菌酶、酸性磷酸酶和碱性磷酸酶活性($P < 0.05$);(4)BSFC显著减少了肠道中潜在致病菌弧菌(*Vibrio*)和发光杆菌(*Photobacterium*)的丰度($P < 0.05$),0.4%、1.2%和1.6% BSFC显著增加了益生菌*Cetobacterium*的丰度($P < 0.05$),且0.8% BSFC显著增加了益生菌双歧杆菌(*Bifidobacterium*)的丰度($P < 0.05$);BSFC增加了后肠乙酸、丙酸、丁酸和戊酸浓度,以及肌肉中乙酸浓度($P < 0.05$),且0.8%-1.6% BSFC显著增加了后肠总短链脂肪酸水平($P < 0.05$);(5)BSFC显著降低了肌纤维面积和直径($P < 0.05$),而肌纤维密度在0.4%和0.8% BSFC水平下显著增加($P < 0.05$),这与肌肉中上调的*myod*、*myf-5*、*smad-2*、*tgf- β 1*和下调的*myos*的mRNA相对表达水平一致。【结论】大口黑鲈可耐受高达1.6%的日粮BSFC,而0.4% BSFC有利于大口黑鲈的生长;日粮中适宜水平的BSFC可增强大口黑鲈抗氧化能力和非特异性免疫力,调节其肠道微生物组成,促进短链脂肪酸的产生,改善其健康状况;推测肌肉乙酸含量的上升可能与BSFC促进大口黑鲈肌肉发育的作用有关。

关键词: 大口黑鲈; 黑水虻幼虫几丁质; 生长性能; 健康状况; 肌肉发育

Effects of black soldier fly larvae chitin in diet on growth performance, health status and muscle development of largemouth bass *Micropterus salmoides*

Zechao Hu; Meng Xia; Hong Ji*

College of Animal Science and Technology, Northwest A&F University, Yangling, Shaanxi, China, 712100

Abstract: **【Objective】** To evaluate the effects of black soldier fly larvae (*Hermetia illucens*, BSF) chitin on growth performance, health status and muscle development of largemouth bass (*Micropterus salmoides*). **【Method】** A total of 300 largemouth bass with a body weight of 8.00 ± 0.29 g were randomly divided into 5 groups (3 replicates per group and 20 tail/replicate). Five experimental diets containing different levels (0%, 0.4%, 0.8%, 1.2%, 1.6%) of black soldier fly larvae chitin (BSFC) were formulated to feed largemouth bass for 56 days. **【Result】** (1) The 0.4% BSFC distinctly increased the specific growth rate and weight gain rate of fish ($P < 0.05$), and evidently promoted the deposition of C22:1n-9, C24:1n-9 and increased total monounsaturated fatty acids content in the muscle ($P < 0.05$). (2) The BSFC distinctly stimulated the secretion of β -N-acetylglucosaminidase in the hindgut ($P < 0.05$). (3) The BSFC markedly decreased the malonaldehyde contents in the muscle and midgut and the increased total superoxide dismutase and catalase activities in the midgut. The 1.2%-1.6% BSFC significantly enhanced the activities of lysozyme, acid phosphatase and alkaline phosphatase in the serum or midgut ($P < 0.05$). (4) The BSFC notably reduced the abundance of potential pathogenic bacterium *Vibrio* and *Photobacterium* ($P < 0.05$), and 0.4%, 1.2%, 1.6% BSFC markedly increased the abundance of probiotic bacterium *Cetobacterium* ($P < 0.05$), and the 0.8% BSFC significantly increased the abundance of the probiotics *Bifidobacterium* ($P < 0.05$). The BSFC increased the acetic acid, propionic acid, butyric acid and valeric acid concentrations in the hindgut and the acetic acid level in the muscle, and 0.8%-1.6% BSFC obviously increased the total short-chain fatty acid levels in the hindgut ($P < 0.05$). (5) The BSFC remarkably reduced muscle fiber area and diameter ($P < 0.05$), while fiber densities were significantly increased under 0.4%, 0.8% BSFC levels ($P < 0.05$), which was accordant with increased mRNA expression levels of the *myod*, *myf-5*, *smad-2*, *tgf- β 1* and decreased mRNA expression levels of *myos* in muscle. **【Conclusion】** Largemouth bass can tolerate up to 1.6% BSFC in diet, while 0.4% BSFC is beneficial for the growth of largemouth bass. Suitable BSFC addition in diet can enhance the antioxidant capacity and non-specific immunity, improve the composition of intestinal microbiota and the production of intestinal short-chain fatty acids of largemouth bass. It is speculated that the increase of acetic acid content in muscle may be related to the role of BSFC in promoting muscle development of largemouth bass.

Keywords: Largemouth bass; Black soldier fly larvae chitin; Growth performance; Health status; Muscle development

水解鱼蛋白体外对弧菌的抗菌活性及其在大菱鲆体内对哈维氏弧菌抗病力的探究

卫育良, 王璐, 李炎璐, 马强, 梁萌青, 徐后国*

(海水养殖生物育种与可持续产出全国重点实验室, 中国水产科学研究院黄海水产研究所, 山东 青岛 266071)

摘要: 本实验旨在研究水解鱼蛋白(FPH)对哈维氏弧菌、鳃弧菌和大菱鲆弧菌的体外抑菌活性,并在此基础上进一步探究大菱鲆对哈氏弧菌的非特异性免疫、肠道菌群和抗病性的影响。FPH以鳕鱼(*Theragra chalcogramma*)的副产品为原料,经碱性蛋白酶和风味蛋白酶酶解而制得。FPH的体外抗菌活性通过琼脂打孔扩散法、浊度比色法和平板计数法测定。然后,通过生长实验研究在大菱鲆上FPH对哈维氏弧菌的抵抗作用。实验饲料分为3个处理组,即高鱼粉(FM)组、高豆粕(SM)组和FPH(100 g/kg)组。琼脂打孔扩散实验表明,FPH对哈维氏弧菌的抑制区最明显,其次为大菱鲆弧菌。微生物生长曲线和平板计数结果表明,FPH对鳃弧菌也有轻微的抗菌作用。养殖实验结果表明,FPH可通过调节血清中免疫球蛋白M和补体3水平、过氧化氢酶和髓过氧化物酶活性以及肠道中杯状细胞的数量,增强哈维氏弧菌攻击前的抗氧化和免疫反应。同时,发现FPH可以下调攻毒后部分促炎因子(*il-1 β* 、*il-6*、*il-8*)的基因表达。根据Kaplan-Meier分析,摄食FPH的大菱鲆在哈维氏弧菌攻毒后存活率显著增加。另外,对肠道菌群的分析发现,弧菌的相对丰度在SM组最高,其次为FPH组和FM组;同样,通过分析*vhhp2*基因,FPH组后肠的哈维氏弧菌相对丰度也显著增加。综上所述,本实验所用的FPH对弧菌的抑菌作用具有种特异性,对哈维氏弧菌的抑菌活性最强。饲料中添加FPH可增强大菱鲆的非特异性免疫和抗菌活性,增强对哈氏弧菌的抵抗力。

关键词: 水解鱼蛋白; 抗菌活性; 免疫响应; 肠道微生物; 弧菌

Exploring antibacterial activity of fish protein hydrolysate *in vitro* against *Vibrio* strains and disease resistance to *V. harveyi* in turbot (*Scophthalmus maximus*)

Yuliang Wei, Lu Wang, Yanlu Li, Qiang Ma, Mengqing Liang, Houguo Xu*

(State Key Laboratory of Mariculture Biobreeding and Sustainable Goods, Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Qingdao, Shandong 266071, China)

Abstract: This study was to investigate *in vitro* antimicrobial activity of fish protein hydrolysate (FPH) against *Vibrio harveyi*, *V. anguillarum* and *V. Scophthalmi* as well as the non-specific immunity, intestinal microbiota and disease resistance to *V. harveyi* in turbot. FPH was prepared from by-products of Pollock. Antibacterial activity of FPH was measured by the agar well diffusion, turbidometric assay and plate count. The feeding trial was performed to study the effect of FPH on the resistance against *V. harveyi* in turbot after feeding three diets containing a high level of fish meal (FM), a high level of soybean meal (SM) and 100 g / kg FPH (FPH). Agar well diffusion showed the clearest inhibition zone of FPH was observed against *V. harveyi*, followed by *V. Scophthalmi*. Bacterial growth curve and plate count showed a slight antibacterial effect of FPH against *V. anguillarum*. Results of the feeding trial showed that FPH enhanced antioxidant and immune responses before *V. harveyi* challenge as modulating immunoglobulin M and Complement 3 levels, catalase and myeloperoxidase activities in serum, as well as the number of goblet cells in intestine. Meanwhile, the expression of some pro-inflammatory cytokines (*il-1 β* , *il-6* and *il-8*) was down-regulated in the FPH group after *V. harveyi* challenge. Survival probability in the FPH group increased after challenging to *V. harveyi* based on the Kaplan–Meier analysis. Results of intestinal microbiota showed the relative abundance of *Vibrio* in the SM group was the highest, followed by the FPH and control groups. Similarly, the relative abundance of distal intestinal *V. harveyi* was significantly reduced in the FPH group by analyzing the *vhhp2* gene. In conclusion, the present FPH against *Vibrio* strains was species-specific, with strongest antibacterial activity to *V. Harveyi*. Dietary FPH enhanced the non-specific immunity and antibacterial activity of turbot, increasing the resistance to *V. Harveyi*.

Keywords: Fish protein hydrolysate; Antibacterial activity; Immune response; Intestinal microbiota; *Vibrio*

资助项目：国家自然科学基金(31972803, 31902387)、中国水产科学研究院黄海水产研究所基本科研业务费(20603022023021)

通讯作者：徐后国，E-Mail: xuhg@ysfri.ac.cn

糖萜素对克氏原螯虾的生长性能、肌肉抗氧化能力和品质的影响

田红艳¹, 胡长东^{1,2}, 杨志刚², 张武肖¹, 夏斯蕾¹, 刘飞¹, 杨文平¹, 於叶兵¹, 王爱民^{1*}

(1. 盐城工学院海洋与生物工程学院, 江苏 盐城 224051;

2. 农业农村部环境生态与鱼类营养研究中心, 上海海洋大学, 上海 201306)

摘要: 进行一项为期 6 周的养殖试验, 以评价绿色饲料添加剂糖萜素不同添加量 (0 g/kg、0.1 g/kg、0.3 g/kg、0.6 g/kg、1.2 g/kg 和 2.4 g/kg, 分别命名为 S0、S0.1、S0.3、S0.6、S1.2 和 S2.4) 对小龙虾 (*Procambarus clarkii*) 生长性能、肌肉抗氧化性和品质的影响。结果表明, S0.6 组小龙虾的增重率 (WGR) 和特定生长率 (SGR) 显著提高, 饲料转化率 (FCR) 显著降低 ($P < 0.05$)。与对照组相比, S1.2 组小龙虾的料肉比 (FMR) 显著增加 ($P < 0.05$)。与其他组相比, S1.2 组小龙虾肌肉中的抗氧化酶活性 (T-AOC、SOD、GR、GST) 较高 ($P < 0.05$)。肉质营养指标显示, 糖萜素增加了肌肉中的脂肪, 降低了水分。与对照组相比, S2.4 组小龙虾肌肉中的总氨基酸 (TAA)、必需氨基酸 (EAA) 显著增加, S1.2 组的多不饱和脂肪酸 (PUFA)、二十二碳六烯酸 (DHA)、二十碳五烯酸 (EPA) 显著增加 ($P < 0.05$)。结果显示 S2.4 组肌肉的黄度值较高, S1.2 组的红度值明显较低, 且补充糖萜素能够降低肌肉亮度。与其他组相比, S0.3 和 S2.4 组的肌肉弹力明显较低 ($P < 0.05$)。此外, S1.2 组的蒸煮损失也明显较低 ($P < 0.05$)。S0.6、S1.2 和 S2.4 组的肌肉纤维直径明显高于对照组, S1.2 和 S2.4 组粗纤维 ($>50 \mu\text{m}$) 的频率明显高于对照组 ($P < 0.05$)。进一步分析表明, S1.2 和 S2.4 组的肌肉生长基因和萎缩基因均上调。根据糖萜素添加量对 FBW、WGR、SGR、FMR 的二次回归分析, 饲料中添加 1.3-1.4 g/kg 糖萜素时, 小龙虾的生长性能和经济效益最佳, 更高的糖萜素添加量可适度提高小龙虾的营养价值, 但会影响其外观和口感。

关键词: 克氏原螯虾; 糖萜素; 肌肉品质; 生长性能; 抗氧化

Moderate dietary sacchariterpenin supplement ameliorates growth performance, muscle antioxidant capacity and quality of the crayfish (*Procambarus clarkii*)

Hongyan Tian¹, Changdong Hu^{1,2}, Zhigang Yang², Wuxiao Zhang¹, Silei Xia¹, Fei Liu¹, Wenping Yang¹, Yebing Yu¹, Aimin Wang^{1*}

(1. School of Marine and Bioengineering, Yancheng Institute of Technology, Yancheng 224051, P.R China; 2. Centre for Research on Environmental Ecology and Fish Nutrition of the Ministry of Agriculture and Rural Affairs, Shanghai Ocean University, Shanghai 201306, P.R China; 3. Fishery Machinery and Instrument Research Institute, Chinese Academy of Fishery Sciences, No. 63 Chifeng Road, Yangpu District, Shanghai 200092, P.R China; 4. Key Laboratory of Freshwater Fisheries and Germplasm Resources Utilization, Ministry of Agriculture and Rural Affairs, Freshwater Fisheries Research Center, Chinese Academy of Fishery Sciences, Wuxi 214081, P.R China)

Abstract: A 6-week feeding trial was conducted to evaluate the effect of different green feed additive sacchariterpenin supplemental levels (0 g/kg, 0.1 g/kg, 0.3 g/kg, 0.6 g/kg, 1.2 g/kg and 2.4 g/kg, named S0, S0.1, S0.3, S0.6, S1.2, S2.4, respectively) on growth performance, muscle antioxidant and quality of crayfish (*Procambarus clarkii*). The results showed that S0.6 showed significant increase in weight gain rate (WGR), specific growth rate (SGR) and significant decrease in feed conversion ratio (FCR) ($P < 0.05$). Compared with the control group, S1.2 showed significant increase in feed-meat ratio (FMR) ($P < 0.05$). Antioxidant enzyme activities (T-AOC, SOD, GR, GST) were higher in crayfish muscle in S1.2 compared to other groups ($P < 0.05$). Nutritional indices of meat quality showed that sacchariterpenin increased fat and decreased water of the muscle. Total amino acids (TAA), essential amino acids (EAA) were significantly higher in S2.4 and polyunsaturated fatty acids (PUFA), docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA) were significantly higher in S1.2 compared to the control group (S0) ($P < 0.05$). Dietary sacchariterpenin supplemental could reduce muscle brightness since muscle in S2.4 group possessed a higher degree value of yellowness, while S1.2 group had significantly lower redness value. Muscle springiness was significantly lower in S0.3 and S2.4 compared to the other groups ($P < 0.05$). In addition, the cooking loss was significantly lower in S1.2 ($P < 0.05$). The muscle fiber diameter was significantly higher in S0.6, S1.2, S2.4 than in the S0 group, and the frequency of coarse muscle fibers ($>50 \mu\text{m}$) was significantly higher in S1.2 and S2.4 ($P < 0.05$). Further analysis showed that both muscle growth and atrophy genes were upregulated in S1.2 and S2.4. Based on the quadratic regression analysis of FBW, WGR, SGR, FMR with sacchariterpenin supplement, the best growth performance and economic benefits of crayfish were achieved with the addition of

1.3-1.4 g/kg sacchariterpenin to the diet. Higher sacchariterpenin supplement may moderately increase the nutritional value but with the loss of appearance and taste.

Key words: crayfish, sacchariterpenin, flesh quality, growth performance, antioxidant

资助项目：国家自然科学基金（32102767、32273154）、国家重点研发计划（2023YFD2402000）、江苏省农业产业技术体系（克氏原螯虾）（JATS[2022]-515）、上海市自然科学基金（22ZR1427300）
通讯作者：王爱民，E-Mail: bluesaewam@ycit.cn

外源肌肽提高了克氏原螯虾生长性能和肌肉品质

李薪源^{1,2}, 田娟^{1,2*}, 刘洋洋¹, 张健敏¹, 黄峰²

(1. 中国水产科学研究院长江水产研究所, 湖北 武汉 430223;

2. 武汉轻工大学, 动物营养与饲料科学湖北省重点实验室, 湖北 武汉 430023)

摘要: 为探究肌肽对克氏原螯虾 (*Procambarus clarkii*) 生长性能和肌肉品质的影响, 在基础饲料中分别添加 0 (对照组)、0.05、0.10、0.20、0.40 和 0.80 g/kg 的肌肽, 饲喂克氏原螯虾 [初始体质量 (6.19±0.03) g] 8 周。结果显示: 克氏原螯虾增重率、特定生长率、蛋白质效率、蛋白质沉积率、腹部含肉率、全虾粗蛋白含量、肌肉粗蛋白含量、硬度、咀嚼性、碱不溶性羟脯氨酸含量、总羟脯氨酸含量、直径<50 μm 肌纤维比例、肌纤维密度、肌肉中结合总必需氨基酸和总氨基酸含量均随饲料肌肽添加量的增加呈显著的线性和二次多项式变化趋势, 且均在肌肽添加水平为 0.40 g/kg 有最大值, 且显著高于对照组。饲料系数和直径>70 μm 肌纤维比例均随饲料肌肽添加量的增加呈显著的二次多项式变化趋势, 且均在肌肽添加水平为 0.40 g/kg 有最小值, 且显著低于对照组。与对照组相比, 肌肽添加水平为 0.20 和 0.40 g/kg 时显著上调了肌肉蛋白质合成的 TORC1 通路关键基因 (*igf-1*、*pi3k*、*akt*、*tor*、*s6k1* 和 *eif2a*) 和 eIF2B-eIF2 通路关键基因 (*eif2a*) 的相对表达量; 肌肽添加水平为 0.40 g/kg 时显著下调了肌肉蛋白质降解的泛素-蛋白酶体系统关键基因 (*ub*、*psma2*、*psmc1* 和 *murfl*) 和自噬-溶酶体系统关键基因 (*atg16l1*、*atg5*、*beclin1* 和 *atg12*) 的相对表达量; 肌肽添加水平为 0.40 g/kg 时显著上调了肌肉胶原蛋白合成的 TGFβ/Smad 通路相关基因 (*tgf-β1*、*smad6*、*smad3*、*smad4* 和 *colla1*) 的相对表达量; 肌肽添加水平为 0.40 g/kg 时显著上调了肌肉发育关键基因 (*mef2a* 和 *mef2b*) 的相对表达量, 显著下调 *mstn* 的相对表达量。综上所述, 本试验条件下外源添加肌肽能够提高克氏原螯虾的生长性能和饲料利用率, 促进蛋白质沉积和肌肉发育, 并提高肌肉品质。根据饲料系数、增重率、特定生长率、蛋白质效率、蛋白质沉积率和腹部含肉率进行二次回归分析, L-肌肽的最适添加量为 0.44-0.49 g/kg。

关键词: 肌肽; 克氏原螯虾; 生长性能; 硬度; 蛋白质沉积; 肌肉发育

Carnosine supplementation improved the growth performance and flesh quality of the red swamp crayfish (*Procambarus clarkii*)

Xinyuan Li^{1,2}, Juan Tian^{1,2*}, Yangyang Liu¹, Jianmin Zhang¹, Feng Huang²

(1. Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Wuhan China 430223; 2.

Hubei Key Laboratory of Animal Nutrition and Feed Science, Wuhan Polytechnic University, Wuhan China 430023)

Abstract: To investigate the effects of carnosine on growth performance and flesh quality, *Procambarus clarkii* (6.19±0.03 g) were fed six diets with different levels of carnosine supplementation (0, 0.05, 0.10, 0.20, 0.40, and 0.80 g/kg) for 8 weeks. The results showed that: weight gain rate, specific growth rate, protein efficiency ratio, protein deposition rate, flesh percentage, crude protein content of the red swamp crayfish, crude protein content of muscle, hardness, chewiness, alkaline-insoluble hydroxyproline content, total hydroxyproline content, myofiber density, the percentage of small-sized fiber (<50 μm), total essential amino acids and total amino acids content in muscle all demonstrated significant linear quadratic trends with increasing carnosine supplementation levels, and all of them obtained the optimal values and were significantly higher than the control group, when the carnosine supplementation level was 0.40 g/kg. The feed conversion ratio and the proportion of myofiber diameter >70 μm showed significant quadratic trends with increasing the carnosine supplementation levels, and both had minimum values and were significantly lower than those of the control group, when the carnosine supplementation level was 0.40 g/kg. Compared with the control group, the relative expression levels of the key genes of the TORC1 pathway (*igf-1*, *pi3k*, *akt*, *tor*, *s6k1* and *eif2a*) and the key gene of the eIF2B-eIF2 pathway (*eif2a*) of muscle protein synthesis were significantly up-regulated when the carnosine supplementation levels were 0.20 and 0.40 g/kg; the relative expression levels of key genes of ubiquitin-proteasome system (*ub*, *psma2*, *psmc1* and *murf1*) and key genes of autophagy-lysosomal system (*atg16l1*, *atg5*, *beclin1* and *atg12*) in muscle protein degradation were significantly down-regulated when carnosine supplementation level was 0.40 g/kg; the relative expression levels of $\text{tgf-}\beta$ /Smad pathway-related genes (*TGF- β 1*, *smad6*, *smad3*, *smad4* and *colla1*) in muscle collagen synthesis were significantly up-regulated when carnosine supplementation level was 0.40 g/kg; the relative expression levels of key genes of muscle development (*mef2a* and *mef2b*) were significantly up-regulated, and the relative expression level of *mstn* was significantly down-regulated when carnosine supplementation level was 0.40 g/kg. In conclusion, dietary supplementation the addition of carnosine under the present experimental conditions effectively improved the growth performance and feed utilization, promoted protein deposition and muscle development, and improved flesh quality of the red swamp crayfish. Based on the quadratic curve regression model

analysis of the relationship between feed conversion ratio, weight gain rate, specific growth rate, protein efficiency ratio, protein deposition rate and flesh percentage and the carnosine supplementation levels, the optimal supplementation level of carnosine was 0.44-0.49 g/kg.

Key words: Carnosine; *Procambarus clarkii*; Growth performance; Hardness; Protein deposition; Muscle development

资助项目：国家重点研发计划 (2023YFD2402000)；中央级公益性科研院所基本科研业务费专项资金 (YFI202404)；湖北省特色淡水产品产业链科技研发项目资助 [Supported by National Key R&D Program of China (2023YFD2402000)；Central Public-interest Scientific Institution Basal Research Fund (No. YFI202404)；the R&D Program of Hubei in Characteristic Freshwater Products Industry Chain]
通讯作者：田娟，副研究员，主要从事水产动物营养与饲料学研究，E-mail: tianjuan@yfi.ac.cn

缬氨酸对草鱼生长性能和肌肉营养沉积的影响

蔡梦玲¹, 周小秋^{1,2,3}, 姜维丹^{1,2,3}, 吴培^{1,2,3}, 刘杨^{1,2,3}, 冯琳^{1,2,3*}

(1. 四川农业大学动物营养研究所, 成都, 611130; 2. 鱼类营养与安全生产重点实验室, 成都, 611130; 3. 动物抗病营养农业部、教育部、四川省重点实验室, 成都, 611130)

摘要:【目的】本试验旨在研究饲料缬氨酸(Val)对生长后期草鱼生长性能、肌肉营养物质沉积的影响, 并确定生长后期草鱼 Val 需要量。【方法】选取 450 尾均重 539 ± 0.89 g 的健康草鱼, 随机分为 6 组(每组 3 个重复, 每个重复 30 尾), 分别饲喂 Val 水平为 2.8、6.0、9.0、12.4、16.2、19.4 g/kg 的饲料, 试验期 10 周。【结果】结果表明: 1) 6.0-19.4 g/kg 饲料 Val 显著提高了草鱼的增重百分比(PWG)和特定生长率($P < 0.05$), 促进了生长。2) 6.0-19.4 g/kg 饲料 Val 显著提高了草鱼肌肉中粗蛋白、必需氨基酸、粗脂肪和不饱和脂肪酸含量($P < 0.05$), 促进了肌肉中营养物质的沉积。3) 9.0-12.4 g/kg 饲料 Val 显著提高了草鱼肌肉中 IGF-1、PI3K、AKT 的 mRNA 水平和 p-TOR、p-S6K1、AKT 的蛋白水平($P < 0.05$), 促进了蛋白质合成; 显著降低了 FoxO3a、FoxO1a、Ub 的 mRNA 水平和 p-4EBP1、Fbx32、MuRF1、FoxO1 的蛋白水平($P < 0.05$), 抑制了蛋白质降解。4) 9.0-12.4 g/kg 饲料 Val 显著提高了草鱼肌肉中 FAS、ACC、SCD1 的 mRNA 水平和 SREBP1 的蛋白水平($P < 0.05$), 促进了脂肪酸合成; 显著降低了 CPT1、ACOX 的 mRNA 水平和 PPAR α 的蛋白水平($P < 0.05$), 抑制了脂肪酸分解。【结论】综上所述, 饲料中适宜水平的 Val 显著提高草鱼的生产性能, 同时可通过促进肌肉蛋白质和脂肪酸合成, 抑制肌肉蛋白质和脂肪酸分解, 增加肌肉中营养物质的沉积。在本试验条件下, 以 PWG 确定的生长后期草鱼 Val 需要量为 8.96 g/kg。

关键词: 缬氨酸; 草鱼; 生产性能; 蛋白质沉积; 脂肪酸代谢。

通讯作者: 冯琳, 教授, 博士生导师; E-mail: fenglin@sicau.edu.cn;

基金项目: 国家现代农业产业技术体系(CARS-45); 国家自然科学基金项目(U23A20250, 32172988); 四川省科技创新人才工程项目(2023JDRC0043)。

亚油酸通过 5-脂氧合酶途径诱导肌肉氧化应激

曹秀飞, 戴永军, 郭慧星, 王曦, 张定东, 李向飞, 刘文斌*, 蒋广震*

(南京农业大学, 动物科技学院, 江苏省水产重点实验室, 江苏 南京, 210095)

摘要: 【目的】肌肉氧化应激与胰岛素抵抗、肌肉无力萎缩、年龄相关性肌少症、癌症的发生密切相关。醛是多不饱和脂肪酸的初级氧化中间体, 已被证明是氧化应激的重要触发因素。然而, 亚油酸(LA)作为挥发性醛类的供体触发氧化应激的潜在机制尚未报道。【方法】本实验配制五种不同亚油酸水平(7、14、21、28 和 35 g/kg)的等氮等能日粮, 饲喂中华绒螯蟹 12 周。【结果】本研究中, 我们发现日粮添加过量 LA 会导致中华绒螯蟹肌肉氧化还原失衡, 且含有己醛、2-己醛和壬醛的挥发性醛是导致氧化应激的主要代谢物。值得注意的是, 我们首次确定了 5-脂氧合酶(5-LOX)是甲壳类动物介导 LA 氧化的关键酶。抑制 5-LOX 可以显著抑制过量 LA 产生的醛含量。进一步研究发现环腺苷单磷酸(cAMP)-蛋白激酶 A (PKA) 途径的激活促进了 5-LOX 从细胞核向细胞质的转移, 在细胞质中 5-LOX 氧化 LA, 通过醛的产生导致氧化应激。【结论】这项研究表明, 5-LOX 是甲壳类动物产生醛类物质的关键靶标。

关键词: 亚油酸, 氧化应激, 挥发性醛, 5-脂氧合酶, cAMP/PKA 信号通路

Excessive Linoleic Acid Induces Muscle Oxidative Stress through 5-lipoxygenase-Dependent Peroxidation

Xiufei Cao, Yongjun Dai, Huixing Guo, Xi Wang, Dingdong Zhang, Xiangfei Li, Wenbin Liu*,
Guangzhen Jiang*

(Key Laboratory of Aquatic Nutrition and Feed Science of Jiangsu Province, College of Animal Science and
Technology, Nanjing Agricultural University, Nanjing, China)

Abstract: [Objective] Oxidative stress in muscles is closely related to the occurrence of insulin resistance, muscle weakness and atrophy, age-related sarcopenia, and cancer. Aldehydes, a primary oxidation intermediate of polyunsaturated fatty acids, have been proven to be an important trigger for oxidative stress. However, the potential role of linoleic acid (LA) as a donor for volatile aldehydes to trigger oxidative stress has not been reported. [Methods] Five isonitrogen isolipid diets with different linoleic acid levels (7 g/kg, 14 g/kg, 21 g/kg, 28 g/kg and 35 g/kg) were prepared and fed to *Eriocheir sinensis* for 12 weeks. [Results] Here, we reported that excessive dietary LA caused muscle redox imbalance and volatile aldehydes containing hexanal, 2-hexenal, and nonanal were the main metabolites leading to oxidative stress. Importantly, we identified 5-lipoxygenase (5-LOX) as a key enzyme mediating LA peroxidation in crustaceans for the first time. The inhibition of 5-LOX significantly suppressed the content of aldehydes produced by excessive LA. Mechanistically, the activation of the cyclic adenosine monophosphate (cAMP)-protein kinase A (PKA) pathway facilitated the translocation of 5-LOX from the nucleus to the cytoplasm, where 5-LOX oxidized LA, leading to oxidative stress through the generation of aldehydes. [Conclusion] This study suggests that 5-LOX is a potential target to prevent the production of harmful aldehydes. **Key words:** Linoleic acid, Oxidative stress, Volatile aldehydes, 5-Lipoxygenase, cAMP/PKA signaling pathway

通讯作者: 刘文斌, E-Mail: wbliu@njau.edu.cn; 蒋广震, E-Mail: jianggz@njau.edu.cn

基金项目: 国家重点研发计划 (2023YFD2402003)

氧化豆粕和氧化豆油对团头鲂肌肉氧化稳定性、品质、氨基酸组成和脂肪酸组成的影响

黄洋洋, 曹秀飞, 刘文斌, 蒋广震*

(江苏省水产动物营养重点实验室, 动物科技学院, 南京农业大学, 江苏 南京 210095)

摘要:【目的】本研究旨在探究氧化豆粕和氧化豆油对团头鲂肌肉氧化稳定性、品质、氨基酸组成和脂肪酸组成的影响。【方法】氧化豆粕(OSM)和氧化豆油(OSO)分别通过加热新鲜豆粕和新鲜豆油获得。在试验日粮中,氧化豆粕和氧化豆油的比例分别为30%和4.19%。进行了为期8周的养殖试验。【结果】研究表明,OSM和OSO都降低了肌肉中的谷胱甘肽过氧化物酶(GSH-Px)、超氧化物歧化酶(SOD)、过氧化氢酶(CAT)、硬度、咀嚼性、氧合肌红蛋白(OxyMb),并提高了丙二醛(MDA)、蛋白质羰基(PC)、高铁肌红蛋白(MetMb)的含量。与CON和OSO相比,OSM显著降低了肌肉中必需氨基酸(EAA)、非必需氨基酸(NEAA)、呈味氨基酸(DAA)和总氨基酸(TAA)的含量。而与CON和OSO相比,OSO显著降低了油酸(C18:1n9t)、亚油酸(C18:2n6c)、多不饱和脂肪酸(PUFA)、 ω -6 PUFA及 ω -6/ ω -3比值,同时饱和脂肪酸(SFA)、硬脂酸(C18:0)和 γ -亚麻酸(C18:3n6)的含量显著升高。【结论】总之,本研究表明,氧化豆粕和氧化豆油均对团头鲂肌肉的抗氧化能力和肌肉品质产生了负面影响。此外,OSM对肌肉的氨基酸组成产生了不利影响,而OSO则损害了脂肪酸组成。

关键词: 团头鲂; 氧化豆粕; 氧化豆油; 氧化稳定性; 品质; 氨基酸; 脂肪酸。

Effects of oxidized soybean meal and oxidized soybean oil on muscle oxidative stability, flesh quality, amino acid profile and fatty acid profile of *Megalobrama amblycephala*

Yangyang Huang, Xiufei Cao, Wenbin Liu, Guangzhen Jiang*

(Key Laboratory of Aquatic Nutrition and Feed Science of Jiangsu Province, College of Animal Science and Technology, Nanjing Agricultural University, Jiangsu Nanjing 210095)

Abstract: [Objective] This study aimed to investigate effects of oxidized soybean meal and oxidized soybean oil on muscle oxidative stability, flesh quality, amino acid profile and fatty acid profile of blunt snout bream *Megalobrama amblycephala*. [Methods] Oxidized soybean meal and oxidized soybean oil are obtained from fresh soybean meal (FSM) and fresh soybean oil (FSO) by heating. In the experimental diet, the proportions of oxidized soybean meal (OSM) and oxidized soybean oil (OSO) were 30% and 4.19%, respectively. The feeding trial was conducted for 8 weeks. [Results] The findings revealed that both OSM and OSO reduced glutathione peroxidase (GSH-Px), superoxide dismutase (SOD), catalase (CAT), hardness, chewiness, oxymyoglobin (OxyMb), and elevated the content of malondialdehyde (MDA), protein carbonyl (PC), metmyoglobin (MetMb) in the muscle. OSM notably decreased the content of muscle essential amino acids (EAA), nonessential amino acids (NEAA), delicious amino acids (DAA), and total amino acids (TAA) compared to CON and OSO. While compared to the CON and OSM, OSO significantly reduced the content of elaidic acid (C18:1n9t), linoelaidic acid (C18:2n6c), polyunsaturated fatty acids (PUFA), ω -6 PUFA and the ratio of ω -6/ ω -3, While the stearic acid (C18:0), γ -linolenic acid (C18:3n6) and saturated fatty acids (SFA) were significantly elevated. [Conclusion] In conclusion, this study demonstrated that both OSM and OSO negatively impacted the muscle antioxidant capacity and flesh quality. Moreover, OSM adversely affects the amino acid profile of the muscle, while OSO impaired the fatty acid profile.

Key words: *Megalobrama amblycephala*; Oxidized soybean meal; Oxidized soybean oil; Oxidative stability; Flesh quality; Amino acid profile; Fatty acid profile

资助项目: 国家自然科学基金 (32273146)、国家大宗淡水鱼产业技术体系 (CARS-45-12)

通讯作者: 蒋广震, E-Mail: jianggz@njau.edu.cn

异亮氨酸对生长后期草鱼生长性能及肌肉胞外基质的影响

任凯璇¹, 冯琳^{1,2,3}, 吴培^{1,2,3}, 刘杨^{1,2,3}, 周小秋^{1,2,3}, 姜维丹^{1,2,3*}

1. 四川农业大学动物营养研究所, 成都, 611130; 2. 鱼类营养与安全生产重点实验室, 成都, 611130; 3. 动物抗病营养农业部、教育部、四川省重点实验室, 成都, 611130

摘要: 骨骼肌作为肉制品的主要可食用部位, 它的发育可以直接影响肉制品的产量。细胞外基质为骨骼肌的构建提供了支持框架, 支持骨骼肌细胞增殖、分化、粘附和迁移。异亮氨酸作为一种必需氨基酸, 可以调节动物的营养吸收和能量代谢。本试验旨在探讨饲料异亮氨酸对草鱼肌肉营养成分、物化品质和胞外基质成分的影响。实验选取 450 尾健康草鱼 (初始体重 615.69 ± 0.03 g) 随机分为 6 组, 每个组三个重复, 每个重复 25 尾: 对照组为基础饲料, 试验组饲料中分别添加 3.00、6.00、9.00、12.00 和 15.00 g/kg 异亮氨酸, 试验期 9 周。实验结果表明: 1) 饲料中添加 10.81 g/kg 异亮氨酸可以提高生长后期草鱼的生长性能 (增重百分比、采食量)、肌肉营养物质含量 (粗蛋白、粗脂肪) 和物化品质 (pH、剪切力)。2) 10.81 g/kg 异亮氨酸可显著提高草鱼肌肉中 I 型胶原蛋白、层粘连蛋白和纤维黏连蛋白等胞外基质成分 ($P < 0.05$)。3) 异亮氨酸促进胞外基质的生物合成可能与 TGF- β /Smad 和 MST/LATS/YAP 信号通路相关。4) 异亮氨酸抑制胞外基质的降解可能与 TIMP-2/MMP-2、MMP-9 有关。此外, 本实验通过对增重百分比和胶原纤维面积的二次回归分析, 确定生长后期草鱼饲料中异亮氨酸最适添加量分别为 12.34 和 10.97 g/kg。本研究结果为探讨异亮氨酸对提高生长后期草鱼肌肉胞外基质成分和肌肉品质的贡献奠定了基础。

关键词: 异亮氨酸; 草鱼; 肌肉; 胞外基质成分; 胞外基质合成; 胞外基质降解

通讯作者: 姜维丹, 教授, 博士生导师; E-mail: WDJiang@sicau.edu.cn

基金项目: 国家现代农业产业技术体系 (CARS-45), 国家自然科学基金项目 (U21A20266, U23A20250, 32172988), 四川省科技创新人才项目 (2023JDRC0043) 资助。

运动训练和高脂饲料对斑点叉尾鮰营养成分和肌肉品质的影响

胡晓敏^{1,2}, 刘昊昆¹, 韩冬^{1,3}, 金俊琰¹, 杨云霞¹, 朱晓鸣^{1*}, 解绥启^{1,2,3}

(1. 中国科学院水生生物研究所, 湖北 武汉 430072; 2. 中国科学院大学, 北京 100049; 3. 湖北水产动物营养与饲料工程研究中心, 湖北 武汉 430072)

摘要:【目的】高脂饲料因具有节约饲料蛋白质的作用, 在水产养殖中被广泛使用。然而, 高脂饲料会对鱼类肉质造成一定的负面影响。本实验探究了运动训练对高脂饲料饲喂的斑点叉尾鮰营养成分和肌肉品质的影响。【方法】在水流速度为 0.84 m/s (自主游泳) 和 20.84 m/s (运动训练) 下, 分别以对照饲料 (6%脂肪) 和高脂饲料 (11%脂肪) 饲喂斑点叉尾鮰 (54.58 ± 0.32 g) 58 天。【结果】结果表明, 高脂饲料和游泳运动对斑点叉尾鮰的生长没有显著性影响。高脂饲料增加了鱼体脂肪、腹腔和肌肉脂肪积累, 增加了肌肉中糖原以及 PUFA 和 n-6 PUFA 含量, 降低了全鱼水分、肌肉蛋白以及肌肉中 MUFA、n-3/n-6 PUFA、ARA 和 DHA 含量。运动训练降低了鱼体肥满度、腹脂率、全鱼脂肪和灰分、肌肉脂肪、肌肉糖原及异味物质 GSM 含量, 增加了肌肉蛋白、胶原蛋白、游离氨基酸和甜味氨基酸含量, 提高了肌肉硬度和系水力。高脂饲料结合运动训练可以增加肌肉中 PUFA、n-3 PUFA、EPA 和 DHA 的含量, 提高肌肉过氧化氢酶活力和总抗氧化能力。对肌肉中相关基因表达检测发现, 运动训练促进了肌肉中蛋白质合成代谢, 抑制了糖原合成 (*gys1*) 代谢。此外, 高脂饲喂情况下, 运动训练促进了肌肉中肌纤维发育相关基因 (*myod1*, *myog* 和 *mrf4*) 的表达, 抑制了脂肪代谢相关基因 (*acaca*, *srebp1*, *hsl* 和 *aco*) 和肌肉生长抑制素基因 (*mstna* 和 *mstnb*) 的表达。【结论】运动训练可以改善饲喂高脂饲料造成的鱼体脂肪过度沉积和肌肉异味物质积累。通过减少肌肉脂肪积累, 促进蛋白质合成、肌纤维发育和胶原蛋白合成, 改善肌肉质地。并且, 可以改善鱼肉营养价值, 提升肌肉抗氧化能力和风味物质含量。

关键词: 运动训练; 高脂饲料; 营养成分; 肌肉品质; 斑点叉尾鮰。

Effects of exercise training and high-fat diet on nutritional composition and flesh quality in channel catfish (*Ictalurus punctatus*)

Xiaomin Hu^{1,2}, Haokun Liu¹, Dong Han¹, Junyan Jin¹, Yunxia Yang¹, Xiaoming Zhu^{1,3*}, Shouqi Xie^{1,2,3}

(1. Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China; 2. University of Chinese Academy of Sciences, Beijing 100049, China; 3. Hubei Engineering Research Center for Aquatic Animal Nutrition and Feed, Wuhan 430072, China)

Abstract: [Objective] High-fat diets have been widely used in aquaculture because of their protein-sparing effect. However, high-fat diets have some negative effects on flesh quality. The present study investigated the effects of exercise training on the nutritional composition and flesh quality of channel catfish fed a high-fat diet. [Methods] According to two-factor design, channel catfish (54.58 ± 0.32 g) were fed with a control diet (6% fat) or a high-fat diet (11% fat) for 58d at water velocities of 0.84 m/s (voluntary swimming) and 20.84 m/s (exercise training), respectively. [Results] The results showed that exercise training and high-fat diet had no significant effect on growth performance. High-fat diet increased whole body, abdominal and muscle lipid accumulation, increased muscle glycogen as well as PUFA and n-6 PUFA content, but decreased whole body moisture, muscle protein as well as muscle MUFA, n-3/n-6 PUFA, ARA, and DHA content. Exercise training decreased CF, IPF, whole body lipid and ash, muscle lipid, muscle glycogen and GSM content, but increased muscle protein, collagen, free amino acids and sweet amino acids content, and improved muscle hardness and water holding capacity. High-fat diet combined with exercise training increased muscle PUFA, n-3 PUFA, EPA and DHA content, CAT activity and T-AOC. At the molecular level, exercise training promoted protein anabolism and inhibited glycogen synthesis (*gys1*) metabolism in muscle. In addition, exercise training promoted the expression of genes involved in myofiber growth and development (*myod1*, *myog* and *mrf4*) while suppressing the expression of genes involved in lipid metabolism (*acaca*, *srebp1*, *hsl* and *aco*) and myostatin (*mstna* and *mstnb*) in the muscle under high-fat feeding conditions. [Conclusion] Exercise training can reduce excessive lipid deposition and muscle off-flavour accumulation caused by high-fat diets. It improved muscle texture by reducing lipid accumulation, promoting protein synthesis, myofiber development and collagen synthesis. Besides, it improved the flesh nutritional values, muscle antioxidant capacity and flavour.

Key words: Exercise training; High fat diet; Nutritional value; Flesh quality; Channel catfish

资助项目：国家特色淡水鱼产业技术体系（CARS-46）

通讯作者：朱晓鸣，E-Mail: xmzhu@ihb.ac.cn

长江口不同生态类型鱼类的脂肪酸组成及营养品质评价

宋超^{1,2}, 杨承尧^{1,2}, 俞文杰^{1,2}, 赵峰¹, 庄平¹

(1.中国水产科学研究院 东海水产研究所, 上海 200090; 2.上海理工大学 环境与建筑学院, 上海 200093)

摘要: 【目的】长江口具有繁育场、索饵场和洄游通道等栖息地功能, 其渔业资源丰富, 不同生态类型的鱼类均可在长江口适宜水域进行栖息。为探明长江口不同生态类型鱼类的脂肪酸组成及营养品质, 本研究选取长吻鮠、刀鲚、凤鲚和棘头梅童鱼等不同生态类型鱼类, 分析其脂肪酸组成及营养品质差异。【方法】采用国标的方法对长江口不同生态类型鱼类的脂肪酸组成进行测定分析。【结果】凤鲚肌肉中的饱和脂肪酸(SFA)含量最高, 其次为棘头梅童鱼, 长吻鮠和刀鲚的含量较低, 且后两者间差异不显著($P>0.05$); 凤鲚肌肉的单不饱和脂肪酸(MUFA)含量最低, 显著的低于另外 3 种鱼肌肉中含量, 且后三者间差异不显著($P<0.05$); 长吻鮠肌肉的多不饱和脂肪酸(PUFA)含量最高, 棘头梅童鱼肌肉中最低, 且两者间差异显著($P<0.05$)。SFA 中 C16:0 的含量最高, 其在凤鲚肌肉中含量最高, 长吻鮠肌肉中最低, 两者间差异显著($P<0.05$); MUFA 中 C18:1n9c 的含量最高, 其次为 C16:1, 其中刀鲚中 C18:1n9c 的含量最高, 棘头梅童鱼中 C16:1 的含量; PUFA 中 EPA、DHA、ARA、DPA 的含量较高, 在四种鱼类间, DHA、DPA、ARA、n3-PUFA 和 n6-PUFA 的含量均在长吻鮠中最高, EPA 在刀鲚和凤鲚中含量较高, 且两者间差异不显著。长吻鮠、刀鲚、凤鲚和棘头梅童鱼肌肉中 UFA/SFA 的比值依次为 2.53、2.35、1.68 和 2.01, n3-PUFA/n6-PUFA 的比值依次为 2.94、4.32、4.81 和 3.18。【结论】凤鲚以饱和脂肪酸营养为主, 棘头梅童鱼以单不饱和脂肪酸营养为主, 长吻鮠以多不饱和脂肪酸营养为主, 刀鲚的各类脂肪酸营养相对均衡, 这与其咸淡水间的洄游习性相关, 可见生活在同一水域的不同生态类型鱼类的脂肪酸组成存在明显差异, 这与不同鱼类的生态类型和摄食习性相关, 该结果为进一步探明长江口不同生态类型鱼类的脂肪酸组成及营养品质差异原因提供依据, 为长江口鱼类的脂肪酸营养状况评估提供数据支撑。

关键词: 长江口; 生态类型; 肌肉; 脂肪酸; 品质评价

资助项目: 上海市科技兴农项目 (2022-02-08-00-12-F01192); 中国水产科学研究院中央级公益性科研院所基本科研业务费专项 (2023TD14)

通讯作者: 赵峰, 研究员, E-mail: zhaof@ecsf.ac.cn; 庄平, 研究员, E-mail: pzhuang@ecsf.ac.cn

支链氨基酸与 miR-203a/*fosb* 协同促进鲤的骨骼肌生长¹³

康秋霞¹, 崔晗¹, 卢荣华¹, 张玉茹¹, 徐歆歆¹, 曹香林^{1*}

1.河南师范大学水产学院, 新乡 453007

摘要: 【目的】支链氨基酸 (Branched chain amino acids, BCAAs) 作为鱼类必需氨基酸可改善饥饿胁迫的水产动物生长过程, 调节能量稳态。本文旨在探讨在鲤饥饿胁迫恢复过程中, 补充 BCAAs 对蛋白质合成、肌肉损伤恢复等的作用。【方法】实验以鲤 (*Cyprinus carpio* L.) 为动物模型饥饿处理四周, 添加不同浓度的复合 BCAAs (亮氨酸: 异亮氨酸: 缬氨酸=2:1:1) 饲喂 4 周。养殖结束后采集背肌进行 Masson 染色、蛋白质沉积, 肌肉增殖与分化以及肌肉萎缩等相关指标进行分析, 并进行转录组和 MicroRNA 检测。【结果】结果表明, 饥饿后饲喂 BCAAs 能够缓解肌细胞萎缩并缩小肌束间隙, 同时增加鱼体重和肌肉粗蛋白含量 ($P<0.05$), 饲喂 BCAAs 可上调蛋白质合成相关基因 (*ampk*、*mtor*、*EIF4E* 和 *ef*) 的表达并抑制自噬相关基因 (*atg12*、*atg5*、*atg16*、*atg4b* 和 *lc3b*) 的表达 ($P<0.05$), 同时促进肌肉发育相关基因 (*myod1*、*myhc*、*cyclind1* 和 *pcna*) 的表达 ($P<0.05$), 其中 18g/kg BCAAs 饲料添加组恢复效果最好。通过高通量 microRNA 与 mRNA 测序, 证明 BCAAs 能够与 miR-192、miR-203a 等 miRNA 协同调节靶向蛋白参与蛋白质代谢、支链氨基酸代谢以及肌细胞增殖分化过程中的相关基因, 同时发现基因 *fosb* 参与调节肌肉蛋白质合成和骨骼肌增殖与分化, 缓解肌肉萎缩的作用。进一步分析验证, 发现 miR-203a 能够靶向 *fosb* 参与调节骨骼肌蛋白质沉积和增殖与分化。【结论】综上所述, BCAAs 能有效缓解饥饿引起的肌肉损伤, 提高生长性能, 改善肌肉质量; BCAAs 协同 miR-203a 及其靶基因 *fosb* 介导 AMPK-EEF2K 对饥饿鲤骨骼肌生长发育的调控。这些结果丰富了饲料氨基酸对水产动物肌肉蛋白质沉积和饲料利用的理论研究, 为 BCAAs 在水产动物肌肉生长中的作用机制提供了新的视角。

关键词: 饥饿胁迫; 支链氨基酸; microRNA-203a; *fosb*。

资助项目: 河南省科技开发联合基金重点项目 (235200810023)

通讯作者: 曹香林, E-Mail: 041114@htu.edu.cn

脂质脂肪酸组成可以影响其在卵形鲳鲹饲料中的应用水平

张关荣, 关俊锋, 苏宁宁, 高欣, 谢帝芝, 李远友*

华南农业大学海洋学院, 广东 广州 510642

摘要: 高脂饲料已普遍应用于鱼类养殖中, 但其与饲料脂肪酸组成之间的关系及机制尚不清楚。因此, 本研究分别以基于卵形鲳鲹必需脂肪酸需求特性的复合油 (BO1) 及鱼油:豆油=2:3 的复合油 (BO2) 为脂肪源, 配制 6 种脂肪水平分别为 13%、16%和 19%的饲料, 在海上网箱投喂初重为 7.63 g 的金鲳幼鱼 9 周后, 与 BO2 饲料组相比, BO1 饲料组鱼的增重率、摄食量、肝脏超氧化物歧化酶 (SOD) 活性、总抗氧化能力 (T-AOC)、肌肉蛋白及氨基酸含量更高, 肌肉质构特性更好, 以肝脏脂肪、丙二醛 (MDA) 和亚油酸 (LA) 含量更低 ($P < 0.05$)。对于 BO1 饲料, 将脂肪水平提高至 19%不影响生长、肝脏脂肪及 LA 含量 ($P > 0.05$), 但提高了肝脏 SOD 活性和 T-AOC、肌肉脂肪及 DHA 和 EPA 的含量, 降低了肝脏 MDA 水平 ($P < 0.05$)。而对于 BO2 饲料, 脂肪水平提高至 19%降低了鱼的存活率和摄食量, 同时增加了肝脏脂肪和 MDA 水平及肝脏和肌肉的 LA 含量 ($P < 0.05$)。当饲料脂肪水平为 19%, BO1 饲料组鱼肝脏中与 GABA 能系统 (GABA、琥珀酸半醛) 和三羧酸 (TCA) 循环 (琥珀酸、顺-乌头酸等) 相关的代谢物, 及其相关基因 (*gababr*、*gat2*、*cs* 等) 的表达水平更高 ($P < 0.05$)。此外, 在金鲳鱼离体肝细胞也发现类似的基因表达结果。结果表明, 通过评估金鲳生长性能、抗氧化能力及肉质, 以 BO1 为脂肪源至少可将饲料脂肪水平提高到 19%, 这可能是由于其好的脂肪酸组成可以改善 GABA 代谢和 TCA 循环。

关键词: 卵形鲳鲹, 脂肪酸组成, 高脂饲料, 生长性能, 肌肉品质, 肝脏代谢组

The fatty acid composition of lipid can affect its application level in diet of *Trachinotus ovatus*

Guanrong Zhang, Junfeng Guan, Ningning Su, Xin Gao, Dizhi Xie, Yuanyou Li*

College of Marine Sciences, South China Agricultural University, Guangzhou 510642, Guangdong, China

Abstract: High-fat feed is common in fish farming, but its relationship with the fatty acid composition of dietary lipid and the underlying mechanisms are still unclear. To explore this issue, six diets were formulated using either blended oil 1 (BO1), tailored to meet the essential fatty acid requirements of *Trachinotus ovatus*, or BO2, a mix of fish oil and soybean oil (2:3) used in commercial feeds for this fish, with dietary lipid levels set at 13%, 16%, and 19%, respectively. After juvenile *T. ovatus* (initial weight: 7.63 g) was fed with this six diets in sea cages for 9 weeks, the fish fed BO1 diets exhibited higher weight gain, feed intake, liver superoxide dismutase (SOD) activity, total antioxidant capacity (T-AOC), muscle protein and amino acids contents, better muscle texture, and lower liver lipid, malondialdehyde and linoleic acid (LA) levels compared to those fed BO2 diets ($P < 0.05$). For the BO1 diet, increasing the lipid level to 19% did not affect the growth, or liver lipid and LA contents ($P > 0.05$), but increased liver SOD activity and T-AOC, and contents of muscular lipid, docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), and reduced liver malondialdehyde level ($P < 0.05$). Conversely, the BO2 diet at 19% lipid level reduced survival rate and feed intake, alongside increased lipid and malondialdehyde levels in liver, and LA contents in both liver and muscle ($P < 0.05$). Notably, at 19% lipid, fish fed the BO1 diet displayed elevated hepatic metabolites related to the GABAergic system (gamma-aminobutyric acid, succinic acid semialdehyde) and the tricarboxylic acid (TCA) cycle (succinate, cis-aconitic acid, etc.), alongside increased expression of the relevant genes (*gababr*, *gat2*, *cs*, etc.) compared to the BO2 group ($P < 0.05$). Moreover, similar gene expression patterns were detected in primary hepatocytes of *T. ovatus* incubated with a blend of fatty acids resembling the composition of BO1 or BO2 diets. These results suggest that using BO1 as lipid source allows for a dietary lipid level of at least 19% in *T. ovatus* by evaluating the growth performance, antioxidant capacity and muscle quality, likely due to its superior fatty acid composition, potentially by improving GABA metabolism and TCA cycle.

Key words : *Trachinotus ovatus*, Fatty acid composition, High lipid diets, Growth performance, Muscle quality, Liver metabolome

通讯作者: 李远友, 教授, E-Mail: yuli16@scau.edu.cn,

基金项目: 国家自然科学基金面上项目 (32273148)

组氨酸通过调节肌肉 pH 和硬度改善草鱼肌肉品质

曾鑫¹, 周小秋^{1,2,3}, 姜维丹^{1,2,3}, 吴培^{1,2,3}, 刘杨^{1,2,3}, 冯琳^{1,2,3*}

(1. 四川农业大学动物营养研究所, 成都, 611130; 2. 鱼类营养与安全生产重点实验室, 成都, 611130; 3. 动物抗病营养农业部、教育部、四川省重点实验室, 成都, 611130)

摘要: 为探究组氨酸对生长后期草鱼生长性能和肌肉品质的影响。试验选用 450 尾健康草鱼 (594.63 ± 0.68 g), 随机分为 6 组, 每组 3 个重复, 分别饲喂含 1.08 (基础饲料)、2.91、5.87、8.83、11.78 和 14.79 g/kg 组氨酸的 6 种饲料, 试验期 63 d。结果表明: 1) 适宜水平的组氨酸 (8.83 g/kg) 可提高草鱼的生长性能参数 (FBW, PWG, SGR 和 FE) 和肌肉营养成分 (粗蛋白和粗脂肪) ($P < 0.05$)。2) 组氨酸 (8.83 g/kg) 可提高草鱼肌肉 pH 值、硬度、不饱和脂肪酸和游离氨基酸含量 ($P < 0.05$)。3) 组氨酸 (8.83 g/kg) 可提高草鱼肌肉中肌肽和胶原蛋白含量以及肌肽合酶、脯氨酰 4-羟化酶和赖氨酰氧化酶活性, 并降低肌肉中乳酸含量 ($P < 0.05$)。4) 组氨酸 (8.83 g/kg) 可提高草鱼肌肉中肌肽合成转运 (SLC36A1, SLC15A4, SLC6A6) 并抑制肌肽降解 (CNDP1 和 CNDP2) 相关基因的表达 ($P < 0.05$)。5) 组氨酸 (8.83 g/kg) 可提高草鱼肌肉胶原蛋白合成并抑制胶原蛋白降解相关基因和蛋白的表达 ($P < 0.05$)。由此可见, 组氨酸 (8.83 g/kg) 能促进生长后期草鱼生长, 并且可能通过促进肌肉肌肽的合成来提高鱼肉的 pH 值以及通过促进肌肉胶原蛋白合成和抑制胶原蛋白分解来提高鱼肉的硬度, 改善草鱼肉品质。最后, 以增重百分比 (PWG) 为标识, 通过折线回归分析确定生长后期草鱼饲料组氨酸需要量为 8.94 g/kg 饲料 (34.12 g/kg 蛋白)。

关键词: 组氨酸; 草鱼; 生产性能; 肌肉品质; 肌肽; 胶原蛋白

基金项目: 国家自然科学基金项目 (U23A20250, 32172988)、国家现代农业产业技术体系专项基金 (CARS-45)、四川省科技创新人才工程项目 (2023JDRC0043)

通讯作者: 冯琳, E-mail: fenglin@sicau.edu.cn

专题三

亲本与幼体营养

不同粒径开口饲料对克氏原螯虾仔虾生长性能和营养组成的影响

张武肖¹, 江青青^{1,2}, 夏斯蕾¹, 杨志刚², 田红艳¹, 刘飞¹, 杨文平¹, 於叶兵¹, 王爱民^{1*}

(1. 盐城工学院海洋与生物工程学院, 江苏 盐城 224051;

2. 农业农村部环境生态与鱼类营养研究中心, 上海海洋大学, 上海 201306)

摘要: 【目的】适宜的饲料粒径对动物的饲养有重要的影响, 对水产动物来说, 适宜粒径的开口饲料对其仔稚期的生长非常重要。因此, 本试验分析和比较了不同粒径开口饲料对克氏原螯虾仔虾生长性能、体成分、肌肉氨基酸和脂肪酸组成的影响。【方法】试验设置 5 组不同粒径开口饲料, 分别为对照组 (A 组, <0.40mm)、B 组 (0.40-0.50mm)、C 组 (0.71-0.85mm)、D 组 (0.90-1.00mm)、E 组 (1.5mm), 投喂 2000 尾初均重为 0.0786 ± 0.0031 g 克氏原螯虾仔虾 100 天后采样。【结果】结果表明, 随着饲料粒径的增加, 小龙虾的末均重、增重率 (WG)、特定生长率 (SGR) 均先上升后趋于平稳, 而对照组最低。饲料系数 (FCR) 随饲料粒径的增加而先下降后趋于平稳, 但除了对照组, 其他各组之间差异不显著 ($P>0.05$)。SGR 和 FCR 折线回归分析表明, 小龙虾仔虾适宜饲料粒径的临界值分别为 0.55mm 和 0.537mm。B 组、C 组和 D 组的粗蛋白含量最高且显著高于对照组 ($P<0.05$)。E 组的鲜味氨基酸 (UAA) 含量最高且显著高于对照组 ($P<0.05$)。C 组的异亮氨酸 (Ile) 和苯丙氨酸 (Phe) 含量最高且显著高于对照组 ($P<0.05$)。主成分分析表明, C 组和 D 组的亮氨酸 (Leu)、谷氨酸 (Glu)、蛋氨酸 (Met)、缬氨酸 (Val)、组氨酸 (His)、Phe 和 Ile 含量显著升高。C 组的亚油酸 (C18:2n6)、亚麻酸 (C18:3n3)、饱和脂肪酸 (SFA)、单不饱和脂肪酸 (MUFA)、多不饱和脂肪酸 (PUFA)、n-6PUFA 含量最高且显著高于对照组 ($P<0.05$)。主成分分析显示, C 组显著诱导小龙虾肌肉 C18:2n6、C18:3n3、DHA、EPA、n-3 PUFA 和 n-6 PUFA 水平的升高。【结论】因此, 我们的研究表明, 适宜的饲料粒径可以改善小龙虾的生长性能和营养组成。基于 SGR 和 FCR 的折线回归分析, 小龙虾的最佳饲料粒径临界值为 0.55mm 和 0.537 mm, 当饲料粒径超过这些临界值时 (不超过 1.5mm), 小龙虾的生长性能和 FCR 不再发生变化。而相比于其他组, C 组蛋白含量高、脂肪含量低、氨基酸和脂肪酸营养更好。因此, 综合分析生长性能和营养组成, 建议小龙虾仔虾的适宜开口饲料粒径为 0.71-0.85mm (C 组)。

关键词: 克氏原螯虾; 饲料粒径; 开口饲料; 生长性能; 体成分; 氨基酸; 脂肪酸

Influence of Different Feed Particle Sizes on the Growth Performance and Nutrition Composition in Crayfish, *Procambarus clarkii* Larvae

Wuxiao Zhang¹, Qingqing Jiang^{1,2}, Silei Xia¹, Zhigang Yang², Hongyan Tian¹, Fei Liu¹, Wenping Yang¹, Yebing Yu¹, Aimin Wang^{1*}

(1. School of Marine and Bioengineering, Yancheng Institute of Technology, Yancheng 224051, P.R China; 2. Centre for Research on Environmental Ecology and Fish Nutrition of the Ministry of Agriculture and Rural Affairs, Shanghai Ocean University, Shanghai 201306, P.R China)

(2.

Abstract: [Objective] A suitable feed size has a positive effect on animal feeding. For aquatic larvae, the correct feed size is very important for their growth. This experiment analyzed and compared the effect of different particle sizes of feed for larval stages on the growth performance, whole body composition, and muscle amino acid and fatty acid composition of crayfish. [Methods] Five larval crayfish diets of different particle sizes, namely < 0.40 mm (Group A, control group), 0.40–0.50 mm (Group B), 0.71–0.85 mm (Group C), 0.90–1.00 mm (Group D) and 1.5 mm (Group E), were fed to 2000 crayfish (initial weight 0.0786 ± 0.0031 g) for 100 d. [Results] The results showed that as the particle size increased, final weight, weight gain (WG, $p = 0.001$) and specific growth rate (SGR, $p = 0.000$) of the crayfish tended to increase and then leveled off, with the control group being the lowest. The feed conversion ratio (FCR, $p = 0.000$) showed a decreasing and then equalizing trend with increasing particle size, but there was no significant difference between the groups except the control group. Broken-line regression analysis showed that the critical values for the appropriate particle feed size for crayfish larvae were 0.55 mm and 0.537 mm using SGR and FCR as indicators. Groups B, C and D had the highest crude protein content and were significantly higher than the control group ($p = 0.001$). Group E had the highest umami amino acid (UAA) and was significantly higher than the control group ($p = 0.026$). The content of isoleucine (Ile, $p = 0.038$) and phenylalanine (Phe, $p = 0.038$) was highest in group C and significantly higher than in the control group. Through principal component analysis, groups C and D were shown to contain leucine (Leu), glutamic (Glu), methionine (Met), valine (Val), histidine (His), Phe, and Ile levels significantly induced. The content of linoleic acid (C18:2n6, $p = 0.000$), linolenic acid (C18:3n3, $p = 0.000$), saturated fatty acid (SFA, $p = 0.000$), monounsaturated fatty acid (MUFA, $p = 0.001$), polyunsaturated fatty acid (PUFA, $p = 0.000$) and n-6 PUFA ($p = 0.000$) in group C was the highest and significantly higher than the control group. Principal component analysis showed that group C significantly induced the levels of C18:2n6, C18:3n3, DHA, EPA, n-3 PUFA and n-6 PUFA in muscle. [Conclusion] Therefore, our results suggest that appropriate feed particle size can improve the growth performance and nutrient composition of crayfish. Based on the broken-line regression analysis of SGR and FCR, the critical values of optimal particle size for crayfish are 0.55 mm and 0.537 mm, and when the particle size exceeds these critical values (not more than 1.5 mm commercial feed), growth performance and FCR of the crayfish are no longer changed. Nevertheless, group C has high protein and low lipid content, as well as better nutrition with amino acids and fatty acids. Overall, combined with growth performance and nutrient composition, it is recommended

that the particle size of the diet at the larval stage for crayfish is between 0.71 and 0.85 mm.

Keywords: *Procambarus clarkii*; Particle size; Larval stage feed; Growth performance; Whole body composition; Amino acids; Fatty acids

资助项目：江苏省种业振兴揭榜挂帅项目（JBGS [2021] 032-3）、江苏省农业产业技术体系（克氏原螯虾）（JATS[2023]-471）、国家自然科学基金（32273154）、上海市自然科学基金（22ZR1427300）
通讯作者：王爱民，E-Mail: bluesaewam@ycit.cn

不同饲料添加物对脊尾白虾 (*Exopalaemon carinicauda*) 卵巢和精子发育的影响

庞智予^{1,2}, 赵真慧^{1,2}, 邓康裕¹, 邓登^{1*}

(1. 深圳市澳华集团股份有限公司, 广东 深圳 518054; 2. 江苏海洋大学, 江苏 连云港 222005)

摘要: 为解决脊尾白虾群体性腺发育不同步的问题, 本研究通过投喂含有不同浓度裂壶藻粉 (0、3%、6%、9%)、紫球藻粉 (0、0.5%、1%、2%) 和 5-羟色胺肌酸酐硫酸盐 (0、0.0025%、0.005%、0.01%) 等添加物的饲料, 探讨了不同添加物在脊尾白虾雌、雄个体性腺发育中的作用。结果表明, 对雌性而言, 裂壶藻粉 6%、紫球藻粉 1%、5-羟色胺肌酸酐硫酸盐 0.0025% 的添加下, 脊尾白虾的性腺指数显著高于其他浓度添加组 ($P < 0.05$), 卵巢发育率最高, 达到了 $(79.30 \pm 2.64)\%$; 此时, 雌虾血淋巴促性腺激素释放激素、卵巢卵黄蛋白原和雌二醇的最终含量均显著高于其他组 ($P < 0.05$)。对雄性而言, 裂壶藻粉 9%、紫球藻粉 0%、5-羟色胺肌酸酐硫酸盐 0.01% 添加浓度下的雄性性腺指数高于其他实验组但并未达到显著差异 ($P > 0.05$), 精子存活率各组间无显著性差异 ($P > 0.05$); 此时, 精子超微量总 ATP 酶和乳酸脱氢酶最终活性在各组也未达到显著性差异 ($P < 0.05$)。总的来说, 我们探究了这 3 种饲料添加物对脊尾白虾性腺发育相关指标的影响, 其中雌性所受影响更为显著。

关键词: 脊尾白虾; 性腺发育; 裂壶藻; 紫球藻; 5-羟色胺肌酸酐硫酸盐

Effects of different feed additives on the development of ovaries and testicles in the ridgetail white shrimp *Exopalaemon carinicauda* (Decapoda, Caridea, Palaemonidae)

Zhiyu Pang^{1,2}, Zhenhui Zhao^{1,2}, Kangyu Deng¹, Deng Deng^{1*}

(1. Shenzhen Alpha Feed Co., Ltd, Shenzhen, 518054 Guangdong, P.R. China; 2. Jiangsu Ocean University, Lianyungang, 222005 Jiangsu, P.R. China)

Abstract: To solve the problem of unsynchronized gonadal development in *Exopalaemon carinicauda*, different feed additives were evaluated for their effect on gonadal development among female and male individuals. Different concentrations of *Schizochytrium* (0%, 3%, 6%, and 9%), *Porphyridium cruentum* (0%, 0.5%, 1%, and 2%) and 5-hydroxytryptamine (5-HT) creatinine sulfate (0%, 0.0025%, 0.005%, and 0.01%) were used. For females, the gonadal index of *E. carinicauda* was significantly higher with the addition of 6% *Schizochytrium*, 1% *P. cruentum*, and 0.0025% 5-HT creatinine sulfate ($P < 0.05$). The ovarian development rate reached its highest at $79.30 \pm 2.64\%$, and the final contents of blood ovarian vitellogen and estradiol were significantly higher, compared to the other groups ($P < 0.05$). For males, the gonadal index was higher with the addition of 9% *Schizochytrium*, 0% *P. cruentum*, and 0.01% 5-HT creatinine sulfate, though the difference was not significant ($P > 0.05$). No significant difference was found in the sperm survival rate ($P > 0.05$), and the activities of sperm total ATPase and lactate dehydrogenase showed significant differences in each group ($P < 0.05$). Overall, we report the effects of the three additives on gonadal development in *E. carinicauda*, with females showing the more significant effects.

Key words: *Exopalaemon carinicauda*; gonadal development; *Schizochytrium*; *Porphyridium cruentum*; 5-hydroxytryptamine creatinine sulfate

不同碳水化合物对小规格草鱼生长性能、血清生化指标、抗氧化以及肠道健康的影响

刘文硕^{1,2,3}, 廖钰宏^{1,2,3}, 陈正旺^{1,2,3}, 李佑杰^{1,2,3}, 陈琪^{1,2,3}, 潘杰^{1,2,3}, 李雅萍^{1,2,3}
张亚洲^{1,2,3}, 李加敏^{1,2,3}, 彭墨^{1,2,3}, 王自蕊^{1,2,3*},

(1. 江西农业大学动物科学技术学院, 南昌, 330045; 2. 南昌市特色水生生物营养生理与健康养殖重点实验室, 南昌, 330045; 3. 江西农业大学特种水产研究所, 南昌, 330045)

摘要:【目的】本试验旨在研究饲料中小麦淀粉含量对小规格草鱼生长性能、营养成分、消化吸收酶、血清生化和肠道组织形态的影响。【方法】试验选取均重约为 12 ± 0.30 g 的草鱼 450 尾, 随机分为 5 个组, 每组 3 个重复, 每个重复 30 尾。本试验配制了 5 种等氮等能的饲料, 分别为对照组 (淀粉含量 11.6%组)、淀粉含量 14.6%组、淀粉含量 17.6%组、淀粉含量 20.6%组和淀粉含量 23.6%组, 养殖周期为 56 d。【结果】研究表明: (1) 随着饲料中小麦淀粉含量的增加, 草鱼的增重率 (WGR)、特定生长率 (SGR) 均呈现出先升高后下降的趋势, 其中 14.6% 小麦淀粉组草鱼的增重率 (WGR)、特定生长率 (SGR) 均显著大于其他组 ($P < 0.05$), 饲料系数 (FCR) 显著小于其他组 ($P < 0.05$), 并且经过二次回归曲线模型拟合后得出, 当小麦淀粉含量为 16.02% 时, 小规格草鱼的生长性能最好。(2) 对照组 (11.6% 小麦淀粉组) 草鱼的全鱼水分和蛋白含量显著大于其他组 ($P < 0.05$)。14.6% 小麦淀粉组草鱼的脂肪含量显著大于其他组 ($P < 0.05$)。(3) 14.6% 小麦淀粉组草鱼的前肠脂肪酶 (LPS) 活力、前肠胰蛋白酶 (PRS) 活性和肌肉 ATP 含量均显著大于其他组 ($P < 0.05$)。17.6% 小麦淀粉组草鱼肠道淀粉酶活性显著大于其他组 ($P < 0.05$)。(4) 23.6% 小麦淀粉组草鱼血清的谷丙转氨酶 (ALT)、谷草转氨酶 (AST)、碱性磷酸酶 (AKP) 和血尿素氮 (BUN) 含量显著大于其他组 ($P < 0.05$)。(5) 14.6% 小麦淀粉组草鱼肠道的绒毛长度、隐窝深度和肌层厚度均显著大于其他组 ($P < 0.05$)。【结论】综上所述, 本试验表明小规格草鱼饲料中的小麦淀粉适宜含量在 14.6%~17.6% 之间, 小麦淀粉含量过高会对小规格草鱼的生长性能和肠道健康等方面造成显著性的负面影响。

关键词: 小规格草鱼; 小麦淀粉; 碳水化合物; 生长性能; 营养成分; 消化酶

资助项目: 草鱼新品系选育及养殖模式创制 (JXNK202305)

第一作者: 刘文硕, E-Mail: 2602146894@qq.com

通讯作者: 王自蕊, E-Mail: wangzirui0406@163.com

不同碳水化合物水平对中规格草鱼生长、血清生化指标、抗氧化以及肠道健康的影响

陈正旺¹, 许燕燕¹, 廖述军¹, 王自蕊^{1,2,3}, 彭墨^{1,2,3}, 张亚洲^{1,2,3*}

(1.江西农业大学动物科学技术学院, 南昌, 330045; 2.南昌市特色水生生物营养生理与健康养殖重点实验室, 南昌, 330045; 3.江西农业大学特种水产研究所, 南昌, 330045)

摘要:【目的】碳水化合物是水产养殖饲料中常用的能量物质, 大部分研究表明鱼类利用碳水化合物的能力是有限的, 本试验旨在探究不同碳水化合物水平对中规格草鱼生长、血清生化指标、抗氧化以及肠道健康的影响。【方法】试验将 450 尾初始体重为 45 g 左右的中规格草鱼随机分为五个组, 每组三个重复, 每个重复 30 尾, 分别用五种不同碳水化合物水平的等氮饲料: A 组(28.84%)、B 组(33.74%)、C 组(38.64%)、D 组(43.54%)、E 组(48.44%), 进行为期 8 周的饲喂。【结果】试验结果表明: B 组的增重率(WGR)和特定生长率(SGR)均显著高于其他组($P < 0.05$), B、C 组饲料系数(FCR)显著低于其他组($P < 0.05$), 蛋白质转化效率(PER)显著高于其他组; 以饲料转化率为指标推导出中规格草鱼饲料碳水化合物最适添加量为 26.15%, 以特定生长率为指标推导出中规格草鱼饲料碳水化合物最适添加量为 17.81%; 随着饲料中碳水化合物含量的升高, 草鱼的脏体指数(VSL)、肝体指数(HSI)和脂体指数(BMI)呈现出上升的趋势, 肠体指数(ISI)则呈下降趋势, 而各组之间脾体指数(SPI)、肥满度(CF)以及肌肉粗蛋白质含量无显著差异($P > 0.05$); 随着饲料中碳水化合物含量的升高, 血清中甘油三酯(TG)、总胆固醇(T-CHO)、低密度脂蛋白胆固醇(LDL-C)含量显著上升($P > 0.05$), B 组谷草转氨酶(AST)、谷丙转氨酶(ALT)含量显著低于其他组, 而 E 组尿素氮含量显著低于其他组($P < 0.05$); 此外, 草鱼血清中的丙二醛含量(MDA)、碱性磷酸酶活性(AKP)、超氧化物歧化酶活性(SOD)随着碳水化合物水平的升高而显著升高, 血清中过氧化氢酶活性(CAT)和肝脏中谷胱甘肽过氧化物酶活性(GSH-PX)则显著降低($P < 0.05$); 肠道方面, 淀粉酶(AMS)和胰蛋白酶(PRS)活性随着饲料中淀粉含量的提高呈现出上升趋势, 从 C 组开始具有显著性变化, 而 E 组脂肪酶(LPS)活性显著低于前四组($P < 0.05$), 同时随着淀粉水平的提高, 草鱼前肠和后肠均出现绒毛完整性变差, 排列紧密度降低, 粘液细胞逐渐减少, D、E 组肠道甚至出现绒毛断裂肿胀现象。【结论】综上所述, 试验表明中规格草鱼饲料中淀粉最适添加量应在 17.81%~26.15%之间, 过高碳水化合物水平会对中规格草鱼的生长性能和肠道健康等方面造成显著性的负面影响。**关键词:** 中规格草鱼; 碳水化合物; 生长性能; 血清生化指标; 肠道健康。

资助项目: 草鱼新品系选育及养殖模式创制(JXNK202305)

通讯作者: 张亚洲, E-Mail: zyzaiyisky@163.com

不同温度对脊尾白虾 (*Exopalaemon carinicauda*) 生长与性腺发育相关指标的影响

赵真慧^{1,2}, 庞智予^{1,2}, 邓康裕¹, 邓登^{1*}

(1. 深圳市澳华集团股份有限公司, 广东 深圳 518054; 江苏海洋大学 江苏 连云港 222005)

摘要: 为探讨不同温度对脊尾白虾生长与性腺发育相关指标的影响, 本研究设置 5 个温度梯度 (16、20、24、28、32°C) 养殖脊尾白虾, 测定其生长、消化酶活力、卵巢发育性能、卵巢营养物质浓度、卵黄蛋白原和性激素水平等指标。结果显示, 在 20°C~32°C 之间, 脊尾白虾的存活率随着温度的升高而逐渐降低; 终末体重和特定生长率随温度的升高呈现先升高后降低的趋势 ($P < 0.05$), 在温度为 28°C 的条件下生长最快; 脂肪酶活力随着温度的升高先上升后下降 ($P < 0.05$), 在温度为 28°C 时达到最高值 (1.22 ± 0.09) (U/gprot), 胰蛋白酶活力随温度的升高而升高, 温度为 32°C 时胰蛋白酶活力达到最高值 (1695.45 ± 163.42) (U/mgprot); 性腺指数和卵巢成熟率随着温度的上升而增大; 卵巢中的总蛋白、总胆固醇以及甘油三脂浓度随温度的升高总体呈上升趋势; 肝胰腺中的卵黄蛋白原随温度的升高呈现先上升后下降再上升的趋势 ($P < 0.05$), 在温度为 24°C 和 28°C 的条件下, 血淋巴中的促性腺激素释放激素浓度相对较高且比较接近, 分别为 (81.82 ± 4.03) ng/L 和 (82.67 ± 3.22) ng/L, 卵巢中的雌二醇在温度为 28°C 时浓度最高为 (26.62 ± 1.49) ng/L。以上结果表明, 28°C 是脊尾白虾亲虾促熟和工厂化养殖较为适宜的温度。

关键词: 脊尾白虾; 温度; 性腺发育; 生长; 激素

Effects of different temperatures on growth and gonad development related indexes of the ridgetail white shrimp, *Exopalaemon carinicauda*

Zhenhui Zhao^{1,2}, Zhiyu Pang^{1,2}, Kangyu Deng¹, Deng Deng^{1*}

(1. Shenzhen Alpha Feed Co., Ltd, Shenzhen, 518054 Guangdong, P.R. China; 2. Jiangsu Ocean University, Lianyungang, 222005 Jiangsu, P.R. China)

Abstract: To explore the optimal growth and reproduction temperature of *Exopalaemon carinicauda*, this study tested five temperature gradients (16°C, 20°C, 24°C, 28°C, 32°C) to determine the effects of different temperatures on the growth, digestive enzyme activity, ovarian development performance, ovarian nutrient concentration, vitellogenin, and sex hormone levels of *E. carinicauda*. The results showed that (1) Between 20°C and 32°C, the survival rate gradually decreased with the increase of temperature. As the temperature increases, the final body weight and specific growth rate first increase and then decrease ($P < 0.05$), with the fastest growth at 28°C; (2) The lipase activity first increases and then decreases with the increase of temperature ($P < 0.05$), reaching a maximum value of 1.22 ± 0.09 U/gprot at 28°C. The trypsin activity increased with the increase of temperature and reached a maximum value of 1695.45 ± 163.42 U/gprot at 32°C; (3) the gonadosomatic index and ovarian maturation rate increased with increasing temperature; the concentrations of total protein, total cholesterol, and triglycerides generally increased with temperature; the vitellogenin showed a trend of first increasing, then decreasing, and then increasing with the increase of temperature ($P < 0.05$); and (4) at temperatures of 24°C and 28°C, the concentrations of gonadotropin-releasing hormone were relatively high and close. The highest estradiol concentration was 26.62 ± 1.49 ng/L at temperatures of 28°C. These findings indicate that 28°C is a suitable temperature for promoting the maturation of the parent shrimp of *E. carinicauda* and may be recommended for a commercialized culture of this species.

Key words: *Exopalaemon carinicauda*; temperature; gonadal development; growth, hormone

胆固醇通过 *Srb* 和 *Star* 途径调控三疣梭子蟹卵巢发育的分子机制

朱婷婷^{1,2,3}, 金敏^{1,2,3*}, 赵文丽^{1,2,3}, 谢适超^{1,2,3}, 邓瑶^{1,2,3}, 鲍阳光^{1,2,3},
孙蓬^{1,2,3}, 周歧存^{1,2,3*}

(1. 宁波大学, 海洋学院, 鱼类与甲壳动物营养研究室, 浙江 宁波 315211; 2. 水产生物技术教育部重点实验室浙江 宁波 315211; 3. 农业农村部绿色海水养殖重点实验室(省部共建)浙江 宁波 315211)

摘要: 【目的】胆固醇是甲壳动物必需的营养物质, 也是合成类固醇激素的前体物质, 但其作用机制尚不清楚, 因此, 本研究拟通过在体和离体实验探究胆固醇对三疣梭子蟹卵巢发育的分子调控机制。【方法】配置对照组(不添加胆固醇)和胆固醇组两组饲料, 分别去投喂第一次卵巢发育和第二次卵巢发育的三疣梭子蟹 30 天。构建 *Srb* 和 *Star* 干扰和过表达质粒, 分别进行在体和离体干扰和过表达实验。通过生化指标、组织学、免疫荧光、基因表达、蛋白表达等检测, 对三疣梭子蟹胆固醇转运、类固醇激素合成和卵巢发育进行评价。【结果】饲料胆固醇水平可以显著提高雌性三疣梭子蟹胆固醇、类固醇激素和卵黄蛋白原(VTG)含量, 并显著上调胆固醇转运、类固醇激素合成、Vtg 基因及蛋白的表达水平。在体干扰和过表达 *Srb* 后, 发现 *Srb* 通过调控胆固醇外排基因 *abcg1* 维持体内胆固醇稳态, 而不是通过补偿性调控 *ldlr* 维持体内胆固醇稳态。在体干扰 *star*, 发现血淋巴类固醇激素及 VTG 含量显著下降, 卵巢类固醇激素合成和 Vtg 的基因及蛋白表达均显著降低。而在体过表达 *Star* 后, 结果相反。在离体水平上添加胆固醇后, 进行 *Srb* 干扰和过表达, 发现 *Srb* 促进 *Star* 和 Vtg 的表达水平。进一步的, 在离体水平上添加胆固醇后, 进行 *Star* 干扰和过表达, 发现与 CH+NC 组相比, *Star* 促进类固醇合成和卵巢发育相关基因及蛋白的表达。【结论】胆固醇可通过 *Srb* 和 *Star* 途径促进三疣梭子蟹卵巢发育。

关键词: 三疣梭子蟹; 胆固醇; 卵巢发育; 营养生理; 代谢调控

Molecular mechanisms of cholesterol regulation of ovarian development in swimming crab through Srb and Star pathways

Tingting Zhu^{1,2,3}, Min Jin^{1,2,3*}, Wenli Zhao^{1,2,3}, Shichao Xie^{1,2,3}, Yao Deng^{1,2,3}, Yangguang Bao^{1,2,3},
Peng Sun^{1,2,3}, Qicun Zhou^{1,2,3*}

(1. Laboratory of Fish and Shellfish Nutrition, Ningbo University, Ningbo 315211, PR China; 2. Key Laboratory of Aquacultural Biotechnology Ministry of Education, Ningbo University, Ningbo 315211, PR China; 3. Key Laboratory of Green Mariculture (Co-construction by Ministry and Province), Ministry of Agriculture and Rural, Ningbo 315211, PR China)

Abstract: [Objective] Cholesterol is an essential nutrient for crustaceans and a precursor of anabolic steroid hormones, but its mechanism of action is still unclear. Therefore, this study aims to explore the regulatory mechanism of cholesterol on ovarian development of swimming crab through *in vivo* and *in vitro* experiments. [Methods] The control diet (without adding cholesterol) and the cholesterol diet were fed to the first and second ovarian development of swimming crab for 30 days, respectively. Srb and Star interference and overexpression plasmids were constructed, and interference and overexpression experiments were performed *in vivo* and *in vitro*, respectively. Biochemical indexes, histology, immunofluorescence, gene expression and Western blot were conducted to evaluate cholesterol transport, steroid hormone synthesis and ovarian development of swimming crab. [Results] *In vivo*: cholesterol could significantly increased the contents of cholesterol, steroid hormone and vitellogenin (VTG), and significantly up-regulated the expression levels of genes and proteins related to cholesterol transport, steroid hormone synthesis and Vtg. After interference and overexpression of Srb, the results showed that Srb maintained cholesterol homeostasis through regulation of cholesterol efflux gene *abcg1*, but not through compensatory regulation of *ldlr*. After interference of Star, the contents of steroid hormone and VTG in hemolymph were significantly decreased, and the expression levels of the gene and protein related to ovarian steroid hormone synthesis and Vtg were significantly down-regulated. However, the results were reversed after overexpression of Star. *In vitro*: After adding cholesterol, through interference and overexpression of Srb, it was found that Srb promoted the expression levels of genes and proteins of Star and Vtg. Further, after adding cholesterol *in vitro*, through interference and overexpression of Star, it was found that Star promoted the expression of genes and proteins related to steroid synthesis and ovarian development compared with the CH+NC group. [Conclusion] cholesterol can promote ovarian development of swimming crab through Srb and Star pathways.

Key Words: *Portunus trituberculatus*; Cholesterol; Ovarian development; Nutritional physiology; Metabolic regulation

资助项目：国家自然科学基金（32072987），农业农村部国家虾蟹产业技术体系（CARS-48），浙江省自然科学基金项目（LQ20C190005），区域创新计划项目（No.U23A20248），宁波大学王宽诚基金。

通讯作者：金敏，E-Mail: jinmin@nbu.edu.cn；周歧存，E-Mail: zhouqicun@nbu.edu.cn

对虾亲体脂质营养研究现状与展望

李二超¹, 梁小龙², 常通¹, 徐畅², 韩凤禄², 陈立侨¹

(1.华东师范大学生命科学学院, 上海 200241; 2. 海南大学海洋生物与水产学院, 海南 海口, 570228)

摘要: 对虾亲体的脂质营养对其繁殖效能具有重要影响, 然而, 目前对这一领域的研究不足且缺乏高效的专用饲料, 严重制约了对虾的健康繁育和种业的可持续发展。脂质作为亲体繁殖过程中最为关键的营养素之一, 主要通过提供能量、构成细胞膜及调节生理功能, 影响性腺发育、繁殖健康和幼体存活。磷脂等构成细胞膜的物质确保卵母细胞的生成与发育, 而胆固醇则是类固醇激素合成的关键成分, 直接调控性腺成熟和卵子发育。多不饱和脂肪酸如 EPA、DHA 和 ARA 通过维持细胞膜的流动性、调节类花生酸通路和增强免疫功能, 对对虾的繁殖效能及幼体成活率有显著作用。近年来, 研究发现胆固醇和磷脂在调控类固醇激素和促进卵巢发育方面发挥重要作用, 尤其在性腺成熟过程中表现突出。同时, EPA 和 DHA 通过激活核受体如 PPARs, 参与调节性腺细胞的脂质代谢。然而, 目前对不同繁殖阶段脂质需求及其代谢机制的理解仍然有限, 尤其在如何针对各阶段精准补充脂质以提升繁殖表现方面尚待深入研究。未来研究应集中于探索脂质代谢的分子机制, 评估不同脂质来源对繁殖效能的影响, 以及研究脂质营养的长期效应, 以为开发高效专用的亲体饲料提供科学依据, 助力对虾种业的繁育效率提升, 推动水产养殖业的可持续发展。

关键词: 对虾繁育; 脂质营养; 性腺发育; 代谢机制; ;亲体饲料

Current status and prospects of lipid nutrition in Penaeid shrimp broodstock

Li Erchao¹, Xiaolong Liang², Chang Tong¹, Xu Chang², Han Fenglu², Liqiao Chen¹

(1. School of Life Sciences, East China Normal University, Shanghai 200241, China; 2. College of Marine Biology and Aquaculture, Hainan University, Haikou, Hainan 570228, China)

Abstract: Lipid nutrition in shrimp broodstock significantly affects their reproductive performance. However, research in this area is insufficient, and the lack of effective specialized feeds has severely limited the healthy breeding of shrimp and the sustainable development of shrimp seed industries. Lipids, as one of the most critical nutrients during broodstock reproduction, primarily provide energy, form cell membranes, and regulate physiological functions, which in turn influence gonadal development, reproductive health, and larval survival. Phospholipids and other cell membrane components ensure the generation and development of oocytes, while cholesterol is a key component in steroid hormone synthesis, directly regulating gonadal maturation and oocyte development. Polyunsaturated fatty acids (PUFAs) like EPA, DHA, and ARA play significant roles in reproductive performance and larval survival rates by maintaining cell membrane fluidity, regulating eicosanoid pathways, and enhancing immune function. Recent research has shown that cholesterol and phospholipids are crucial in regulating steroid hormones and promoting ovarian development, particularly during gonadal maturation. Additionally, EPA and DHA participate in regulating lipid metabolism in gonadal cells through nuclear receptors such as PPARs. However, the current understanding of lipid requirements and their metabolic mechanisms at different reproductive stages is limited, especially in terms of how to precisely supplement lipids at each stage to enhance reproductive performance. Future research should focus on exploring the molecular mechanisms of lipid metabolism, assessing the impact of various lipid sources on reproductive performance, and investigating the long-term effects of lipid nutrition. This will provide scientific evidence for developing efficient specialized broodstock feeds, improving the breeding efficiency of shrimp seed industries, and promoting the sustainable development of aquaculture.

Key words: shrimp breeding; lipid nutrition; gonadal development; metabolic mechanisms; broodstock feed

花生四烯酸对雌性红螯螯虾卵巢发育和繁殖性能的影响¹⁴

姜宗政¹, 徐畅^{1*}, 韩凤禄¹, 李二超^{2*}

(1.海南大学, 海洋生物与水产学院, 海南 海口, 570228; 2.华东师范大学, 生命科学学院, 上海, 200241)

摘要:【目的】鉴于花生四烯酸 (ARA) 对水产动物雌性亲体卵巢发育及繁殖性能的重要生理作用, 本研究旨在探索红螯螯虾 (*Cherax quadricarinatus*) 雌性亲虾的最佳 ARA 营养强化策略。【方法】本研究配制了五种等氮等脂的实验饲料, ARA 添加水平分别为 0% (对照组)、0.6%、1.2%、1.8% 和 2.4%。选取初始体重为 52.14 ± 0.25 克的雌性红螯螯虾亲虾, 进行为期 10 周的营养强化实验, 并在第 6 周和第 10 周分别评估卵巢发育及繁殖性能。【结果】研究表明, 1.8% ARA 外源性添加显著提高了雌性红螯螯虾亲虾的性腺指数和血清类固醇激素水平, 促进了卵黄颗粒的积累并加速了卵母细胞的成熟。同时, 1.8% ARA 组显著增加了肝胰腺和卵巢之间的总胆固醇和甘油三酯的沉积与转运。ARA 在肝胰腺、卵巢及受精卵中的积累量亦受到饲料中 ARA 水平的显著影响。血清代谢组学分析显示, 与对照组相比, 1.8% ARA 组的 ARA 代谢通路显著上调, 前列腺素 E₂、前列腺素 F₂ α 及 14,15-脱氧- Δ 12,14-PGJ₂ 的相对含量显著升高。在繁殖性能方面, 外源性 ARA 的添加显著增加了雌性亲虾的产卵量及受精卵中营养物质的积累。【结论】ARA 通过调控前列腺素的合成, 改善了脂质积累及类固醇激素的合成, 从而促进卵巢的成熟, 提高繁殖性能。建议在雌性红螯螯虾繁育期的饲料中 ARA 的添加水平控制在 1.675% 至 1.768% 之间。

关键词: 红螯螯虾; 亲体; 花生四烯酸; 卵巢发育; 繁殖性能。

资助项目: 海南省科技专项 (ZDYF2023XDNY060) 和海南省农业产业技术体系 (HNARS-10-ZJ05)。

通讯作者: 徐畅, E-Mail: cxu@hainanu.edu.cn; 李二超, E-Mail: ecli@bio.ecnu.edu.cn

Optimal arachidonic acid supplementation enhances ovarian development and reproductive performance in female redclaw crayfish, *Cherax quadricarinatus*

Zongzheng Jiang¹, Chang Xu^{1*}, Fenglu Han¹, Erchao Li^{2*}

(1. School of Marine Biology and Fisheries, Hainan University, Haikou, Hainan, 570228, China; 2. School of Life Sciences, East China Normal University, 500 Dongchuan Road, Shanghai, 200241, China.)

Abstract: [Objective] Given the significant physiological role of Arachidonic Acid (ARA) in the ovarian development and reproductive performance of female broodstock in aquatic animals, this study aims to explore the optimal ARA supplementation strategy for female *Cherax quadricarinatus* broodstock. [Methods] Five isonitrogenous and isolipidic experimental diets were formulated, with ARA supplementation levels of 0% (control), 0.6%, 1.2%, 1.8%, and 2.4%. A 10-week nutritional enhancement experiment was conducted on female *C. quadricarinatus* broodstock with an initial body weight of 52.14 ± 0.25 g. Ovarian development and reproductive performance were evaluated at weeks 6 and 10 of the experiment. [Results] The results indicated that the 1.8% ARA supplementation significantly increased the gonadosomatic index and serum steroid hormone levels in female *C. quadricarinatus* broodstock, promoting yolk granule accumulation and accelerating oocyte maturation. Additionally, the 1.8% ARA group showed a significant increase in the deposition and transport of total cholesterol and triglycerides between the hepatopancreas and ovary. ARA accumulation in the hepatopancreas, ovary, and fertilized eggs was also significantly influenced by dietary ARA levels. Serum metabolomic analysis revealed that, compared to the control group, the ARA metabolic pathway was significantly upregulated in the 1.8% ARA group, with a marked increase in the relative contents of Prostaglandin E2, Prostaglandin F2 α , and 14,15-deoxy- Δ 12,14-PGJ2. In terms of reproductive performance, exogenous ARA supplementation significantly increased egg production and nutrient accumulation in fertilized eggs. [Conclusion] ARA enhances lipid accumulation and steroid hormone synthesis by regulating prostaglandin production, thereby promoting ovarian maturation and improving reproductive performance. It is recommended that the ARA supplementation level in the diet of female *C. quadricarinatus* broodstock during the breeding period be maintained between 1.675% and 1.768%.

Key words: *Cherax quadricarinatus*; Broodstock; Arachidonic acid; Ovarian development; Reproduction performance

生物饵料冻干粉在雌性凡纳对虾亲体性腺发育及脂质代谢中的 调控作用¹⁵

肖贤明¹, 梁小龙¹, 常通², 韩凤禄^{1*}, 李二超^{2*}

(1. 海南大学海洋生物与水产学院, 海南 海口 570228; 2. 华东师范大学生命科学学院, 上海 200241)

摘要: 【目的】本研究旨在评估不同生物饵料冻干粉制成的饲料对雌性凡纳对虾亲体性腺发育及脂质代谢的影响, 并通过代谢组学技术识别与性腺发育相关的潜在标志代谢物。【方法】本研究以传统鱼粉为主要蛋白源作为对照组, 使用鱿鱼、沙蚕和南极磷虾冻干粉分别等蛋白替代 50% 的鱼粉, 配制成四种等氮等脂的饲料, 对处于性腺发育 I 期的 240 只雌虾 (初始体重: $44.29 \pm 0.42\text{g}$) 进行为期 28 天的营养强化实验。【结果】南极磷虾冻干粉显著提高了亲体的增重率, 并促进了肝胰腺脂质的积累与转运, 表现为肝胰腺总胆固醇、甘油三酯、高密度脂蛋白和低密度脂蛋白水平的显著增加。此外, 该组总抗氧化能力显著增强。在卵巢发育方面, 南极磷虾组的性腺指数、血清卵黄蛋白原含量及卵巢卵黄蛋白原表达量均高于其他组。卵巢组织切片显示出更高的卵黄颗粒沉积及较大的卵细胞面积。同时, 类固醇激素如雌二醇和孕酮水平显著提升, 表明南极磷虾冻干粉可能通过内分泌调节促进卵巢发育。血清代谢组学分析鉴定出三种与性腺发育密切相关的潜在标志代谢物: 磷脂酰胆碱、磷脂酰基醇和神经酰胺, 并通过 KEGG 富集分析发现这些代谢物显著富集于甘油磷脂代谢和糖基磷脂酰肌醇-锚生物合成通路, 并呈上调趋势。【结论】南极磷虾冻干粉相较于其他生物饵料, 表现出最优的生长促进及促熟效果, 有助于加强雌性凡纳对虾亲体的脂质运输及类固醇激素的合成与分泌。

关键词: 凡纳对虾; 亲体; 生物饵料冻干粉; 性腺发育; 内分泌调控。

资助项目: 海南省科技专项 (ZDYF2024XDNY185); 国家重点研发计划 (2023YFD2402000) 和海南省农业产业技术体系 (HNARS-10-ZJ05)。

通讯作者: 韩凤禄, E-Mail: flhan@hainanu.edu.cn; 李二超, E-Mail: ecli@bio.ecnu.edu.cn

Regulatory effect of freeze-dried biological bait powder on gonadal development and lipid metabolism in female *Penaeus vannamei* broodstock

Xianming Xiao¹, Xiaolong Liang¹, Tong Chang², Fenglu Han^{1*}, Erchao Li^{2*}

(1. School of Marine Biology and Fisheries, Hainan University, Haikou, Hainan 570228, China; 2. School of Life Sciences, East China Normal University, Shanghai 20024, China)

Abstract: **【Objective】** The aim of this study was to evaluate the effects of different biological feed freeze-dried powders on the gonadal development and lipid metabolism of female *Penaeus vannamei* broodstock and to identify potential marker metabolites related to gonadal development via metabolomics technology. **【Methods】** In this study, traditional fish meal was used as the main protein source for the control group, and freeze-dried powders of squid, nereid and Antarctic krill were used to replace 50% of the fish meal with equal protein to prepare four isonitrogen and lipid feeds. A 28-day nutritional fortification experiment was conducted on 240 female shrimps (initial body weight: 44.29 ± 0.42 g) at stage I of gonadal development. **【Result】** Freeze-dried powder from Antarctic krill significantly increased the weight gain rate of broodstock and promoted the accumulation and transport of hepatopancreatic lipids, as manifested by significant increases in the levels of total cholesterol, triglycerides, high-density lipoprotein and low-density lipoprotein in the hepatopancreas. In addition, the total antioxidant capacity of this group was significantly enhanced. In terms of ovarian development, the gonadal index, serum vitellogenin content and ovarian vitellogenin expression in the Antarctic krill group were greater than those in the other groups. The ovarian tissue sections presented greater yolk granule deposition and a larger oocyte area. Moreover, the levels of steroid hormones such as estradiol and progesterone significantly increased, indicating that freeze-dried Antarctic krill powder may promote ovarian development through endocrine regulation. Serum metabolomics analysis revealed three potential marker metabolites closely related to gonadal development: phosphatidylcholine, phosphatidyl alcohol and ceramide. KEGG enrichment analysis revealed that these metabolites were significantly enriched in glycerophospholipid metabolism and glycosylphosphatidylinositol-anchor biosynthesis pathways and tended to be upregulated. **【Conclusion】** Compared with other biological baits, the freeze-dried powder of Antarctic krill had the greatest growth-promoting and maturation-promoting effects, which helped to increase lipid transport and steroid hormone synthesis and secretion in female *P. vannamei* broodstock.

Keywords: *Penaeus vannamei*; broodstock; biological freeze-dried bait meal; gonadal development; endocrine regulation

饲料 DHA 对半滑舌鲷雄鱼性类固醇激素合成的调控作用

刘家豪, 马强, 张斐然, 高清岩, 张志君, 卫育良, 梁萌青, 徐后国

(中国水产科学研究院黄海水产研究所, 山东 青岛 266237)

摘要:【目的】长链多不饱和脂肪酸(LC-PUFA)在鱼类性类固醇激素的合成过程中起着关键作用。本研究旨在探讨二十二碳六烯酸(DHA)对半滑舌鲷雄鱼雄性类固醇激素合成的影响。

【方法】配制 3 种不同 DHA 水平的实验饲料: 对照组(总脂肪酸(TFA)中 DHA 占 5.16%)、低 DHA 组(DHA-L, 8.93%)和高 DHA 组(DHA-H, 16.47%)。进行为期 58 d 的投喂试验, 每个处理组 3 个重复。此外, 还对半滑舌鲷精巢细胞进行了体外研究, 以验证体内结果。【结果】血清睾酮(T)和 11-酮睾酮(11-KT)含量随饲料 DHA 含量的升高而升高。同时, 饲料中 DHA 可显著上调雄鱼性类固醇激素合成相关基因 *p450c17*、*hsd17b1*、*hsd3b1*、*aromatase*、*hsd11b2* 和 *p45011b* 的表达。DHA-H 组精巢中 Hsd17b1 蛋白表达量显著高于其他两组, 而 P450c17 蛋白表达量随饲料 DHA 含量的升高呈上升趋势。而体外实验结果证实, 最终浓度为 50 $\mu\text{mol/L}$ 的 DHA 可显著提高精巢细胞中 *p450c17* 基因的表达。【结论】综上所述, 饲料中 DHA 可能通过调节半滑舌鲷雄鱼一系列性类固醇激素关键合成酶的蛋白(Hsd17b1 和 P450c17)和基因(*P450c17*、*Hsd17b1*、*hsd3b1*、*aromatase*、*hsd11b2* 和 *p45011b*)表达促进 T 和 11-KT 的合成。

关键词: 22:6n-3; 性类固醇激素; 营养调控; 海水鲆鲽鱼类; 鱼类繁育。

Dietary DHA regulated the androgen production in male Chinese tongue sole *Cynoglossus semilaevis*

Jiahao Liu¹, Qiang Ma¹, Feiran Zhang¹, Qingyan Gao¹, Zhijun Zhang¹, Yuliang Wei¹, Mengqing Liang¹ and Houguo Xu^{1*}

(Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Qingdao China 266071)

Abstract: [Objective] Long-chain polyunsaturated fatty acids (LC-PUFA) play key roles in sex steroid hormone synthesis in fish. This study aimed to investigate the effects of docosahexaenoic acid (DHA) on the sex steroid hormone production in male Chinese tongue sole. Three experimental diets were prepared, containing different DHA levels: a Control group (C, 5.16% DHA of total fatty acids (TFA)), a low DHA group (DHA-L, 8.93%) and a high DHA group (DHA-H, 16.47%). A 58-day feeding experiment was conducted, and each diet was fed to triplicate tanks of fish. Additionally, an *in vitro* study with Leydig's cells of this species were conducted to validate the *in vivo* results. The concentration of testosterone (T) and 11-ketotestosterone (11-KT) in the serum increased with increasing levels of dietary DHA. Dietary DHA significantly upregulated the expression of steroid hormone biosynthetic genes *p450c17*, *hsd17b1*, *hsd3b1*, *aromatase*, *hsd11b2* and *p45011b* in the testis. The protein expression of Hsd17b1 in the testis of the DHA-H group was significantly higher compared to the other two groups, while the expression level of P450c17 showed an increasing trend with increasing dietary DHA levels. However, The *in vitro* results confirmed that the final concentration of DHA at 50 $\mu\text{mol/L}$ could significantly increase the gene expression of *p450c17* in Leydig's cells. In conclusion, dietary DHA may promote the synthesis of T and 11-KT through the regulation of protein (Hsd17b1 and P450c17) and gene (*p450c17*, *hsd17b1*, *hsd3b1*, *aromatase*, *hsd11b2*, and *p45011b*) expression of a series of key steroid hormone biosynthetic enzymes in male Chinese tongue sole.

Keywords: 22:6n-3; Sex steroid hormone; Nutritional regulation; Marine flatfish; Fish reproduction

资助项目：山东省自然科学基金-优秀青年基金（ZR2021YQ24）、中央公益性科研机构基础研究基金泰山学者奖励计划（2023TD52）、国家海水鱼产业技术体系（CARS-47）
通讯作者：徐后国，E-Mail: xuhg@ysfri.ac.cn

外源甾醇及胆固醇与磷脂配比对凡纳对虾卵巢发育的调控作用

16

梁小龙¹, 常通², 韩凤禄^{1*}, 徐畅¹, 李二超^{2*}

(1. 海南大学海洋生物与水产学院, 海南 海口 570228; 2. 华东师范大学生命科学学院, 上海 200241)

摘要:【目的】凡纳对虾 (*Penaeus vannamei*) 体内无法自主合成甾醇以及对磷脂的合成效率低, 卵巢发育高度依赖外源性甾醇和磷脂的补充。本研究系统探讨不同甾醇来源及胆固醇与磷脂配比对其卵巢发育的调控效应。【方法】以卵巢发育I期的雌性亲虾为研究对象, 通过 28 天的营养强化实验, 分别采用胆固醇、麦角甾醇、 β -谷甾醇和岩藻甾醇作为甾醇源, 探究其对卵巢发育的影响。【结果】胆固醇相较其余甾醇, 显著提高了性腺指数和卵黄颗粒沉积量, 同时增加了血清中 17 β -雌二醇和孕酮的水平, 并显著上调肝胰腺和卵巢中卵黄蛋白原基因的表达, 促进卵巢的成熟发育。此外, 胆固醇组显著增加了卵巢内关键脂质代谢物 (如 γ -亚麻酸和 9,10-环氧十八碳烯酸) 的积累, 并进一步确定 1.61%-1.68% 的添加水平为最优剂量。后续研究考察了胆固醇与大豆卵磷脂不同比例对生殖营养的影响, 胆固醇与磷脂 1:4 的配比在提升性腺指数、卵黄颗粒沉积和卵黄蛋白原基因表达方面表现出最佳效果。而且, 该配比显著提高了血清中与蛋白质合成相关的关键氨基酸代谢物浓度, 并促进了亚油酸和 γ -亚麻酸等脂质代谢物的积累, 为卵巢发育提供了充足的能量支持。【结论】胆固醇在促进凡纳对虾生殖发育方面具有显著优势, 且与磷脂的合理配比可进一步优化生殖营养效果, 为亲虾饲料配方的开发及生殖营养调控提供了重要理论依据。

关键词: 凡纳对虾; 亲虾; 甾醇; 磷脂; 生殖营养; 卵巢发育

资助项目: 海南省科技专项 (ZDYF2024XDNY185); 国家重点研发计划 (2023YFD2402000) 和海南省农业产业技术体系 (HNARS-10-ZJ05)。

通讯作者: 韩凤禄, E-Mail: flhan@hainanu.edu.cn; 李二超, E-Mail: ecli@bio.ecnu.edu.cn

Regulatory effects of exogenous sterols and cholesterol-phospholipid ratio on ovarian development in Pacific white shrimp (*Penaeus vannamei*)

Xiaolong Liang¹, Tong Chang², Fenglu Han^{1*}, Chang Xu¹, Erchao Li^{2*}

(1.School of Marine Biology and fisheries, Hainan University, Haikou, Hainan 570228, China; 2. School of Life Sciences, East China Normal University, Shanghai 20024, China)

Abstract: [Objective] The ovarian development of Pacific white shrimp (*Penaeus vannamei*) is highly dependent on exogenous sterol and phospholipids supplementation, as they cannot synthesize sterols endogenously and have low efficiency in synthesizing phospholipids. This study systematically investigates the effects of different sterol sources and the cholesterol-phospholipid ratio on ovarian development. [Methods] Using female broodstock in the ovarian development stage I as the research subject, a 28-day nutritional fortification experiment was conducted using cholesterol, ergosterol, β -sitosterol, and fucoxanthin as sterol sources. [Results] Cholesterol significantly increased the gonadosomatic index, yolk granule deposition, and elevated serum levels of 17β -estradiol and progesterone. Additionally, cholesterol upregulated vitellogenin mRNA expression in both the hepatopancreas and ovary, promoting ovarian maturation. Cholesterol also markedly increased the accumulation of key lipid metabolites, such as γ -linolenic acid and 9,10-epoxyoctadecenoic acid in the ovary, with an optimal cholesterol supplementation level identified at 1.61%-1.68%. Subsequently, the study examined the effects of different cholesterol and soy lecithin ratios on the reproductive nutrition of shrimp. The findings revealed that a cholesterol-to-phospholipid ratio of 1:4 exhibited the most pronounced effects on improving gonadosomatic index, yolk granule deposition, and vitellogenin mRNA expression. Moreover, this ratio significantly upregulated key amino acid metabolites in serum, such as L-valine and L-aspartic acid, promoting protein synthesis. Simultaneously, the accumulation of lipid metabolites, including linoleic acid and γ -linolenic acid, provided ample energy for ovarian development. [Conclusion] Cholesterol plays a pivotal role in enhancing reproductive development in shrimp, and an optimized cholesterol-phospholipid ratio can further enhance its efficacy, providing a theoretical foundation for broodstock feed formulation and reproductive nutrition.

Key words: *Penaeus vannamei*; Broodstock; Sterols; Phospholipids; Reproductive nutrition, Ovarian development

维生素 E 促进半滑舌鳎生长及繁育的内分泌机制解析

王蔚芳

(海水养殖生物育种与可持续产出全国重点实验室, 中国水产科学研究院黄海水产研究所, 山东 青岛 266071)

摘要: 【目的】维生素 E, 又名生育酚, 在鱼类生长、免疫、抗病、繁育等方面发挥重要作用, 其作用机理主要归结为维生素 E 的抗氧化功能。近年来有关维生素 E 的非抗氧化功能, 如基因调节、内分泌调控等功能被陆续报道。因此, 本研究拟从内分泌角度探讨维生素 E 促进半滑舌鳎成鱼生长与繁育的作用机制。【方法】作者在每千克等氮等能的基础饲料中, 分别添加 0、400 和 1 600 mg 的 DL- α -生育酚乙酸酯 (维生素 E) 投喂半滑舌鳎 (*Cynoglossus semilaevis*) 成鱼 (464 ± 2.6) g, 进行为期 8 周的养殖实验; 另外, 在 L-15 培养基中添加 0、18 和 54 $\mu\text{mol/L}$ 的维生素 E, 对半滑舌鳎成鱼的垂体细胞进行为期 3 d 的体外原代培养实验; 分别检测生长数据及垂体组织和垂体原代细胞中生长激素 (GH) 和促性腺激素 (GtH) 基因表达水平, 并检测细胞蛋白激酶 A (PKA) 信号通路各指标。【结果】结果表明, (1) 饲料中添加 400 mg/kg 的维生素 E 促进半滑舌鳎成鱼的生长; (2) 垂体组织中 GH mRNA 的相对表达量随着饲料中维生素 E 含量的增加而呈现先升高后下降的变化趋势, 在 400 mg/kg 组时显著高于其他各组; 随着细胞培养液中维生素 E 浓度的升高, GH mRNA 的相对表达量显著增加; (3) 饲料中添加 400 和 1600 mg/kg 的维生素 E 能够显著提高垂体组织中 GtH 蛋白表达和基因表达水平; 细胞上清液中 GtH 的分泌水平随维生素 E 含量的增加而显著升高, 细胞中 GtH 基因的 mRNA 表达也显著上调, 细胞的免疫组化显示 GtH 分泌细胞增大; (4) 维生素 E 促进细胞内 NO 合酶 (NOS) 升高并提高细胞内 NO 含量, 解除了抑制型 G 蛋白 (Gi) 对腺苷酸环化酶 (AC) 的抑制, 从而提升细胞内环腺苷酸 (cAMP) 浓度, 并促进了 GtH 基因表达。【结论】研究表明, 半滑舌鳎成鱼饲料中维生素 E 的适宜添加量为 400 mg/kg, 并能够促进其垂体中 GH 和 GtH 的基因表达, 是由垂体细胞内 NO-PKA 信号通路介导实现的。本研究立足营养和繁殖内分泌交叉学科, 从细胞层面探讨营养素发挥生殖调控的作用机制, 为亲鱼营养调控机制研究提供新思路。

关键词: 半滑舌鳎 (*Cynoglossus semilaevis*); 维生素 E; 生长激素; 促性腺激素; 垂体原代细胞; NO-PKA 信号通路

资助项目: 国家自然科学基金青年、面上项目 (31502177、31872578)、国家海水鱼产业技术体系 (CARS-47)、

通讯作者: 王蔚芳, E-Mail: wangwf@ysfri.ac.cn

Endocrine mechanism of vitamin E in promoting the growth and breeding of half-smooth tongue sole

Weifang Wang

(State Key Laboratory of Mariculture Biobreeding and Sustainable Goods, Yellow Sea Fisheries Research

Institute, Chinese Academy of Fishery Sciences, Qingdao, China 266071)

Abstract: [Objective] Vitamin E, also known as tocopherol, plays an important role in fish growth, immunity, disease resistance and breeding, and its action mechanism is mainly attributed to the antioxidant function of vitamin E. In recent years, the non-antioxidant functions of vitamin E, such as gene regulation and endocrine regulation, have been reported successively. Therefore, this study intends to explore the mechanism of vitamin E in promoting the growth and breeding of half-smooth tongue sole from the perspective of endocrine. [Methods] In the basic formulation, DL- α -tocopherol acetate (vitamin E) were supplemented with graded level of 0, 400 and 1600 mg/kg to fed adult half-smooth tongue sole (*Cynoglossus semilaevis*) (464 ± 2.6) g for 8-week; in addition, In L-15 cell culture medium, 0, 18 and 54 $\mu\text{mol/L}$ of vitamin E were added into the *In vitro* primary pituitary cells of half-smooth tongue sole for 3d; Growth data and the gene expression levels of growth hormone (GH) and gonadotropin hormone (GtH) in pituitary tissue and pituitary primary cells were tested, The cellular protein kinase A (PKA) signaling pathway was also measured. [Results] The results showed that, (1) Inclusion of 400 mg/kg dietary vitamin E promoted the growth of semi-smooth tongue sole; (2) the relative expression of GH mRNA in pituitary tissue increased firstly and then decreased with the increasing of dietary vitamin E content, It was significantly higher in the group of 400 mg/kg than in the other groups; With increasing concentrations of vitamin E in the cell culture medium, the relative expression level of GH mRNA has increased significantly; (3) The supplementation of 400 and 1600 mg/kg of dietary vitamin E can significantly improve the GtH protein expression and gene expression level in the pituitary tissues; The level of GtH secretion in the cell supernatant increased significantly with increasing vitamin E content, the mRNA expression of the GtH gene was also significantly upregulated in the cells, Immunohistochemistry of the cells showed enlarged GtH-secreting cells; (4) Vitamin E promoted the increase of intracellular NO synthase (NOS) and intracellular NO content, which resulted in the releasing of adenylyl cyclase (AC) by the inhibitory of G protein (Gi), then increasing the intracellular cyclic adenylylate (cAMP) concentration, and promoting GtH gene expression. [Conclusion] Studies have shown that the appropriate dietary vitamin E for adult tongue sole is 400 mg/kg to promote the gene expression of GH and GtH in the pituitary gland, which is achieved by NO-PKA signaling pathway in pituitary cells. Based on the interdisciplinary of nutrition and reproductive endocrine, this study explored the new ideas for the mechanism study of broodstock fish through nutritional pathway in the cell level .

Keywords: Half-smooth tongue sole; Vitamin E; Growth hormone; Gonadotropin hormone; Primary pituitary cells; NO-PKA signaling pathway

虾青素对罗氏沼虾亲体性腺发育的影响

陶明伟^{1,2,3}, 周航先^{1,2,3}, 魏杰^{1,2,3}, 徐奇友^{1,2,3*}

(1.湖州师范学院生命科学学院, 浙江 湖州 313000; 2.水生动物繁育与营养国家地方联合工程实验室, 浙江 湖州 313000; 3.浙江省水生生物资源养护与开发技术研究重点实验室, 浙江 湖州 313000)

摘要: 本研究旨在探讨虾青素对雌性罗氏沼虾 (*Macrobrachium rosenbergii*) 性腺发育的影响。实验设计 5 种等氮等脂饲料, 虾青素实际含量为 0、27、62、140 和 310 mg/kg, 分别命名为 AS0、AS30、AS60、AS150 和 AS300, 养殖试验 56d。结果表明, 实验组的增重率 (WG)、特定生长率 (SGR) 显著高于 AS0 ($P < 0.05$)。AS60、AS150 和 AS300 组的存活率 (SR) 显著高于 AS0 和 AS30 组 ($P < 0.05$)。AS60 组的性腺指数 (GSI) 显著高于 AS0 和 AS30 组 ($P < 0.05$)。AS60、AS150 组卵黄蛋白原 (VTG) 含量显著高于 AS0 ($P < 0.05$)。AS30、AS60 组睾酮 (T) 含量显著高于 AS300 组 ($P < 0.05$)。AS60、AS150 组雌二醇 (E_2) 含量显著高于 AS0、AS30、AS300 组 ($P < 0.05$)。AS60、AS150 和 AS300 组丙二醛 (MDA) 含量显著低于 AS0 和 AS30 组 ($P < 0.05$)。AS150 组总抗氧化 (T-AOC) 能力显著高于 AS0、AS30 组 ($P < 0.05$)。AS60 组超氧化物歧化酶 (SOD) 活力显著高于 AS0、AS30 和 AS300 组 ($P < 0.05$)。通过对性腺组织进行转录组分析发现, 差异表达基因主要涉及“磷酸戊糖途径 (Pentose phosphate pathway)”“谷胱甘肽代谢 (Glutathione metabolism)”“泛醌和其他萜醌生物合成 (Ubiquinone and other terpenoid-quinone biosynthesis)” ($P < 0.05$) 等通路。此外, 与对照组相比, AS150 组磷酸戊糖途径和谷胱甘肽代谢相关基因葡萄糖-6-磷酸脱氢酶 (*g6pd*)、果糖-1,6-二磷酸酶 (*fbp*)、谷胱甘肽过氧化物酶 (*gpx*)、氨基肽酶 N (*anpep*) 表达量显著上调 ($P < 0.05$)。综上所述, 饲料中添加虾青素可改善罗氏沼虾亲体性腺发育、抗氧化能力和性激素水平, 上调“磷酸戊糖途径”、“谷胱甘肽代谢”和“泛醌和其他萜类醌生物合成”等通路相关基因表达。基于本研究结果, 罗氏沼虾亲体饲料中虾青素的推荐含量为 155.87 mg/kg ~ 184.04 mg/kg。本研究为虾青素影响性腺发育的机制提供了新的见解。

关键词: 虾青素; 罗氏沼虾; 抗氧化; 性腺发育

The effect of astaxanthin on the gonadal development of broodstock *Macrobrachium rosenbergii*

Mingwei Tao¹²³, Jie Wei¹²³, Hangxian Zhou¹²³, Qiyu Xu^{123,*}

(1.College of Life Science, Huzhou Normal University, Huzhou 313000, China; 2.National and Local Joint Engineering Laboratory of Aquatic Animal Breeding and Nutrition, Huzhou 313000, China; 3.Zhejiang Provincial Key Laboratory for Conservation and Development of Aquatic Biological Resources, Huzhou 313000, China)

Abstract: The study aimed to investigate the effects of astaxanthin on ovarian development in female *Macrobrachium rosenbergii*. Five isonitrogenous and isolipidic diets were designed, with actual astaxanthin contents of 0, 27, 62, 140, and 310 mg/kg, named AS0, AS30, AS60, AS150, and AS300, respectively. The feeding trial lasted for 56 days. The results showed that the weight gain and specific growth rate in the experimental groups were significantly higher than those in the AS0 ($P < 0.05$). The survival rate in the AS60, AS150, and AS300 groups was significantly higher than that in the AS0 and AS30 groups ($P < 0.05$). The gonadosomatic index (GSI) in the AS60 group was significantly higher than that in the AS0 and AS30 groups ($P < 0.05$). The vitellogenin (VTG) content in the AS60 and AS150 groups was significantly higher than that in the AS0 ($P < 0.05$). The testosterone (T) content in the AS30 and AS60 groups was significantly higher than that in the AS300 group ($P < 0.05$). The estradiol (E₂) content in the AS60 and AS150 groups was significantly higher than that in the AS0, AS30, and AS300 groups ($P < 0.05$). The malondialdehyde (MDA) content in the AS60, AS150, and AS300 groups was significantly lower than that in the AS0 and AS30 groups ($P < 0.05$). The total antioxidant capacity (T-AOC) in the AS150 group was significantly higher than that in the AS0 and AS30 groups ($P < 0.05$). The superoxide dismutase (SOD) activity in the AS60 group was significantly higher than that in the AS0, AS30, and AS300 groups ($P < 0.05$). Transcriptome analysis of gonadal tissues revealed that differentially expressed genes were mainly involved in pathways such as the “pentose phosphate pathway”, “glutathione metabolism”, and “ubiquinone and other terpenoid-quinone biosynthesis” ($P < 0.05$). Furthermore, compared to the control group, genes related to the pentose phosphate pathway and glutathione metabolism, such as glucose-6-phosphate dehydrogenase (*g6pd*), fructose-1,6-bisphosphatase (*fbp*), glutathione peroxidase (*gpx*), and aminopeptidase N (*anpep*), were significantly upregulated in the AS150 group ($P < 0.05$). In conclusion, the addition of astaxanthin to the diet improves gonadal development, antioxidant capacity, and sex hormone levels of broodstock *Macrobrachium rosenbergii*, upregulates genes related to the pentose phosphate pathway, glutathione metabolism, and ubiquinone and other terpenoid-quinone biosynthesis pathways. Based on the results of this study, the recommended astaxanthin content in broodstock diets for *Macrobrachium rosenbergii* is

资助项目：“领雁”研发攻关计划（2023C02024）

通信作者：徐奇友，从事动物营养与饲料研究，E-mail: 02655@zjhu.edu.cn

155.87 mg/kg to 184.04 mg/kg. The study provides new insights in the mechanisms by which astaxanthin affects gonadal development.

Keywords: Astaxanthin; *Macrobrachium rosenbergii*; antioxidation; gonadal development

小肽对罗氏沼虾 (*Macrobrachium rosenbergii*) 亲体卵巢发育的影响

魏杰^{1,2,3}, 陶明伟^{1,2,3}, 周航先^{1,2,3}, 徐奇友^{1,2,3,*}

(1.湖州师范学院生命科学学院; 2.水生动物繁育与营养国家地方联合工程实验室; 3.浙江省水产资源保护与开发重点实验室, 浙江 湖州 313000)

摘要: 探究两种小肽在不同水平鱼粉饲料对罗氏沼虾 (*Macrobrachium rosenbergii*) 雌性亲体卵巢发育的影响。实验设计 2 个鱼粉水平 (20% FM 和 40% FM) 基础饲料, 分别添加两种小肽 (SP1 和 SP2) 等蛋白替代 5% 鱼粉制成 6 组等氮等脂饲料, 分别标记为 L0、L1、L2、H0、H1 和 H2。罗氏沼虾雌性亲体 (初始体重: 8.61 ± 0.79 g) 720 尾, 平均分为 6 个组, 每组 4 个重复, 每个重复 30 尾。养殖实验 56 天。结果表明, 20% FM 组末重、增重率(WG)、性腺指数 (GSI) (0.33 ± 0.10 %) 和卵巢 *e75* 表达量显著高于 40% FM 组 (0.28 ± 0.10 %) ($P < 0.05$); 而 40% FM 组饲料系数、血清雌二醇 (E2) 含量和肝脏过氧化氢酶 (CAT) 活性显著高于 20% FM 组 ($P < 0.05$)。SP1 组 E2、卵黄蛋白原 (Vtg) 含量和卵巢 *srebp1* 表达量显著高于 SP2 组 ($P < 0.05$); SP2 组血清总胆固醇 (TC) 和低密度脂蛋白胆固醇 (LDL-C) 含量显著高于 SP1 组 ($P < 0.05$); SP2 组的肝脏碱性磷酸 (AKP) 活性显著高于未添加 SP 组 ($P < 0.05$)。L1 组肝脏酸性磷酸酶 (ACP)、CAT 活性和丙二醛 (MDA) 含量显著高于 L0 组 ($P < 0.05$)。综上所述, 20% FM 可以促进罗氏沼虾的生长和卵巢发育; 饲料中添加 5% SP1 可以促进 Vtg 的分泌; 添加 5% SP2 可以促进肝脏免疫。本研究为罗氏沼虾亲体人工配合饲料配制提供参考价值。

关键词: 亲体营养; 卵巢发育; 罗氏沼虾; 小肽。

资助项目: 浙江省‘领雁’研发攻关计划(2023C02024)

通信作者: 徐奇友, E-mail: xuqiyou@sina.com。

Effects of small peptides on the ovarian development of broodstock in *Macrobrachium rosenbergii*

Wei Jie^{1,2,3}, Tao Mingwei^{1,2,3}, Zhou Hangxian^{1,2,3}, Xu Qiyu^{1,2,3,*}

(1. College of Life Science, Huzhou University, Huzhou 313000, PR China; 2. Nation Local Joint Engineering Laboratory of Aquatic Animal Genetic Breeding and Nutrition; 3. Zhejiang Provincial Key Laboratory of Aquatic Bioresource Conservation and Development Technology, Huzhou 313000, PR China)

Abstract: To investigate the effects of two small peptides in different fishmeal levels diets on the ovarian development of female broodstock of *Macrobrachium rosenbergii*, two basal diets with fishmeal levels (20% FM and 40% FM) were designed, with two small peptides (SP1 and SP2) added as 5% fishmeal substitutes respectively, resulting in six isonitrogenous and isolipidic diets, labeled L0, L1, L2, H0, H1, and H2. 720 female broodstock (initial weight: 8.61 ± 0.79 g) were equally divided into 6 groups, with 4 replicates per group and 30 per replicate. The feeding trial lasted for 56 days. The results showed that the final weight, weight gain (WG), gonadosomatic index (GSI) ($0.33 \pm 0.10\%$), and ovarian *e75* expression in the 20% FM group were significantly higher than those in the 40% FM group ($0.28 \pm 0.10\%$) ($P < 0.05$); meanwhile, the feed conversion ratio, serum estradiol (E2) levels, and hepatic catalase (CAT) activity in the 40% FM group were significantly higher than those in the 20% FM group ($P < 0.05$). The E2 levels, vitellogenin (Vtg) content, and ovarian *srebpl* expression in the SP1 group were significantly higher than those in the SP2 group ($P < 0.05$); serum total cholesterol (TC) and low-density lipoprotein cholesterol (LDL-C) levels in the SP2 group were significantly higher than those in the SP1 group ($P < 0.05$); the hepatic alkaline phosphatase (AKP) activity in the SP2 group was significantly higher than that in the group without SP supplementation ($P < 0.05$). Hepatic acid phosphatase (ACP) activity, CAT activity, and malondialdehyde (MDA) content in the L1 group were significantly higher than those in the L0 group ($P < 0.05$). In conclusion, 20% FM can promote the growth and ovarian development of *Macrobrachium rosenbergii*; the addition of 5% SP1 in the feed can enhance Vtg secretion; the addition of 5% SP2 can boost liver immunity. This study provides valuable reference for the formulation of artificial broodstock diets for *Macrobrachium rosenbergii*.

Keywords: broodstock nutrition; ovarian development; *Macrobrachium rosenbergii*; small peptides.

专题四

新型饲料原料和添加剂的研发与应用

18 β -甘草次酸对高脂日粮诱导大口黑鲈肝损伤的影响

赵菊¹, 姜俊^{1,2*}

(1.四川农业大学动物科技学院, 四川 成都 611130; 2.四川农业大学鱼类营养与安全生产四川省高校重点实验室, 四川 雅安 625014)

摘要: 脂肪是鱼类生长的必不可少的营养素。在养殖过程中, 适当提高饲料中脂肪水平, 不但可以有效地促进鱼类的生长, 还能有效地改善养殖环境。但饲料中过高的脂肪水平会导致鱼类出现肝脏受损, 严重时, 甚至导致鱼类肝脏出现肝损伤, 进而影响鱼类的生长。针对这一问题, 本研究以我国重要的经济鱼类-大口黑鲈 (*Micropterus salmoides*) 为实验对象, 探讨 18 β -甘草次酸 (18 β -glycyrrhetic acid, GA) 对高脂日粮诱导的大口黑鲈肝损伤的缓解作用。以鱼粉、鸡肉粉、豆粕为主要蛋白源, 豆油为主要的脂肪源。分别配制对照组、高脂日粮组、高脂日粮加 GA 0.5 mg/kg 组、高脂日粮加 GA 1.0 mg/kg 组和高脂日粮加 GA 1.5 mg/kg 组。选取初均重为 17.39 ± 0.09 g 健康大口黑鲈 750 尾, 随机分配到 15 个方形水泥池中 ($200 \times 100 \times 105$ cm³), 每个水泥池 50 尾, 饲养 11 周。结果表明, 高脂日粮会上调大口黑鲈肝功能相关酶的活力, 增加肝脏脂滴沉积, 胶原的聚集, 而添加 GA 后降低了肝功能相关酶的活力, 减少肝脏脂肪变性, 脂滴沉积和胶原纤维聚集, 从而来缓解高脂日粮诱导的大口黑鲈肝损伤; 高脂日粮饲喂大口黑鲈后会上调促纤维化标志物的表达; 而添加 GA 处理后, 可通过下调 TGF β 1 介导的 Smad2/3 信号来降低促纤维化标志物的表达, 从而来缓解高脂日粮诱导大口黑鲈肝纤维化; 高脂日粮饲喂大口黑鲈会导致其线粒体的损伤, 增加 ROS 含量; 而 GA 可通过上调线粒体 MMP 和 ATP 含量, 下调 ROS 含量, 保护线粒体膜、线粒体嵴和内质网免受高脂日粮导致的线粒体损伤, 从而改善线粒体功能; 虚拟对接分析发现, GA 与 Sirt3 之间的对接能量为 -9.0 kcal/mol, 两者可以稳定结合。通过 Sirt3 siRNA 实验进一步证实, 表明 GA 可能通过调控 Sirt3 表达来影响线粒体钙单转运体 (Mcu) 的表达, 从而降低线粒体钙离子含量。上述结果表明, GA 具有抗脂肪变性和抗纤维化作用, 并可以通过调节 Sirt3 表达维持线粒体钙离子含量。因此, GA 作为一种有前途的饲料添加剂, 在预防鱼类肝损伤方面具有潜在的效用。

关键词: 18 β -甘草次酸; 高脂日粮; 大口黑鲈; 肝损伤; 肝脏纤维化; 线粒体损伤

资助项目: 国家自然科学基金 (32172987)

通讯作者: 姜俊, Email:jjun@sicau.edu.cn

Effects of 18 β -glycyrrhetic acid on liver injury of largemouth bass induced by high fat diet

Ju Zhao¹, Jun Jiang^{1,2*}

(1 College of Animal Science and Technology, Sichuan Agricultural University, Chengdu 611130;
2 Fish Nutrition and Safety Production University Key Laboratory of Sichuan Province, Sichuan Agricultural University, Ya'an 625014)

Abstract: Fat is an essential nutrient for fish growth. In the breeding process, appropriately increasing the level of fat in feed can not only effectively promote the growth of fish, but also effectively improve the breeding environment. However, the high level of fat in the feed will lead to liver damage in fish, and even lead to liver damage in fish, which will affect the growth of fish. To solve this problem, this study took largemouth bass (*Micropterus salmoides*), an important economic fish in China, as the experimental object to investigate the alleviating effect of 18 β -glycyrrhetic acid (GA) on the liver injury of largemouth bass induced by high fat diet. Fish meal, chicken meal, soybean meal as the main protein source, soybean oil as the main fat source. Control group, high fat diet group, high fat diet plus GA 0.5 mg/kg group, high fat diet plus GA 1.0 mg/kg group and high fat diet plus GA 1.5 mg/kg group were prepared respectively. A total of 750 healthy largemouth bass with an initial average weight of 17.39 ± 0.09 g were randomly assigned to 15 square cement pools ($200 \times 100 \times 105$ cm³) with 50 bass in each pool for 11 weeks. The results showed that high-fat diet regulated the activity of liver function related enzymes, increased liver fat drop deposition and collagen aggregation, while GA supplementation decreased the activity of liver function related enzymes, reduced liver steatosis, lipid drop deposition and collagen fiber aggregation, and thus alleviated liver injury induced by high-fat diet. The expression of fibrosis markers in largemouth bass fed with high fat diet was up-regulated. After addition of GA treatment, the expression of pro-fibrosis markers could be reduced by down-regulating TGF β 1-mediated Smad2/3 signal, so as to alleviate liver fibrosis induced by high-fat diet. Feeding largemouth bass with high fat diet can cause mitochondrial damage and increase ROS content. GA can protect mitochondrial membrane, mitochondrial ridge and endoplasmic reticulum from mitochondrial damage caused by high fat diet by up-regulating mitochondrial MMP and ATP content and down-regulating ROS content, thereby improving mitochondrial function. Virtual docking analysis shows that the docking energy between GA and Sirt3 is -9.0 kcal/mol, and the two can be stably combined. Sirt3 siRNA experiments further confirmed that GA may affect the expression of mitochondrial calcium montransporter (Mcu) by regulating the expression of Sirt3, thereby reducing the content of mitochondrial calcium ions. These results indicate that GA has anti-steatosis and anti-fibrosis effects, and can maintain mitochondrial calcium content by regulating Sirt3 expression. Therefore, GA as a promising feed additive has potential utility in preventing liver injury in fish.

Keywords: 18 β -glycyrrhetic acid; High-fat diet; Largemouth bass; Liver injury; Liver fibrosis; Mitochondrial damage

阿魏酸对草鱼生长性能和消化吸收能力的影响及其机制研究

冯琳¹, 邵绪远¹, 吴培¹, 姜维丹¹, 刘杨¹, 马耀斌¹, 任红梅¹, 金小琬¹, 史合群², 周小秋^{1,*}

(1.四川农业大学动物营养研究所, 成都 611130; 2.广州科虎生物科技有限公司, 广州 510663)

摘要: 阿魏酸是一种植物酚类添加剂, 据报道其对草鱼幼鱼生长有促进作用, 但相关分子机制尚不清楚。因此, 本研究进一步考察了阿魏酸对草鱼 (*Ctenopharyngodon idellus*) 生长性能、消化能力以及氨基酸和寡肽转运功能的影响。试验选取 375 尾健康草鱼 (678.83 ± 1.00g) 随机分为 5 组 (阿魏酸添加水平分别为 0、50、100、150 和 200 mg/kg), 生长试验周期为 63 天, 同时开展为期 14 天的消化试验。研究表明, 饲料中添加 100-200 mg/kg 的阿魏酸 1) 显著提高了草鱼采食量、增重百分比、饲料效率以及粗蛋白和脂肪的表观消化率 ($P < 0.05$); 2) 显著提高了草鱼肠道胰蛋白酶和 Na^+/K^+ -ATP 酶活性 ($P < 0.05$), 但对脂肪酶、淀粉酶和碱性磷酸酶无显著影响; 3) 显著上调了部分中性和碱性氨基酸转运蛋白 mRNA 水平 (SLC7A7、SLC7A8、SLC6A6、SLC6A14 和 SLC6A19b, $P < 0.05$) 以及 PepT1 mRNA 和蛋白水平 ($P < 0.05$), 但对酸性氨基酸转运体的 mRNA 表达无显著影响。进一步研究发现, 阿魏酸促进上述氨基酸转运载体基因表达可能与 Akt/TOR 信号通路有关; 同时, 阿魏酸促进 PepT1 的转录可能与草鱼肠道瘦素含量增加 ($P < 0.05$) 以及转录相关因子 CREB、Cdx2 和 Sp1 的 mRNA 水平上调有关; 此外, 阿魏酸还可能通过下调蛋白激酶 C β II 基因和蛋白水平来提高 PepT1 的转运活性。最后, 通过线性回归分析, 以增重百分比和饲料效率为标识, 确定阿魏酸在草鱼成鱼饲料配方中的适宜添加水平分别为 102.94 和 103.92 mg/kg。综上所述, 饲料中添加阿魏酸可提高草鱼的生长性能和消化吸收能力, 包括氨基酸和寡肽的转运能力, 而这可能与草鱼肠道中部分氨基酸转运载体 (Akt/TOR) 和 PepT1 (Leptin/CREB/Cdx2/Sp1) 的上调有关。

关键词: 阿魏酸; 草鱼; 消化吸收; PepT1; 氨基酸转运载体

通讯作者: 周小秋, 教授, 博士生导师

E-mail: zhouxq@sicau.edu.cn (周小秋)

基金项目: 国家现代农业产业技术体系 (CARS-45); 国家自然科学基金项目 (32273144, 32072985); 国家重点研发计划“蓝色粮仓科技创新”重点专项 (2019YFD0900200)

白藜芦醇改善西伯利亚鲟的消化能力和肠道健康，并提高其抗热应激能力

徐紫涵¹，徐文强¹，冯浪坤¹，张朝阳²，杜小刚²，李云坤²，杨世勇^{1*}

(1.四川农业大学动物科技学院，四川 成都 611130；2.四川农业大学生命科学学院，四川 雅安 625014)

摘要：夏季水温升高引发的热应激导致包括西伯利亚鲟(*Acipenser baerii*)在内的鲟类健康养殖产业发展受阻，寻找合适的添加剂保护肠道正常生理功能对于西伯利亚鲟健康养殖至关重要。本研究旨在探究白藜芦醇对西伯利亚鲟肠道消化能力和肠道健康的影响，以及白藜芦醇对热应激下西伯利亚鲟肠道的保护作用。在饲料中补充不同浓度的白藜芦醇，通过组织病理学观察、酶活检测、16S rRNA 基因测序和转录组学分析等方法进行探究。结果表明，白藜芦醇增加了西伯利亚鲟的肠绒毛高度以及相关消化酶活性，改变了肠道中微生物群落的丰度和组成。热应激处理下白藜芦醇改善了西伯利亚鲟肠道形态并提高肠道抗氧化酶活性，进一步转录组学分析表明，白藜芦醇激活了肠道 PPAR 和 NF- κ B 信号通路的表达。总的来说，白藜芦醇可以改善西伯利亚鲟的消化能力和肠道健康，推测其可以通过 PPAR 信号通路和 NF- κ B 信号通路分别调控肠道的脂质代谢和免疫功能，保护西伯利亚鲟免受热应激损伤。

关键词：白藜芦醇；西伯利亚鲟；肠道；消化；热应激

Resveratrol improves the Siberian sturgeon's digestive capacity and gut health, as well as increase its resistance to heat stress

Zihan Xu¹, Wenqiang Xu¹, Langkun Feng¹, Chaoyang Zhang², Xiaogang Du², Yunkun Li²,
Shiyong Yang^{1*}

(1. College of Animal Science & Technology, Sichuan Agricultural University, Chengdu China 611130; 2. College of Life Science, Sichuan Agricultural University, Ya'an China 625014)

Abstract: The rise in water temperature during the summer, which triggers heat stress, has impeded the development of healthy aquaculture industries for sturgeon species, including Siberian sturgeon. Identifying appropriate additives to protect the normal physiological functions of the intestine is crucial for the healthy cultivation of Siberian sturgeon. This study aims to investigate the impact of resveratrol on the intestinal digestive capacity and gut health of Siberian sturgeon, as well as its protective effect on the intestine under heat stress conditions. Supplementing the diet with varying concentrations of resveratrol, the investigation was conducted using methods such as histopathological observation, enzyme activity assays, 16S rRNA gene sequencing, and transcriptome analysis. The results indicate that resveratrol increases the height of intestinal villi and the activity of related digestive enzymes in Siberian sturgeon, and alters the abundance and composition of the gut microbiota. Under heat stress conditions, resveratrol improves intestinal morphology and enhances the activity of intestinal antioxidant enzymes in Siberian sturgeon. Further transcriptome analysis suggests that resveratrol activates the expression of PPAR and NF- κ B signaling pathways in the intestine. In summary, resveratrol can improve the digestive capacity and intestinal health of Siberian sturgeon. It is hypothesized that resveratrol may modulate intestinal lipid metabolism and immune function through the PPAR signaling pathway and the NF- κ B signaling pathway, respectively, thereby protecting Siberian sturgeon from heat stress injury.

Keywords: Resveratrol; Siberian sturgeon; Intestinal; Digestion; Heat stress

资助项目：四川省重点研发计划(2021YFYZ0015)、四川省自然科学基金(2022NSFSC0070)、四川省科技成果转化示范项目(2021ZHCG0065)、四川省自然科学基金青年基金(2022NSFSC1723)

通讯作者：杨世勇，E-Mail: yangshiyong@sicau.edu.cn

不同蛋白水平饲料中添加 α -酮戊二酸对中华绒螯蟹 (*Eriocheir sinensis*) 生长和蛋白质代谢的影响

李进平¹, 李雯¹, 王晓丹¹, 李二超¹, 陈立侨^{1*}

(1.华东师范大学生命科学学院, 上海 200241)

摘要:【目的】低蛋白饲料的开发是降低水产养殖成本和减少环境污染的重要途径, 而其关键在于提高蛋白质利用效率。 α -酮戊二酸(AKG)是三羧酸循环中的关键中间体和谷氨酸合成前体, 其在能量代谢和氨基酸代谢中起重要作用。本研究旨在探究不同蛋白水平饲料中添加 α -酮戊二酸对中华绒螯蟹生长和蛋白质代谢的影响。【方法】采用 3×3 双因子设计, 设置试验 3 种饲料蛋白水平(38%、33%、28%)和 3 种 AKG 水平(0%、0.05%和 1%)配置 9 种等脂饲料, 饲喂幼蟹(0.58±0.02g) 8 周。【结果】结果表明, 与 38%蛋白组相比, 低蛋白组(33%和 28%)显著降低幼蟹的增重率和特定增长率($p<0.05$), 添加 0.5%和 1%AKG 显著提高了幼蟹的生长性能, 降低了饲料系数, 提高全蟹和肌肉粗蛋白含量。添加 1%AKG 能显著降低 28%蛋白组血清尿素氮含量, 提高氨基酸利用率和血清蛋白含量, 同时提高肝胰腺中消化酶的活性, 促进营养物质消化吸收。此外, 1%AKG 显著提高 28%蛋白组肝胰腺谷氨酸相关代谢酶活性, 促进谷氨酸代谢, 提高非必需氨基酸代谢水平, 由此节约必需氨基酸; 同时上调了 mTOR 信号通路相关基因的表达水平, 促进蛋白质合成。【结论】综上, 饲料蛋白水平过低会抑制中华绒螯蟹生长, 而添加 1%AKG 可以通过提高消化酶活性、促进氨基酸代谢和激活 mTOR 信号通路, 改善低蛋白饲料的利用效率。

关键词: α -酮戊二酸; 低蛋白饲料; 蛋白质代谢

Effect of alpha-ketoglutarate supplementation on growth and protein metabolism in Chinese Mitten crab (*Eriocheir sinensis*) under varying protein diets

Jinping Li¹, Wen Li¹, Xiaodan Wang¹, Erchao Li¹, Liqiao Chen^{1*}

(1. Laboratory of Aquaculture Nutrition and Environmental Health, School of Life Sciences, East China Normal University, Shanghai China 200241)

Abstract : [Objective] Low protein feed is an important way to reduce aquaculture cost and environmental pollution, and the key is to improve protein utilization efficiency. Alpha-ketoglutaric acid (AKG), an intermediate of the TCA cycle and precursor of glutamate synthesis, serves diverse functions, including promoting protein synthesis and acting as an oxidative fuel source. This study aims to investigate effect of alpha-ketoglutarate supplementation on growth and protein metabolism in Chinese Mitten crab (*Eriocheir sinensis*) under varying protein diets. [Methods] The 8-week growth trial included three dietary protein levels (38%, 33% or 28%) crossing three AKG levels (0%, 0.05% or 1%). In the trial, (0.58±0.02 g) crab was selected for 3 × 3 factor test. [Results] The low protein group (33% and 28%) significantly reduced the weight gain rate and specific growth rate of juvenile crabs compared to 38% ($p < 0.05$). 0.5% and 1% AKG additives significantly improved the growth performance of juvenile crabs, decreased the feed coefficient, and increased the whole crab and muscle crude protein content. The addition of 1% AKG could significantly reduce the serum urea nitrogen content of 28% protein group, improve the amino acid utilization rate and serum total protein content, and improve the activity of digestive enzymes in the liver and pancreas to promote the digestion and absorption of nutrients. In addition, 1% AKG significantly improved the activity of liver and pancreatic glutamate-related metabolic enzymes in the 28% protein group, promoted glutamate metabolism, and increased the metabolic level of non-essential amino acids, thus saving essential amino acids. It also upregulated the expression level of genes involved in the mTOR signaling pathway and promoted protein synthesis. [Conclusion] In conclusion, low protein level can inhibit the growth of juvenile Chinese mitten crab, while 1% AKG could improve the utilization efficiency of low protein feed by improving digestive enzyme activity, promoting amino acid metabolism and activating mTOR signaling pathway.

Keywords : Alpha-Ketoglutarate; Low protein; Protein metabolism

大豆酶解蛋白替代不同鱼粉对大口黑鲈摄食、生长和健康状况的影响

阮琦鸿¹，周良星¹，彭文¹，胡百文^{2*}，余进峰²，王文兵²，熊暑光²

(1. 新希望六和股份有限公司；2. 江苏富海生物科技有限公司)

摘要：本研究目的是通过比较大豆酶解蛋白替代不同鱼粉对大口黑鲈摄食、生长和健康状况的影响，以验证大豆酶解蛋白（富太宝 655）替代不同鱼粉的可行性，为开发高效大口黑鲈饲料提供科学的营养解决方案，以减少对鱼粉的依赖，提高养殖效益。设计生产含秘鲁和国产全脱与半脱鱼粉对照组、替代秘鲁超级蒸汽鱼粉组、替代国产全脱鱼粉组、替代国产半脱鱼粉组共 4 种饲料，选取体质健康，规格整齐的大口黑鲈，随机分入 4 个试验组，每组 5 个重复，每个网箱 70 尾（初始尾重为 28.29 ± 0.14 g），试验周期为 84 天。试验结束后，停食 2 天后采样进行各项指标的测定。结果显示：各试验组与对照组相比，在终末尾重，增重率，特定生长率、饵料系数、成活率方面均无显著差异（ $P > 0.05$ ）；各试验组日摄食率显著高于对照组（ $P < 0.05$ ）。健康指标方面，各组脏体比无显著差异（ $P > 0.05$ ），肝体比替代国产半脱鱼粉组显著高于对照组（ $P < 0.05$ ），其余各组与对照组相比无显著差异；体背长比、尾柄宽厚积、肠体比、肠体指数各组均无显著差异（ $P > 0.05$ ）。综上所述，在本试验条件下，以大豆酶解蛋白替代大口黑鲈饲料中的秘鲁超级蒸汽鱼粉和国产全脱、国产半脱鱼粉是可行的。

关键词：大口黑鲈；大豆酶解蛋白；鱼粉替代；

*周良星为通讯作者，联系方式：广州新希望六和饲料有限公司

Effects of enzymatic hydrolysis soybean protein replacing different fish meal on feeding, growth performance and health condition of Largemouth Bass

Qihong Ruan¹, Liangxing Zhou¹, Wen Liu¹, Baiwen Hu^{2*}, Jinfeng Yu², Wenbing Wang²,
Shuguang Xiong²

(2. **1. New Hope Liuhe Co., Ltd; 2. Jiangsu Fuhai Biotech Co., Ltd*)

Abstract: The purpose of this study was to explore the feasibility of replacing different fish meal with enzymolysis hydrolysis soybean protein on feed intake, growth performance, and health condition of Largemouth Bass, to provide a scientific nutritional solution to reduce fishmeal dependent. We design and produced four different diets as control group with Peruvian and domestic fishmeal, replacing Peruvian super steam fish meal, replacing domestic normal fishmeal, replacing domestic fishmeal with sprayed squeezed liquid. Healthy and regular fish were randomly divided into four experimental groups with five replicates. Each cage contained 70 fish (the initial tail weight was 28.29 ± 0.14 g). The experimental period was 84 days. The growth indexes were measured after 2 days fasting. The results showed that there were no significant differences in final weight, weight gain rate, specific growth rate, feed coefficient and survival rate between the experimental group and the control group ($P > 0.05$). The daily feed intake rate of each experimental group was significantly higher than that of the control group ($P < 0.05$). In terms of health condition indexes, there was no significant difference in the visceral body ratio among the groups ($P > 0.05$). The liver body ratio in the replacing domestic fishmeal group with sprayed squeezed liquid was significantly higher than that in the control group ($P < 0.05$), while there was no significant difference in the other groups compared with the control group. There were no significant differences in condition factor, body back length ratio, caudal stalk width thickness product, intestinal body ratio and intestinal body index among the groups ($P > 0.05$). In conclusion, in this experiment, it is feasible to replace Peruvian super steam fish meal and domestic fishmeal with enzymatic hydrolysis soybean protein in Largemouth bass.

Key words: Largemouth bass; Enzymatic hydrolysis soybean protein; Fish meal replacement

大豆酶解蛋白替代不同鱼粉对南美白对虾摄食和生长的影响

胡百文¹, 余进峰¹, 王文兵¹, 熊暑光¹, 吴飞龙², 周良星^{2*}, 席庆凯²

(1. 江苏富海生物科技有限公司; 2. 新希望六和股份有限公司)

摘要: 为了水产养殖的可持续发展, 本试验使用大豆酶解蛋白(富太宝 655)替代不同级别鱼粉, 研究对南美白对虾摄食和生长的影响。试验共设置4个处理组, 分别为鱼粉对照组(FH1)、替代国产半脱鱼粉组(FH2)、替代国产全脱鱼粉组(FH3)、替代进口超级蒸汽鱼粉组(FH4), 每组各设3个重复。选取个体大小基本一致、生长状况健康、基地自己标粗的日夜快品系南美白对虾为试验对象, 在水泥池中进行养殖实验, 对虾初始均重0.95g/尾, 试验周期60天。从试验结果来看, 与鱼粉对照组相比, 替代国产半脱鱼粉组和替代国产全脱鱼粉组的摄食率、饵料系数和成活率无显著差异, 增重率、特定生长率显著增加 ($P>0.05$)。替代秘鲁超级蒸汽鱼粉组的摄食数据明显异常, 需要后续进一步研究。在本试验中, 大豆酶解蛋白在南美白对虾饲料中可完全替代国产半脱鱼粉和国产全脱鱼粉, 并且增重表现优于对照组。

关键词: 南美白对虾; 大豆酶解蛋白; 鱼粉替代

*胡百文为通讯作者, info@fatide.com

大豆浓缩蛋白替代鱼粉并补充蛋氨酸在杂交鲟饲料中的评估

谢凯¹, 谷九丰¹, 李昭林^{1,2}, 郭百新³, 朱学芝², 李权¹, 张俊智^{1*}, 胡毅^{1*}

(1. 湖南农业大学水产学院, 长沙 410128; 2. 广东粤海饲料集团股份有限公司, 湛江 524017; 3. 湖南润梓兴生态农业旅游开发有限公司, 郴州 423500)

摘要: 大豆浓缩蛋白作为近年来比较优质的鱼粉蛋白替代源被广泛应用于水产行业, 然而与鱼粉相比, 大豆浓缩蛋白必需氨基酸的缺乏成为其应用的瓶颈。为此, 本研究以杂交鲟 (*Acipenser baerii* ♀ × *A. schrenckii* ♂) 为研究对象, 以大豆浓缩蛋白替代鱼粉并平衡赖氨酸后补充蛋氨酸, 配置 4 组等氮等脂饲料, 分别为鱼粉组 (FM)、大豆浓缩蛋白替代鱼粉后分别添加 0%、0.25%、0.50% 蛋氨酸组 (M0、M2.5、M5)。再通过营养学和分子生物学探讨大豆浓缩蛋白替代鱼粉后补充氨基酸对杂交鲟生长、肝脏和肠道健康以及肌肉品质的影响。养殖实验在粤海实验基地养殖系统中进行, 试验选用初始体重为 8.0 g 左右杂交鲟, 每个实验桶放养 30 尾, 每个处理三个实验桶。养殖实验持续 8 周, 采样前禁食 24h。结果表明: (1) 与 FM 组相比, M0 和 M2.5 组杂交鲟末均重、增重率显著下降; M0 组饵料系数显著上升, 蛋白质效率显著下降。与 M0 组相比, M5 组杂交鲟末均重、增重率、蛋白质效率显著上升, 饵料系数显著下降。与 FM 组相比, M0、M2.5 和 M5 组杂交鲟肠道淀粉酶活性显著上升。与 FM 组相比, M0 组杂交鲟肠道脂肪酶、胰蛋白酶活性显著下降。与 M0 组相比, M5 组杂交鲟肠道脂肪酶、胰蛋白酶活性显著上升。与 FM 组相比, M0 组杂交鲟肠道绒毛高度和杯状细胞数量显著下降。与 M0 组相比, M2.5 和 M5 组杂交鲟肠道绒毛高度和杯状细胞数量显著上升。与 FM 组相比, M0 组杂交鲟肠道 *claudin1*、*claudin2*、*occludin*、*zo1*、*zo2* 和 *zo3* 基因表达量显著下调。与 M0 组相比, M5 组杂交鲟肠道 *claudin1*、*claudin2*、*occludin*、*zo1*、*zo2* 和 *zo3* 基因表达量显著上调。与 FM 组相比, M0 组杂交鲟肠道 *il8* 基因表达量显著上调, *tgfb* 和 *c3* 基因表达量显著下调。与 M0 组相比, M5 组杂交鲟肠道 *il1b*、*il8* 和 *tnfa* 基因表达量显著下调, *tgfb*、*lysozyme* 和 *c3* 基因表达量显著上调。(2) 在体组成方面, 与 FM 组相比, M0 和 M2.5 组杂交鲟肝体比显著上升; M0 组脏体比显著上升。与 M0 组相比, M2.5 和 M5 组杂交鲟脏体比显著下降。各组杂交鲟存活率、肥满度无显著差异。与 FM 组相比, M0 组杂交鲟全鱼粗蛋白含量显著下降; 与 M0 组相比, 和 M5 组全鱼粗蛋白含量显著下降。各组杂交鲟全鱼粗脂肪、灰分含量无显著差异。与 FM 组相比, M0 和 M2.5 组杂交鲟血清总胆固醇 (TC)、高密度脂蛋白胆固醇 (HDL-C)、低密度脂蛋白胆固醇 (LDL-C) 含量显著上升; M0 组 TG 含量和 GOT、GPT 活性显著上升。与 M0 组相比, M5 组杂交鲟血清甘油三酯 (TG)、TC、LDL-C 含量和谷草转氨酶 (GOT)、谷丙转氨酶 (GPT) 活性显著下降; HDL-C 含量显著上升。与 FM 组相比, M0、M2.5 和 M5 组杂交鲟肝脏丙二醛 (MDA) 含量及过氧化氢酶 (CAT)、超氧化物歧化酶 (SOD) 活性显著上升。与 M0 组相比, M2.5 和 M5 组杂交鲟肝脏 MDA 含量和 CAT、SOD 活性显著下降。(3) 在肌肉品质方面, 各组氨基酸组成无显著差异。与 FM 组相比, M0 组杂交鲟肌肉硬度、咀嚼性显著下降。与 M0 组相比, M5 组杂交鲟肌肉硬度、胶黏性和咀嚼性显著上升。与 FM 组相比, M0 组杂交鲟肌纤

维密度显著下降。与 M0 组相比，M5 组杂交鲟肌纤维密度显著上升。综上所述，大豆浓缩蛋白替代鱼粉并平衡单一必需氨基酸后仍会对杂交鲟生长、肝脏和肠道健康以及肌肉品质造成负面影响。当平衡赖氨酸后，补充蛋氨酸将促进杂交鲟生长、保护肝脏及肠道健康，并提升肌肉品质，在本实验条件下，蛋氨酸添加量最适为 0.5%。

关键词：杂交鲟；蛋氨酸；生长；肝脏健康；肠道健康；肌肉品质

Evaluation of soybean protein concentrate replacing fish meal with methionine supplementation in diets for hybrid sturgeon

(*Acipenser baerii* ♀ × *A. schrenckii* ♂)

Kai Xie¹, Jiufeng Gu¹, Zhaolin Li^{1,2}, Baixin Guo³, Xuezhi Zhu², Quan Li¹, Junzhi Zhang^{1*}, Yi Hu^{1*}

(1. College of Fisheries, Hunan Agricultural University, Changsha 410128, China; 2. Guangdong Yuehai Feeds Group Co., Ltd, Zhanjiang 524017, China; 3. Hunan Runzixing Eco-Agricultural Tourism Development Co., LTD., Chenzhou 423500, China)

Abstract: Soy protein concentrate (SPC) has recently been widely utilized as a high-quality alternative protein source to fish meal in the aquaculture industry. However, compared to fish meal, the deficiency of essential amino acids in SPC has limited its application. In this study, hybrid sturgeon (*Acipenser baerii* ♀ × *A. schrenckii* ♂) was used as the research subject, and SPC was employed to replace fish meal with balanced lysine, followed by methionine supplementation. Four isonitrogenous and isolipidic diets were formulated: the fish meal group (FM) and SPC replacement groups with 0%, 0.25%, and 0.50% methionine supplementation (M0, M2.5, M5). Nutritional and molecular biology analyses were conducted to examine the effects of amino acid supplementation following fish meal replacement with SPC on growth, liver and intestinal health, and muscle quality in hybrid sturgeon. The feeding trial was conducted in an aquaculture system at the Yuehai Experimental Base using hybrid sturgeon with an initial body weight of approximately 8.0 g. Each tank contained 30 fish, and each treatment was triplicated. The feeding trial lasted for eight weeks, with a 24-hour fasting period before sampling. Results showed that: (1) Compared to the FM group, the final body weight and weight gain rate significantly decreased in the M0 and M2.5 groups, while feed conversion ratio (FCR) significantly increased and protein efficiency ratio (PER) significantly decreased in the M0 group. Compared to the M0 group, the final body weight, weight gain rate, and PER significantly increased, while FCR significantly decreased in the M5 group. Intestinal enzyme activity analysis revealed significantly higher amylase activity in the M0, M2.5, and M5 groups compared to the FM group, while lipase and trypsin activities were significantly lower in the M0 group and significantly higher in the M5 group. Intestinal morphology showed that villus height and goblet cell counts were significantly lower in the M0 group than in the FM group, but significantly increased in the M2.5 and M5 groups compared to the M0 group. Expression levels of *claudin1*, *claudin2*, *occludin*, *zo1*, *zo2*, and *zo3* genes were significantly downregulated in the M0 group

资助项目：国家自然科学基金项目（32172986）；桂东县高山特色冷水鱼产业生态发展关键技术研究示范项目（2022xczx-317）。

*通讯作者：胡毅，E-mail: huyi740322@163.com；张俊智，E-mail: 969266981@qq.com

compared to the FM group, while significantly upregulated in the M5 group. Inflammatory and immune gene expression showed significant upregulation of *il8* and downregulation of *tgfb* and *c3* in the M0 group compared to the FM group. Conversely, the M5 group showed significant downregulation of *il1b*, *il8*, and *tnfa*, and significant upregulation of *tgfb*, *lysozyme*, and *c3* compared to the M0 group. (2) For body composition, the hepatosomatic index (HSI) was significantly higher in the M0 and M2.5 groups than in the FM group, and the viscerosomatic index (VSI) was significantly higher in the M0 group. VSI significantly decreased in the M2.5 and M5 groups compared to the M0 group. No significant differences in survival rate or condition factor were observed across groups. Whole-body crude protein content significantly decreased in the M0 group compared to the FM group, and significantly increased in the M5 group. Serum biochemical analysis revealed that TC, HDL-C, and LDL-C levels were significantly higher in the M0 and M2.5 groups than in the FM group, while TG, GOT, and GPT levels significantly decreased in the M5 group and HDL-C significantly increased. Liver antioxidant indices showed that MDA, CAT, and SOD levels significantly increased in all experimental groups compared to the FM group, with significant decreases in MDA, CAT, and SOD in the M2.5 and M5 groups compared to the M0 group. (3) For muscle quality, no significant differences were observed in amino acid composition among groups. However, muscle hardness and chewiness significantly decreased in the M0 group compared to the FM group, while hardness, adhesiveness, and chewiness significantly increased in the M5 group. Muscle fiber density was significantly lower in the M0 group compared to the FM group, and significantly increased in the M5 group. In conclusion, replacing fish meal with SPC and balancing single essential amino acids still negatively affected growth, liver and intestinal health, and muscle quality in hybrid sturgeon. Methionine supplementation after lysine balancing enhanced growth, liver and intestinal health, and muscle quality, with an optimal methionine supplementation level of 0.5% under the conditions of this study.

Keywords: Hybrid sturgeon; Methionine; Growth; Liver health; Intestinal health; Muscle quality

大豆异黄酮对中华绒螯蟹幼蟹生长性能、抗氧化能力、非特异性免疫和脂质代谢的影响²¹

何龙¹, 王涵¹, 王晓丹¹, 李二超^{1*}, 陈立侨^{1*}

(1.华东师范大学, 生命科学学院, 水生动物营养与环境健康实验室, 上海 200241)

摘要:【目的】本研究旨在评估大豆异黄酮对中华绒螯蟹幼蟹体组成、抗氧化能力、非特异性免疫和脂质代谢的影响。【方法】试验选用幼蟹 960 只 (1.09 ± 0.01 g), 随机分为 24 个 300 L 水池, 每个池 40 只, 4 个重复。6 种大豆异黄酮水平 (0、8.8、15.8、33.8、66.8 和 137.0 mg/kg) 的饲料 (蛋白质 43.5%, 脂肪 7%), 投喂量为 4% BW/d, 养殖 56 天。【结果】添加 15.8 和 33.8 mg/kg 大豆异黄酮幼蟹的最终生物量和生物量增重显著高于对照组; 且全蟹和肝胰腺总脂肪含量显著低于对照组。与对照组相比, 大豆异黄酮可显著提高肝胰腺超氧化物歧化酶、谷胱甘肽过氧化物酶活性和总抗氧化能力, 分别提高了 40%、57% 和 79%, 显著降低 24% 的丙二醛含量。高水平的大豆异黄酮提高血淋巴中总蛋白和血蓝蛋白含量, 并显著提高碱性磷酸酶活性。大豆异黄酮添加组幼蟹的肝胰腺和血淋巴甘油三酯含量显著降低。大豆异黄酮可能通过抑制脂质合成相关基因和促进脂质氧化和转运基因的表达来减少肝胰腺的脂质蓄积。生物量增重随饲料中大豆异黄酮含量变化的折线回归模型分析得出, 大豆异黄酮的最佳添加水平约为 26.66 mg/kg。【结论】由此可见, 饲料中添加大豆异黄酮可改善幼蟹的生长性能和健康状况, 减少肝胰腺脂肪的积累。

关键词: 中华绒螯蟹; 大豆异黄酮; 生长性能; 脂质代谢

资助项目: 财政部和农业农村部: 国家现代农业产业技术体系; 上海市现代农业产业技术体系(202304); 国家自然科学基金 (32072986); 广东省重点领域研发计划(2020B0202010001); 长江上游鱼类资源保护与利用四川省重点实验室开放基金(NJTCCJSYSYS01)

通讯作者: 陈立侨, E-mail: lqchen@bio.ecnu.edu.cn; 李二超, E-mail: ecli@bio.ecnu.edu.cn;

Effects of soy isoflavones on growth performance, antioxidant capacity, non-specific immunity and lipid metabolism of juvenile Chinese mitten crab, *Eriocheir sinensis*

Long He¹, Han Wang¹, Xiaodan Wang¹, Erchao Li^{1*}, Liqiao Chen^{1*}

(1. East China Normal University, School of Life Sciences, Laboratory of Aquaculture Nutrition and Environmental Health, Shanghai China 200241)

Abstract: [Objective] This study investigates the effects of soy isoflavones on body composition, antioxidant activity, non-specific immunity, and lipid metabolism in juvenile Chinese mitten crabs, *Eriocheir sinensis*. [Methods] A total of 960 juvenile crabs (1.09 ± 0.01 g) were randomly assigned to 24 tanks (300 L), with 40 crabs in each tank in four replicates. The crabs were fed diets (43.5% protein and 7% lipid) with six levels of soy isoflavones (0, 8.8, 15.8, 33.8, 66.8, and 137.0 mg/kg) at 4% BW/day for 56 days. [Results] The final biomass and biomass gain of crabs supplemented with 15.8 and 33.8 mg/kg soy isoflavones were significantly higher than those in the control group. The total lipid content in the whole-body and hepatopancreas of the crabs fed 15.8 and 33.8 mg/kg soy isoflavones was significantly lower than in the control group. Compared with the control group, soy isoflavones significantly enhanced the activities of superoxide dismutase, glutathione peroxidase and total antioxidant capacity in the hepatopancreas by 40%, 57% and 79%, respectively, and significantly decreased malondialdehyde content by 24%. The high dietary soy isoflavones levels increased total protein and hemocyanin contents in hemolymph, and alkaline phosphatase activity was also significantly enhanced. The triglyceride contents in the hepatopancreas and hemolymph were significantly lower in the soy isoflavones-supplemented group. Dietary soy isoflavones may reduce lipid accumulation in the hepatopancreas by repressing genes related to lipid synthesis and promoting the expression of lipid oxidation and transport genes. The broken-line model analysis of biomass gain against dietary soy isoflavones levels shows that the optimal supplemental level of soy isoflavones for juvenile crabs is approximately 26.66 mg/kg. [Conclusion] Thus, this study suggests that dietary soy isoflavones supplementation can improve growth performance and health and reduce lipid accumulation in the hepatopancreas of juvenile crabs.

Keywords: *Eriocheir sinensis*, soy isoflavones, growth performance, lipid metabolism

大黄素改善高植物蛋白诱导的彭泽鲫肝脏代谢功能紊乱

沈凯凯¹, 彭墨², 黄永发¹, 卢祯微¹, 李剑琴¹, 毛茜¹, 张婧杰¹, 胡宝庆¹,
徐金根³, 文春根¹, 阳钢^{1,*}

(1.南昌大学生命科学学院, 江西 南昌 330031; 2.江西农业大学动物科学与技术学院, 江西 南昌
330045; 3.九江市农业科学院, 江西九江 332101)

摘要: 高植物蛋白饮食可诱导鱼类胆汁酸(BA)失衡和脂质代谢紊乱, 本研究探讨饲料添加大黄素对彭泽鲫鱼肝脏代谢功能的影响。结果显示, 大黄素可通过抑制肠道炎症恢复肠道对BAs吸收功能, 并通过抑制FXR-FGF19-CYP7A1信号通路促进摄食高植物蛋白鲫鱼肝脏的BAs合成。同时, 大黄素可抑制胆固醇的过度合成和促进胆固醇的转运来发挥降胆固醇作用, 并驱动肝脏组织中胆固醇向BAs的转化。最后, 大黄素诱导的BAs水平升高可通过激活AMPK抑制脂肪合成并减轻肝脏脂质的异常沉积。综上所述, 饲料添加适宜的大黄素可调节肝组织中BA、胆固醇和脂质的代谢, 最终缓解高植物蛋白饮食诱导的彭泽鲫肝脏代谢功能障碍。

关键词: 大黄素; 高植物蛋白; FXR; 胆汁酸合成; 脂肪代谢

Emodin improved the hepatic metabolic dysfunction induced by high plant-protein diet in Pengze crucian carp (*Carassius auratus* var. Pengze)

Kaikai Shen ¹, Mo Peng ², Yongfa Huang ¹, Zhenwei Lu ¹, Jianqin Li ¹, Qian Mao ¹, Jingjie Zhang ¹, Baoqing Hu ¹, Jingen Xu³, Chungen Wen ¹, Gang Yang ^{1,*}

(1. School of Life Science, Nanchang University, Nanchang China 330031; 2. School of Animal Science and Technology, Jiangxi Agricultural University, Nanchang China 330045; 3. Jiujiang Academy of Agricultural Sciences, Jiujiang China 332101)

Abstract: High plant-protein diet could induce bile acid (BA) imbalance and lipid metabolism disorder in fish, and this study investigated the effects of emodin on hepatic metabolic functions of Pengze crucian carp. The results revealed that emodin supplementation recovered intestinal BAs absorption function by through the inhibition of intestinal inflammation and promoted the hepatic BAs synthesis by inhibiting FXR-FGF19-CYP7A1 signaling pathway in carp fed with high plant-protein diet. Emodin exerted cholesterol-lowering effects by inhibiting the excessive synthesis of cholesterol and promoting the transport of cholesterol, and driven the conversion of cholesterol to BAs in liver tissue. The increase in BAs level induced by emodin supplementation could suppress lipid lipogenesis and alleviate hepatic lipid deposition through the activation of AMPK. In summary, dietary a suitable content of emodin could regulate the metabolism of BA, cholesterol, and lipid in liver tissue, and ultimately attenuate hepatic metabolic dysfunction of Pengze crucian carp induced by high plant-protein diet.

Keywords: Emodin; High plant protein; FXR; Bile acid synthesis; Lipid metabolism

基金项目：国家自然科学基金（32360918）和江西省自然科学基金（20242BAB25398）

通讯作者：阳 钢， E-Mail: gangyang@ncu.edu.cn

胆汁酸对草鱼头肾、脾脏、皮肤的免疫功能的作用及其机制

赵菲¹, 彭秀蓉¹, 冯琳^{1,2,3}, 姜维丹^{1,2,3}, 吴培^{1,2,3}, 刘杨^{1,2,3}, 马耀斌^{1,2,3}, 周小秋^{1,2,3*}

(1.四川农业大学动物营养研究所, 四川 成都 611130; 2.鱼类营养与安全生产重点实验室, 四川 成都 611130; 3.动物抗病营养农业部、教育部、四川省重点实验室, 四川 成都 611130)

摘要: 胆汁酸 (Bile acid, BA) 是一种常用的脂肪乳化剂, 不仅能提高脂肪消化吸收效率, 维持脂质代谢平衡, 而且可以调节动物的免疫功能。本研究旨在探究 BA 对生长中期草鱼头肾、脾脏和皮肤免疫功能的影响及其作用机制。试验选取初始体重为 179.85 ± 1.34 g 的草鱼 540 尾, 随机分为 6 个处理, 每个处理 3 个重复, 分别饲喂正常饲料 (NPNL: 29%粗蛋白和 5%的粗脂肪)、低蛋白高脂饲料 (LPHL: 26%粗蛋白和 6%粗脂肪), 另外在 LPHL 饲料分别添加 (80、160、240 和 320 mg/kg BA), 试验期 50 d。生长试验结束后进行 14 d 的嗜水气单胞菌攻毒试验。结果表明: 1) 与 NPNL 组相比, LPHL 组显著提高了皮肤病变发生率和炎症反应, 并且显著降低了草鱼免疫器官的抗菌化合物水平和抗菌肽相关基因 (*hepcidin*、*LEAP-2A*、*LEAP-2B*、*Mucin2* 和 *β -defensin-1*) 表达 ($P < 0.05$); 2) 在 LPHL 组添加适宜水平 BA 显著提高了草鱼皮肤、头肾和脾脏的抗菌化合物水平以及抗炎因子 (*TGF- β 1*、*IL-11*、*IL-4/13A*、*TOR*、*S6K1* 和 *4E-BP1*) 表达, 并且下调促炎因子 (*TNF- α* 、*IFN- γ 2*、*IL-1 β* 、*IL-6*、*IL-8*、*IL-15*、*IL-17D*、*IL-12p35*、*IL-15*、*NF- κ B p65*、*c-Rel*、*I κ B α* 、*IKK β* 和 *IKK γ*) 表达 ($P < 0.05$)。综上所述, 适宜的 BA 可能通过抑制 NF- κ B 信号通路和激活 TOR 信号通路提高了草鱼免疫功能。基于以上结果, BA 缓解了高脂引起的草鱼免疫器官的损伤, 为草鱼饲料配方提供部分理论依据, 具有重要的指导意义。

关键词: 胆汁酸; 草鱼; 头肾; 脾脏; 皮肤; 免疫

基金项目: 国家现代农业产业技术体系 (CARS-45)、国家重点研发计划“蓝色粮仓科技创新”重点专项 (2018YFD0900400)、四川省青年科技创新研究团队基金 (2017TD0002)、四川省科技计划 (2019YFN0036)

通讯作者: 周小秋, 教授, 博士生导师; E-mail: zhouxq@sicau.edu.cn

胆汁酸在水产动物中的研究进展

谢诗玮^{1,2,3*}, 迟淑艳^{1,2,3}, 章双^{1,2,3}, 董晓慧^{1,2,3}, 杨奇慧^{1,2,3}, 刘泓宇^{1,2,3}, 张卫^{1,2,3}, 邓君明^{1,2,3}, 谭北平^{1,2,3}

(1.广东海洋大学水产动物营养与饲料实验室, 广东 湛江 524088; 2.农业部华南水产与畜禽饲料重点实验室, 广东 湛江 524088; 3.广东省水产动物精准营养与高效饲料工程技术研究中心, 广东 湛江 524088)

摘要: 胆汁酸是胆固醇的衍生物, 对于脂肪的消化吸收和代谢利用具有重要作用。目前, 胆汁酸已在大黄鱼等十余种水产动物上进行了研究, 发现其对水产动物生长性能、脂肪代谢、免疫反应、肠道微生态平衡、肝肠健康等均具有促进作用。本团队先后开展胆汁酸在大口黑鲈和珍珠龙胆石斑鱼高脂饲料中的应用研究, 明确了胆汁酸对于鱼类脂肪代谢的调控机制。无脊椎动物胆汁酸代谢与脊椎动物完全不同, 其不能从头合成胆汁酸, 同时胆汁酸代谢调控机制可能也与脊椎动物有较大差异。本团队以凡纳滨对虾为研究对象, 探究了无脊椎动物对于胆汁酸的代谢利用机制。

关键词: 胆汁酸; 高脂饲料; 脂肪代谢; 大口黑鲈; 凡纳滨对虾

Research progress of bile acids in aquatic animals

Shiwei Xie^{1,2,3*}, Shuyan Chi^{1,2,3}, Shuang Zhang^{1,2,3}, Xiaohui Dong^{1,2,3}, Qihui Yang^{1,2,3}, Hongyu Liu^{1,2,3}, Wei Zhang^{1,2,3}, Junming Deng^{1,2,3}, Beiping Tan^{1,2,3}

(1. Laboratory of Aquatic Nutrition and Feed, College of Fisheries, Guangdong Ocean University, Zhanjiang 524088, PR China; 2. Aquatic Animals Precision Nutrition and High-Efficiency Feed Engineering Research Centre of Guangdong Province, Zhanjiang 524088, PR China; 3. Key Laboratory of Aquatic, Livestock and Poultry Feed Science and Technology in South China, Ministry of Agriculture, Zhanjiang 524088, PR China)

Abstract: Bile acids are derivatives of cholesterol and play an important role in the digestion, absorption, and metabolic utilization of fat. Currently, bile acids have been studied in more than ten aquatic animals, including yellow croaker, and have been found to promote the growth performance, lipid metabolism, immune response, intestinal microbial balance, and liver and intestinal health of aquatic animals. Our group has conducted research on the application of bile acids in high-fat diets for largemouth bass and pearl grouper, clarifying the regulatory mechanism of bile acids for fish lipid metabolism. The metabolism of bile acids in invertebrates is completely different from that of vertebrates. Invertebrates cannot *de novo* synthesize bile acids, and the regulatory mechanism of bile acid metabolism may also be significantly different from that of vertebrates. Our team has studied the metabolic utilization mechanism of bile acids in the *Litopenaeus vannamei*, to explore the metabolic utilization mechanism of invertebrates for bile acids.

Keywords: Bile acids; High fat diets; Lipid metabolism; *Micropterus salmoides*; *Litopenaeus vannamei*

资助项目：国家重点研发计划（2023YFD2402000），国家自然科学基金面上项目（32373141）、国家自然科学基金青年项目（32002402）；广东省基础与应用基础研究基金青年提升项目（2023A1515030007）

通讯作者：谢诗玮，E-Mail: xswzsd@163.com

胆汁酸在水产饲料中应用及其研究进展

谭朋^{1,2} 张翮^{1,4} 张蕾^{1,4} 邵庆均^{1,3*}

(1. 农业农村部饲料与饲料添加剂评价基地(海水鱼虾) 浙江舟山 316021; 2. 浙江省海洋水产研究所, 浙江舟山 316021; 3. 浙江大学, 浙江杭州 310058; 4. 浙江海洋大学 浙江舟山 316022)

摘要: 主要包括: 1.胆汁酸在水产饲料中应用国内外研究进展; 2.胆汁酸生产主要工艺流程; 3.胆汁酸在凡纳滨对虾饲料中应用有效性评价和耐受性评价研究; 4.胆汁酸在罗非鱼和塘虱饲料中应用效果研究。

关键词: 胆汁酸; 水产饲料; 有效性评价; 耐受性评价; 凡纳滨对虾; 罗非鱼; 塘虱

Bile acids application in aquafeeds and their research progress

Peng Tan^{1,2} Pian Zhang^{1,4} Lei Zhang^{1,4} Qingjun Shao^{1,3*}

(1. Evaluation Base of Feedstuffs and Feed Additives, Ministry of Agriculture and Rural Affairs, Zhoushan China 316021; 2. Marine Fisheries Research Institute, Zhejiang Province, Zhoushan China, 316021; Zhejiang University, Hangzhou China 310058; 4. Zhejiang Ocean University, Zhoushan China 316022)

Abstract: The main contents: 1. The research progress of bile acids in aquafeeds; 2. The main production technological progress of bile acids; 3. Evaluations of the effectiveness and the tolerance of bile acid applied in whiteleg shrimp *litopenaeus vannamei* diet; 4. The application of bile acid in tilapia *Oreochromis niloticus* and catfish *Clarias fuscus* diets.

Keywords: Bile acids; Aquafeed; Effectiveness evaluation; Tolerance evaluation; *litopenaeus vannamei*; *Oreochromis niloticus*; *Clarias fuscus*

资助项目: 国家科技部蓝色粮仓项目(2020YFD0900801)、山东龙昌动物保健品有限公司(2023KYY5290160007)

通讯作者: 邵庆均, E-mail: qjshao@zju.edu.cn

当归副产物对颗粒饲料的保护作用及其对鲫生长和缺氧应激的影响

徐静¹, 黄晓兰¹, 王苗苗², 刘海静¹, 杨奇慧², 张会兰¹, 陈厚宏¹, 黎杰¹, 陈岗富¹,
李华涛^{1*}

(1. 内江师范学院生命科学学院, 长江上游鱼类资源保护与利用四川省重点实验室, 内江 641100; 2. 广东海洋大学水产学院, 湛江 524088)

摘要:【目的】本研究旨在以当归副产物 (AP) 作为鱼饲料的功能性原料, 探讨其对颗粒饲料的保护作用, 以及投喂后对鱼生长和缺氧应激的影响。【方法】首先, 在基础饲料中添加 0%、1%、2%、4%、8%、16%和 32%的 AP 粉, 配制 7 种实验饲料, 并制成 1.5 mm 的颗粒饲料。然后, 选择体重 (5.67±0.07) g 的鲫 (*Carassais auratus gibelio*) 420 尾, 随机分为 7 个组, 每组 3 个重复, 每个重复 20 尾鱼。7 个处理组分别投喂含不同水平 AP 粉的饲料, 试验期 60 d。【结果】饲料中添加 AP 显著提高了颗粒饲料的含水率, 降低了其硬度、粉化率和霉菌的生长 ($P<0.05$)。投喂 AP 提高了鲫的增重率 (WGR)、特定增长率、饲料效率、缺氧持续时间、血液中的红细胞比容、红细胞数量和血红蛋白含量以及鳃或红细胞还原性谷胱甘肽含量和超氧化物歧化酶、过氧化氢酶、谷胱甘肽过氧化物酶和谷胱甘肽还原酶活性, 降低了鲫氧消耗率和血液中的平均单红细胞体积以及鳃或红细胞中的过氧化氢、高铁血红蛋白、超氧阴离子、羟自由基和丙二醛含量 ($P<0.05$)。结果说明, AP 能提高颗粒饲料的坚实度, 对颗粒饲料具有防霉和保水的效果。投喂 AP 提高了鱼的生长性能、耐缺氧能力以及鳃和红细胞的抗氧化能力。基于 WGR 的折线回归分析显示, AP 在饲料中的适宜添加量为 8.08%, 最高添加量为 23.07%。基于 DT 和 OCR 的折线回归分析显示, AP 提高鱼耐缺氧能力的适宜添加量为 7.85%。AP 对鱼耐缺氧能力的提高可能与其降低了鱼的有氧代谢, 提高了鱼血液中的红细胞数量和 Hb 含量以及改善了鱼鳃和红细胞的抗氧化能力存在密切关系。【结论】AP 对颗粒饲料有保护作用, 并能改善鱼的生长和耐缺氧能力。

关键词: 当归副产物; 颗粒饲料; 鲫; 生长; 耐缺氧; 抗氧化

基金项目: 四川省科技计划项目 (2018JY0214); 大学生创新创业项目 (X2021207)

*通信作者: 李华涛, 教授, 博士, E-mail: lihuatao666@163.com

Protective Effects of *Angelica sinensis* By-product on Pellet Feed and its Effects on the Growth and Hypoxic Stress in Crucian Carp

XU Jing¹, HUANG Xiaolan¹, WANG Miaomiao¹, LIU Haijing¹, YANG Qihui², ZHANG Huilan¹, CHEN Houhong¹, LI Jie¹, CHEN Gangfu¹, LI Huatao^{1*}

(1. Key Laboratory of Sichuan Province for Conservation and Utilization of Fishes Resources in the Upper Reaches of the Yangtze River, College of Life Sciences, Neijiang Normal University, Neijiang 641100, China; 2. College of Fisheries, Guangdong Ocean University, Zhanjiang 524088, China)

Abstract: The purpose of this study was to investigate the protective roles of *Angelica Sinensis* by-product (AP) on pellet feed and its effects on growth and hypoxia stress in fish. Firstly, seven experimental diets were formulated by adding AP powder to the basal diet to provide a final concentration of 0%, 1%, 2%, 4%, 8%, 16% and 32%, respectively, and make it into 1.5 mm pellet feed. Then, 420 crucian carp (*Carassais auratus gibelio*, 5.67±0.07 g) were selected and randomly divided into 7 groups, with 3 replicates in each group and 20 fish in each replicate. Seven treatment groups were fed with diets containing different levels of AP powder for 60 days. The results showed that AP increased the moisture content, and reduced hardness, powder rate and mildew growth in pellet feed. Dietary AP increased the weight gain rate (WGR), special growth rate, feed efficiency, durative time (DT) after hypoxia, hematocrit, red blood cell count and hemoglobin content in the blood, as well as the content of reduced glutathione and activities of superoxide dismutase, catalase, glutathione peroxidase and glutathione reductase in gills or red blood cells, while reducing the oxygen consumption rate (OCR) after hypoxia and mean corpuscular volume in the blood, as well as the levels of methemoglobin, superoxide anions, hydrogen peroxide, hydroxyl radicals and malondialdehyde in gills or red blood cells of crucian carp. These results indicated that AP improved the solidity and has anti-mold and water retention effects in pellet feed. Dietary AP increased the growth performance, hypoxia tolerance, and antioxidant capacity in gills and red blood cells of fish. According to the broken-line regression analysis based on WGR, the appropriate and highest concentration of AP were estimated to be 8.08% and 23.07% in diets, respectively. The broken-line regression analysis based on DT and OCR showed that the appropriate concentration of AP to improve hypoxia tolerance in fish was 7.85% in diets. The improvement of hypoxia tolerance in fish by AP may be closely related to its reduction of aerobic metabolism and increase in the number of red blood cells and Hb content in blood as well as the antioxidant capacity in gills and red blood cells of fish. In summary, AP has a protective effect on pellet feed and can improve the growth and hypoxia tolerance in fish.

Key words: *angelica sinensis* by-product; pellet feed; crucian carp; growth; hypoxic stress; antioxidant

低聚原花青素对乌鳢生长性能、抗氧化能力、免疫功能、肝脏和肠道健康的影响

刘晓蕊¹, 方琼亚¹, 李科¹, 张欣羽¹, 李民^{1*}, 孔伟颀^{1**}, 王桂芹^{1***}

(1. 吉林农业大学 动物科学技术学院 动物生产及产品质量安全教育部重点实验室/现代农业技术教育部国际合作联合实验室/吉林省动物营养与饲料科学重点实验室, 吉林长春 130118)

摘要: 为研究原花青素对乌鳢 (*Channa argus*) (10.12±0.12g/尾) 生长性能、抗氧化能力、免疫功能、肠道形态、肠道菌群和肝脏健康的影响, 在饲料中添加 4 种不同浓度的低聚原花青素 (OPC) (0、200、400 和 800mg/kg), 每组 3 个重复, 饲养 56 d。在 OPC 浓度在 400 和 800mg/kg 时, 终末体质量 (FBW)、增重率 (WG)、摄食率 (FER)、蛋白质效率 (PER) 和特定生长率 (SGR) 显著提高 ($P<0.05$)。肝脏和肠道中超氧化物歧化酶 (SOD)、谷胱甘肽 S-转移酶 (GST)、谷胱甘肽 (GSH)、过氧化氢酶 (CAT) 和谷胱甘肽过氧化物酶 (GSH-Px) 活性显著增加, 而丙二醛 (MDA) 含量则呈现出相反趋势 ($P<0.05$)。肠道和肝脏中 GST、Cu/Zn 超氧化物歧化酶 (Cu/ZnSOD)、核因子-E2 相关因子 2 (Nrf2)、NAD (P) H 醌脱氢酶 1 (NQO-1) 和血红素加氧酶 1 (HO-1) mRNA 表达水平显著升高, 而 Kelch 样 ECH 相关蛋白 1 (Keap1) 表达则呈现出相反趋势 ($P<0.05$)。血清溶菌酶 (LYS)、免疫球蛋白 M (IgM)、补体 3 (C3) 和补体 4 (C4) 水平显著升高, 血清谷丙转氨酶 (ALT)、天冬氨酸转氨酶 (AST)、总胆汁酸 (TBA) 和总胆固醇 (TC) 水平显著降低 ($P<0.05$)。肝脏和肠道干扰素 γ (IFN- γ)、白细胞介素-8 (IL-8)、白细胞介素-1 β (IL-1 β)、白细胞介素-6 (IL-6) 和肿瘤坏死因子- α (TNF- α) mRNA 表达水平显著降低, 而白细胞介素-10 (IL-10) 表达水平呈相反趋势 ($P<0.05$)。与对照组相比, 补充 400 和 800 mg/kg 浓度 OPC 的饲料显著改善了肝脏和肠道形态。随着 OPC 浓度的增加, 有益菌 (即厚壁菌门) 的相对丰度增加, 而潜在致病菌 (即变形菌门、放线菌门、衣原体菌门、拟杆菌门、蓝细菌门和酸杆菌门) 则呈相反趋势。因此, 饲料中添加 400 mg/kg OPC 有助于提高生长性能, 增强抗氧化能力和免疫功能, 并改善肝脏健康、肠道形态和肠道微生物群组成。

关键词: 生长性能; 低聚原花青素; 肠道微生物群; 肠道形态; 乌鳢

Effects of oligomeric proanthocyanidins on growth performance, antioxidant capability, immunity, liver and intestinal health of *Channa argus*

Xiaorui Liu¹, Qiongya Fang¹, Xinyu Zhang¹, Ke Li¹, Min Li^{1*}, Yidi Kong^{1**}, Guiqin Wang^{1***}

(1. Key Laboratory of Animal Production, Product Quality and Security, Ministry of Education, Jilin Provincial Key Laboratory of Animal Nutrition and Feed Science, College of Animal Science and Technology, Jilin Agricultural University, Changchun 130118, China)

Abstract: To determine the effects of proanthocyanidins on the growth, antioxidant capability, immunity, intestinal morphology, intestinal microbiota, and liver health of *Channa argus* (10.12±0.12 g), four experimental diets with various oligomeric proanthocyanidin (OPC) concentrations (0, 200, 400, and 800 mg/kg) were fed to triplicate groups for 8 weeks. The final body weight (FBW), weight gain (WG), feeding rate (FER), protein efficiency ratio (PER), and specific growth rate (SGR) were significantly improved in the 400 and 800 mg/kg OPC-supplemented diets ($P < 0.05$). The superoxide dismutase (SOD), glutathione-S-transferase (GST), glutathione (GSH), catalase (CAT), and glutathione peroxidase (GSH-Px) activities in the liver and intestines were increased significantly, whereas the malondialdehyde (MDA) content exhibited the opposite pattern ($P < 0.05$). The GST, Cu/Zn superoxide dismutase (Cu/Zn SOD), nuclear factor erythroid 2-related factor 2 (Nrf2), NAD(P)H quinone dehydrogenase 1 (NQO-1), and heme oxygenase 1 (HO-1) mRNA expression levels in the intestines and liver were significantly increased, whereas kelch-like ECH-associated protein 1 (Keap1) expression showed the opposite pattern ($P < 0.05$). Significant increases were noted in the serum lysozyme (LYS), immunoglobulin M (IgM), complement 3 (C3), and complement 4 (C4) levels, and significant decreases were noted in the serum alanine aminotransferase (ALT), aspartate aminotransferase (AST), total bile acid (TBA), and total cholesterol (TC) levels ($P < 0.05$). The interferon gamma (IFN- γ), interleukin-8 (IL-8), interleukin-1 beta (IL-1 β), interleukin-6 (IL-6), and tumor necrosis factor- α (TNF- α) mRNA expression levels in the liver and intestines were significantly decreased, whereas the expression of interleukin-10 (IL-10) showed the opposite trend ($P < 0.05$). Compared with the control diet, the 400 and 800 mg/kg OPC-supplemented diets markedly improved liver and intestinal morphology. With increasing OPC concentration, the relative abundance of the beneficial bacteria, namely, *Firmicutes* increased, whereas the opposite trend was observed for the potential pathogenic bacteria, namely, *Proteobacteria*, *Actinobacteria*, *Chlamydiae*, *Bacteroidetes*, *Cyanobacteria*, and *Acidobacteria*. Therefore, dietary OPC supplementation facilitates growth performance and

enhances antioxidant capability and immunity, as well as improves liver health, intestinal morphology, and microbiota composition of *C. argus*, of which the optimal level is 400 mg/kg.

Keywords: Growth performance; Oligomeric proanthocyanidins; Intestinal microbiota; Intestinal morphology; *Channa argus*

* 通讯作者: 孔伟颀, 博士, 副教授, 硕士生导师, 研究方向为水产动物营养与免疫调控研究, E-mail: kongyidi68@163.com。

基金项目: 吉林省科技发展计划青年成长科技项目 (20240602051RC); 吉林省科技发展计划重点研发项目 20230202067NC; 第七批吉林省青年科技人才托举工程 (QT202303); 财政部和农业农村部: 国家现代农业产业技术体系资助[CARS-46]

低鱼粉饲料中酵母培养物对中华绒螯蟹幼蟹生长性能、肠道健康及抗热应激能力的影响

王松¹, 李雯¹, 王晓丹¹, 李二超^{1*}, 陈立侨^{1*}

(1. 华东师范大学生命科学学院, 上海 200241)

摘要:【目的】酵母培养物, 一种通过酵母发酵得到的微生态制剂, 已显示出促进动物生长、健康和抗热应激效果。尽管其效益已被证实, 对中华绒螯蟹这一物种的影响研究仍然缺乏。本研究探讨了低鱼粉饲料中酵母培养物对中华绒螯蟹幼蟹生长性能、肠道健康以及抗热应激能力的影响。【方法】以鱼粉、豆粕和棉粕为蛋白源设计七种等氮等脂的饲料, 包括对照组(35%鱼粉)和六种不同酵母培养物浓度处理组(15%鱼粉; 0, 0.8、1.6、2.4、3.2 和 4.0 g/kg), 试验蟹初重 0.72 ± 0.01 g, 8 周生长试验取样后, 剩余试验蟹开展 72 h 热应激(32 °C)试验。

【结果】研究发现, 适量添加酵母培养物显著提升了幼蟹的增重率、特定生长率及消化酶活性 ($p < 0.05$), 尤其在 3.2 g/kg 添加量时, 其效果与 35 % 鱼粉组相当。添加酵母培养物还改善了低鱼粉饲料下的肠道形态, 并通过上调围食膜和紧密连接蛋白的基因表达减轻了肠道氧化损伤 ($p < 0.05$)。试验还发现, 酵母培养物能改善幼蟹肠道菌群结构, 增加厚壁菌门和希瓦氏菌属的相对丰度及短链脂肪酸含量, 同时降低变形菌门的相对丰度 ($p < 0.05$)。在热应激试验中, 酵母培养物表现出对高温引起的幼蟹血淋巴免疫能力下降和氧化应激的改善作用。基于增重率的回归模型分析确定, 低鱼粉饲料中酵母培养物的最佳添加水平为 2.71 g/kg。

【结论】因此, 低鱼粉饲料中酵母培养物可有效提升幼蟹的生长性能, 保持肠道健康并缓解高温引发的氧化应激。

关键词: 中华绒螯蟹; 酵母培养物; 生长性能; 肠道健康; 急性热应激。

资助项目: 国家重点研发计划(2023YFD2402000)、国家自然科学基金项目(32072986)、财政部和农业农村部国家现代农业产业技术体系、上海市中华绒螯蟹产业技术体系(202404)

通讯作者: 李二超, E-mail: eclli@bio.ecnu.edu.cn; 陈立侨, E-mail: lqchen@bio.ecnu.edu.cn

Supplementation of yeast culture to low-fishmeal diets improves growth, intestinal health, and heat stress resistance in juvenile Chinese mitten crab (*Eriocheir sinensis*)

Song Wang¹, Wen Li¹, Xiaodan Wang¹, Erchao Li^{1,*}, Liqiao Chen^{1,*}

(1. School of Life Sciences, East China Normal University, 500 Dongchuan Road, Shanghai 200241, China)

Abstract: [Objective] Yeast culture (YC), a microecological product derived from yeast fermentation, can enhance animal growth, health, and resistance to heat stress. However, its impact on the economically significant crustacean *Eriocheir sinensis* has not been demonstrated. This study investigated the effects of low-fishmeal YC on the growth, intestinal health, and heat stress resistance of juvenile Chinese mitten crabs. [Methods] Crabs (0.72 ± 0.01 g) were distributed across 42 tanks, and 40 crabs were randomly maintained per tank in six replicates. The crabs were fed a control diet (35% fish meal) or six YC concentrations (15% fish meal; 0, 0.8, 1.6, 2.4, 3.2, or 4.0 g/kg) for 56 days. After sample collection, the remaining crabs were subjected to a 72-hour heat stress challenge at 32 °C. [Results] A moderate-yield YC diet significantly improved weight gain, specific growth rate, and digestive enzyme activities (α -amylase, trypsin, and lipase) compared to those of crabs fed a 15% fishmeal diet without YC. Notably, the diet with 3.2 g/kg YC supplementation was performed as well as crabs fed a 35% fishmeal diet. YC also enhanced intestinal morphology in the low-fishmeal diet group and reduced oxidative damage by increasing the expression of genes related to the peritrophic membrane and tight junction proteins. Furthermore, YC supplementation diversified the intestinal microbiota, significantly increased the abundance of Firmicutes and the genus *Shewanella*, increased acetate and butyrate levels and decreased the abundance of Proteo-bacteria. Correlation analysis revealed that weight gain and specific growth rate were associated with most digestive activity and intestinal health indicators. Following heat stress challenge, YC protected against oxidative stress and enhanced serum immunity at elevated temperatures. [Conclusion] This study indicated that incorporating YC in low-fishmeal diets significantly increases juvenile crab growth, improves intestinal health, and mitigates oxidative stress induced by temperature elevation. The optimal YC concentration was determined to be 2.71 g/kg through regression analysis.

Key words: *Eriocheir sinensis*; Yeast culture; Intestinal microbiota; Heat stress

低鱼粉饲料中酶解玉米蛋白粉替代鱼粉对中华绒螯蟹幼蟹生长性能、蛋白合成和抗热应激能力的影响²⁴

黄恺骥¹, 王涵¹, 王晓丹¹, 李二超^{1*}, 陈立侨^{1*}

(1. 华东师范大学生命科学学院, 上海 200241)

摘要:【目的】本研究旨在探讨在低鱼粉饲料(15%)中,以酶解玉米蛋白粉替代鱼粉对中华绒螯蟹生长性能、蛋白合成及抗热应激能力的影响。【方法】实验设计了6种等氮等脂的饲料,以酶解玉米蛋白粉替代不同水平的鱼粉(0%、6.67%、13.33%、20%、26.67%、33.33%),投喂初始体重为 $0.60\pm 0.01\text{g}$ 的中华绒螯蟹幼蟹8周。【结果】结果显示,酶解玉米蛋白粉显著提高了幼蟹的增重率、特定生长率及其体内粗蛋白含量,替代组的肝胰腺胰蛋白酶活性显著提升,同时激活了mTOR信号通路(*mTOR*、*S6K1*、*S6*、*EIF4*基因表达显著上调),其中以20%替代组效果最佳。肠道菌群分析结果也表明,20%替代组的幼蟹肠道菌群丰度和多样性有所提升,厚壁菌门丰度增加,放线菌门丰度减少,并显著提高了有益菌 *Dysgonomonas* 的丰度,增强了肠道屏障功能,有效缓解了植物蛋白引起的肠道损伤。此外,在72小时的急性热应激实验中,20%替代组的抗氧化基因(如 *cat*、*gpx*、*gst* 等)表达上调,显著增强了幼蟹的抗热应激能力。【结论】酶解玉米蛋白粉能够通过促进蛋白合成相关基因的表达和提高酶活性,增加蛋白质沉积,从而促进生长。其中,20%替代组表现出最佳的促生长效果,不仅显著改善了肠道健康,还提高了幼蟹的抗热应激能力。

关键词: 酶解玉米蛋白粉; 中华绒螯蟹; 生长性能; 蛋白合成; 热应激。

资助项目: 成都美溢德生物技术有限公司、国家重点研发计划(2023YFD2402000)、国家自然科学基金项目(32072986)、财政部和农业农村部国家现代农业产业技术体系、上海市中华绒螯蟹产业技术体系(202404)

通讯作者: 陈立侨, E-mail: lqchen@bio.ecnu.edu.cn, 李二超, E-mail: ecli@bio.ecnu.edu.cn

Effects of replacing fish meal with enzymatic corn gluten meal in low fish meal diet on growth performance, protein synthesis and heat stress resistance of *Eriocheir sinensis*

Kaiqi Huang¹, Han Wang¹, Xiaodan Wang¹, Erchao Li¹, Liqiao Chen^{1*}
(¹ School of Life Sciences, East China Normal University, Shanghai China, 20024)

Abstract: [Objective] The aim of this study was to investigate the effects of replacing fish meal with enzymatic corn gluten meal in low fish meal diet (15%) on growth performance, protein synthesis and heat stress resistance of *Eriocheir sinensis*. [Methods] Six kinds of iso-nitrogen and iso-lipid diets were designed, and different levels of fish meal (0%, 6.67%, 13.33%, 20%, 26.67%, 33.33%) were replaced by enzymatic corn gluten meal. *Eriocheir sinensis* with an initial body weight of 0.60±0.01g were fed for 8 weeks. [Results] The results showed that enzymatically hydrolyzed corn protein powder significantly increased the weight gain, specific growth rate, and crude protein content in juvenile crabs. The replacement groups exhibited a significant increase in trypsin activity in the hepatopancreas, and the activation of the mTOR signaling pathway (with significant upregulation of *mTOR*, *S6K1*, *S6*, and *eif4* gene expression), with the 20% replacement group showing the best results. Gut microbiota analysis revealed that the 20% replacement group had enhanced gut microbiota abundance and diversity, with an increase in the Firmicutes and a decrease in the Actinobacteria, along with a significant rise in the beneficial bacterium *Dysgonomonas*, strengthening the intestinal barrier and alleviating plant protein-induced intestinal damage. Additionally, in a 72-hour acute heat stress test, the 20% replacement group showed upregulated expression of antioxidant genes (such as *cat*, *gpx*, *gst*, etc.), significantly improving the heat stress resistance of juvenile crabs. [Conclusion] In summary, enzymatically hydrolyzed corn protein powder can promote growth by enhancing the expression of protein synthesis-related genes and increasing enzyme activity, leading to greater protein deposition. The 20% replacement group demonstrated the best growth-promoting effects, significantly improving gut health and enhancing heat stress resistance in juvenile crabs.

Key words : Enzymatic corn gluten meal; *Eriocheir sinensis*; Growth performance; Protein synthesis; Heat stress resistance

鱼粉饲料中添加槲皮素对中华绒螯蟹生长和健康的影响²⁵

林莹莹, 余秋然, 王晓丹, 陈立侨, 李二超 *

(华东师范大学生命科学学院, 上海 200241)

摘要: 用植物蛋白替代鱼粉会诱导水生动物产生氧化应激, 并损害其生长和健康。槲皮素是一种强大的天然抗氧化剂, 但其对中华绒螯蟹的生长和健康的具体影响以及潜在的分子机制尚不清楚。

【目的】 本研究旨在探讨槲皮素对中华绒螯蟹幼体 (*Eriocheir sinensis*) 的生长、生理和生化参数、肠道微生物群以及转录组的影响。**【方法】** 选取体重为 0.53 ± 0.01 g 的中华绒螯蟹幼体, 随机分为七组。一组喂食含有正常鱼粉 (35% 鱼粉) 的饲料, 其余六组喂食含有低水平鱼粉 (15% 鱼粉) 的饲料, 并添加不同浓度的槲皮素 (0、250、500、1000、2000 或 4000 mg/kg)。每组有四个重复的水箱, 每个水箱有 40 只中华绒螯蟹, 容积为 300 L, 实验持续 56 天。**【结果】** 含有 35% 鱼粉组的生长性能显著优于不含槲皮素的 15% 鱼粉组。槲皮素显著增加了幼蟹的增重率和特定生长率, 尤其是在 1000 mg/kg 槲皮素组, 增重率和特定生长率超过了正常鱼粉组。35% 鱼粉组的抗氧化能力和免疫力显著高于 15% 鱼粉组。然而, 槲皮素补充促进了蟹的抗氧化能力和免疫力。4000 mg/kg 槲皮素改变了肠道微生物群结构, 减少了有益细菌并增加了病原细菌。槲皮素补充增强了中国绒螯蟹的生长性能和抗氧化能力, 通过增加谷氨酸代谢、泛酸和辅酶 A 合成、鞘脂代谢、花生四烯酸代谢和半胱氨酸和蛋氨酸代谢来实现。**【结论】** 研究表明, 日粮添加槲皮素可以促进中华绒螯蟹生长, 抗氧化能力和非特异性免疫力, 改善肠道形态结构, 促进肠道菌群稳态, 基于增重率和特定生长率的回归分析, 饲料中的适宜添加量为 688~695 mg/kg。

关键词: 槲皮素、抗氧化、非特异性免疫、肠道菌群、细菌

Quercetin supplementation improved the growth and health of juvenile Chinese mitten crabs (*Eriocheir sinensis*) fed low-fishmeal diets

Yingying Lin , Qiuran Yu , Xiaodan Wang , Liqiao Chen , Erchao Li

(School of Life Sciences, East China Normal University, 500 Dongchuan Road, Shanghai 200241, China)

Abstract : The substitution of fishmeal with plant proteins can induce oxidative stress in aquatic animals and impair their growth and health. Quercetin is a potent natural antioxidant, but its specific effects on the growth and health of Chinese mitten crabs, as well as the underlying molecular mechanisms, remain unclear. [Objective] This study aimed to investigate the impact of quercetin on the growth, physiological and biochemical parameters, gut microbiota, and transcriptome of juvenile Chinese mitten crabs (*Eriocheir sinensis*). [Objective] Crabs (0.53 ± 0.01 g) were randomly divided into seven groups. One group was fed a diet containing normal fishmeal (35% fishmeal), whereas the other six groups were fed diets containing low levels of fishmeal (15% fishmeal) supplemented with different levels of quercetin (0, 250, 500, 1000, 2000, or 4000 mg/kg). Each group had four replicate tanks with 40 crabs per 300 L tank, and the experiment lasted for 56 days. [Results] The growth performance of the 35% fishmeal group was significantly greater than that of the 15% fishmeal group without quercetin. However, quercetin significantly increased the weight gain rate and specific growth rate of juvenile crabs, especially in the 1000 mg/kg quercetin group, where these rates exceeded those of the normal fishmeal group. The antioxidant capacity and immunity of the 35% fishmeal group were significantly greater than those of the 15% fishmeal group. However, quercetin supplementation promoted the antioxidant capacity and immunity of the crabs. Quercetin supplementation at 4000 mg/kg changed the gut microbiota structure by decreasing beneficial bacteria and increasing pathogenic bacteria. Quercetin supplementation enhanced the growth performance and antioxidant capacity of Chinese mitten crabs by increasing glutamate metabolism, pantothenic acid and Coenzyme A biosynthesis, sphingolipid metabolism, arachidonic acid metabolism, and cysteine and methionine metabolism. [Conclusion] This study revealed that dietary supplementation with quercetin can promote Chinese mitten crab growth, antioxidant capacity, and nonspecific immunity; improve gut morphology; and promote gut microbiota homeostasis. The optimal dietary concentration of 688--695 mg/kg is recommended on the basis of weight gain and specific growth rate analyses.

Key words : Quercetin; Antioxidant capacity; Gut microbiota; Immunity; Bacteria

浮萍——有潜力的蛋白饲料²⁶

赵海*, 胡株宾, 靳艳玲

(中国科学院成都生物研究所, 四川 成都 610213)

摘要:【目的】饲用蛋白替代是我国国民经济和社会发展极为紧迫的现实需求, 水生植物浮萍克隆生长、生物量积累快、蛋白含量高、不占用耕地, 具有高产蛋白的潜能。作为替代蛋白, 不但需要在技术上实现单位面积蛋白高产, 而且需要在经济上可与豆粕竞争, 品质不低于或高于大豆蛋白。为此, 开展相关研究。【方法】基于团队建成的全球浮萍活体保藏量最大的种质资源库, 开展了高蛋白株系筛选, 氮素吸收、转运、分配规律解析, 蛋白合成关键基因挖掘, 新种质创制, 蛋白积累调控及浮萍营养品质评价。【结果】筛选、创制了高蛋白浮萍株系, 蛋白含量超过 40%; 在滇池边建立了富营养废水生产浮萍的试验系统 (5 亩), 运行时间超过 10 年, 蛋白生产潜能达 800 kg/亩/年; 所获得的浮萍必需氨基酸含量与 FAO/WHO 推荐摄入量相近, 可消化必需氨基酸评分 (DIAAS) 表明浮萍蛋白品质接近大豆蛋白, 而且其不饱和脂肪酸达总脂肪酸 (TFA) 的 70.85%, 维生素 B12 含量为 0.4 $\mu\text{g}/100\text{ g}$ 鲜重, 较高的总酚和总黄酮含量使浮萍抗氧化能力高于传统农作物, 低浓度的抗营养因子使浮萍的营养成分更易吸收。【结论】浮萍有作为蛋白新资源开发、并实现工厂化生产的巨大潜力, 可望为大豆蛋白替代开辟一条全新的途径。

关键词: 浮萍; 蛋白质; 工厂化生产; 营养品质。

Duckweed - a potential protein feed

Hai Zhao^{1*}, Zhubin Hu^{1,2}, Yanling Jin¹

(Chengdu Institute of Biology, Chinese Academy of Sciences, Chengdu China 610213)

Abstract: [Objective] The substitution of feed protein is an extremely urgent demand for China's national economy and social development. Aquatic plant duckweed has characteristics such as clonal growth, rapid biomass accumulation, high protein content, and does not occupy arable land. As a substitute protein, it is not only necessary to achieve high protein yield technically, but also to be economically competitive with soybean meal, with a quality not lower than or higher than soy protein. Therefore, relevant researches have been conducted. [Methods] Based on the world's largest collection of duckweed germplasms established by our team, screen of high protein duckweed strain, analysis of nitrogen absorption, transport, and distribution patterns, exploration of key genes involved in protein synthesis, creation of new germplasm, control of protein accumulation, and evaluation of nutritional quality of duckweed biomass were carried out. [Results] Several strains of duckweed with protein content exceeding 40% were obtained. An experimental system (5 acres) for producing duckweed from eutrophic wastewater has been established by the Dianchi Lake, with a running time of over 10 years and a protein production potential of 800 kg/acre/year. The essential amino acid content of duckweed is similar to the recommended intake by FAO/WHO. The digestible indispensable amino acids score (DIAAS) showed that the quality of duckweed protein is similar to soy protein, with unsaturated fatty acids accounting for 70.85% of total fatty acids (TFA). The content of vitamin B12 is 0.4 µg/100 g fresh weight, and the higher content of total phenols and total flavonoids makes the antioxidant capacity of duckweed higher than that of traditional crops. The low concentration of anti-nutritional factors makes the nutritional components of duckweed easier to absorb. [Conclusion] Duckweed has great potential as a new protein resource for industrial production, and is expected to open up a new path for soybean protein substitution.

Key words: Duckweed; Protein; Industrial production; Nutritional quality

复方中草药对大鳞副泥鳅生长性能、血清生化及抗氧化能力的影响

陈伦^{1,2}, 王泽曦^{1,2}, 赵家振^{1,2}, 李众阳^{1,2}, 张赛昌^{1,2}, 黄文笑^{1,2}, 王自蕊^{1,2*}

(1. 江西农业大学动物科学技术学院, 南昌 330045; 2. 南昌市特色水生生物营养生理与健康养殖重点实验室, 南昌 330045)

摘要:【目的】为探究复方中草药对大鳞副泥鳅生长性能、血清生化及抗氧化能力的影响,【方法】将 800 尾体型相近、健康无病的大鳞副泥鳅 (5.00 ± 0.02) g 随机分为 5 组, 每组 4 个重复, 每个重复 40 尾, 分别投喂对照组饲料与 1% 复方中草药试验组饲料: 复方 I 组 (杜仲+黄芪=1: 1)、复方 II 组 (党参+当归=1: 1)、复方 III 组 (甘草+黄芪=1: 1)、复方 IV 组 (杜仲+山楂=1: 1), 试验周期为 8 周。【结果】结果表明: 与对照组相比, 复方 I 组与复方 III 组泥鳅的平均增重率(WGR)、粗脂肪含量显著降低 ($P<0.05$), 肝脏总抗氧化能力 (T-AOC)、还原性谷胱甘肽 (GSH) 含量显著增高 ($P<0.05$); 复方 II 组泥鳅的肥满度 (CF) 显著增高 ($P<0.05$), 但肝脏超氧化物歧化酶 (SOD) 含量显著低于其他四组 ($P<0.05$); 复方 III 组与复方 IV 组泥鳅血清的总胆固醇(T-CHO) 与甘油三酯 (TG) 含量显著升高 ($P<0.05$); 复方 IV 组泥鳅肝脏总抗氧化能力 (T-AOC) 显著高于对照组 ($P<0.05$), 过氧化氢酶 (CAT) 含量显著性低于对照组 ($P<0.05$), 同时各试验组泥鳅肝脏丙二醛 (MDA) 含量均显著高于对照组 ($P<0.05$)。【结论】综上, 饲料中添加 1% 的 4 种复方中草药对大鳞副泥鳅生长发育产生了抑制作用, 但对肝脏的抗氧化能力有一定程度的促进作用, 同时也有利于促进脂肪降沉, 其中复方 I 组与复方 III 组效果最佳。

关键词: 大鳞副泥鳅; 中草药; 生长性能; 抗氧化能力; 血清生化指标。

高糖饲料中添加二甲双胍对珍珠龙胆石斑鱼生长性能、糖代谢酶活性和肠道菌群的影响

温家声^{1,2,3}, 于沁彤^{1,2,3}, 潘玲^{1,2}, 谭北平^{1,2,3}, 董晓慧^{1,2,3}, 迟淑艳^{1,2,3},
杨奇慧^{1,2,3}, 章双^{1,2,3}, 邓君明^{1,2,3}, 刘泓宇^{1,2,3*}

(1.广东海洋大学, 水产学院, 水产动物营养与饲料实验室, 广东 湛江 524088; 2.广东省水产动物精准营养与高效饲料工程技术研究中心, 广东 湛江 524088; 3.农业部华南水产与畜禽饲料重点实验室, 广东 湛江 524088)

摘要: 二甲双胍是是双胍类降糖药物。【目的】本研究旨在评估高糖饲料中添加不同水平二甲双胍珍珠龙胆石斑鱼生长、血清生化、糖代谢酶活性和肠道微生物菌群结构的影响。【方法】本实验以红鱼粉和酪蛋白为蛋白源, 以玉米淀粉和预糊化淀粉为糖源配制了六种等氮等脂饲料, 包括两种不同糖水平(20%、PC)和(30%、T0), 及在高糖饲料基础上分别添加0.2%(T2)、0.4%(T4)、0.6%(T6)和0.8%(T8)二甲双胍作为实验饲料。【结果】结果表明, 与PC组相比, T0组末重、增重率和特定生长率显著低于PC组($P < 0.05$)。随着二甲双胍的添加, 末重、增重率、特定生长率和肥满度呈先上升后下。血清中葡萄糖、甘油三酯和低密度脂蛋白的含量显著增加($P < 0.05$); 肝脏葡萄糖激酶和丙酮酸激酶的活性显著上升($P < 0.05$), 磷酸烯醇丙酮酸激酶和葡萄糖-6-磷酸酶的活性显著下降($P < 0.05$)。在微生物群方面, 高碳水化合物饮食增加了致病菌, 如变形菌门(Proteobacteria)和发光杆菌属(*Photobacterium*), 而二甲双胍则增加了有益菌, 如厚壁菌门(Firmicutes)和短芽孢杆菌属(*Brevibacillus*)。【结论】综上所述, 本实验条件下, 以增重率为判据, 在30%高糖饲料中二甲双胍最适宜添加水平为0.20%。

关键词: 二甲双胍; 珍珠龙胆石斑鱼; 生长性能; 肠道菌群

Effect of metformin supplementation to high-carbohydrate diets on growth, serum biochemistry, gluconeogenic enzyme activity and intestinal flora of hybrid grouper (*Epinephelus fuscoguttatus* ♀ × *Epinephelus lanceolatu* ♂)

Jiasheng Wen^{1,2,3}, Qingtong Yu^{1,2,3}, Ling Pan^{1,2}, Beiping Tan^{1,2,3}, Xiaohui Dong^{1,2,3}, Shuyan Chi^{1,2,3}, Qihui Yang^{1,2,3}, Shuang Zhang^{1,2,3}, Junming Deng^{1,2,3}, Hongyu Liu^{1,2,3*}

1.Laboratory of Aquatic Animal Nutrition and Feed, Fisheries College, Guangdong Ocean University, Zhanjiang 524088, PR China; 2.Aquatic Animals Precision Nutrition and High Efficiency Feed Engineering Research Centre of Guangdong Province, Zhanjiang, Guangdong, 524088, PR China; 3.Key Laboratory of Aquatic, Livestock and Poultry Feed Science and Technology in South China, Ministry of Agriculture, Zhanjiang 524088, PR China;

Abstract: [Objective] The objective of this study was to evaluate the effects of supplementing high-carbohydrate diets with different levels of metformin on the growth, serum biochemistry, activity of sugar metabolizing enzymes, and intestinal microflora structure of hybrid grouper. [Methods] Six diets with iso-nitrogenous and iso-lipid compositions were prepared, including a positive control (20% carbohydrate, PC) and a negative control (30% carbohydrate, T0). The experimental diets contained 0.2% (T2), 0.4% (T4), 0.6% (T6), and 0.8% (T8) metformin based on the negative control diet. [Results] The results showed that the end weight, weight gain rate and specific growth rate were significantly lower ($P < 0.05$) in the T0 group compared to the PC group. With the addition of metformin, the end weight, weight gain rate, specific growth rate and fattening degree showed an increase and then a decrease. Serum levels of glucose, triglycerides and low-density lipoprotein increased significantly ($P < 0.05$); hepatic glucokinase and pyruvate kinase activities increased significantly ($P < 0.05$), and phosphoenolpyruvate kinase and glucose-6-phosphatase activities decreased significantly ($P < 0.05$). In terms of microbiota, the high-carbohydrate diet increased pathogenic bacteria such as Proteobacteria and *Photobacterium*, whereas metformin increased beneficial bacteria such as Firmicutes and *Brevibacillus*. [Conclusion] In conclusion, the optimal level of metformin addition in 30% high-sugar feeds under the conditions of this experiment was 0.20%, as judged by the rate of weight gain.

Keywords: *Metformin*; Hybrid grouper; Growth performance; intestinal microbiota

高糖饲料中添加苦瓜粉对鲤生长性能、糖脂代谢及其相关基因表达水平的影响

樊海莹^{1,2}, 卢荣华^{1,2}, 曹香林^{1,2}, 徐歆歆^{1,2}, 张玉茹^{1,2*}
(河南师范大学水产学院, 河南 新乡 453007)

摘要: 碳水化合物是水产饲料中的重要能源物质之一, 但鱼类利用糖类的能力有限, 当饲料中的糖含量超标后, 过量的糖会转化成脂肪, 诱发胰岛素 (Insulin, INS) 抵抗、脂肪肝等代谢性疾病。研究表明, 苦瓜 (Bitter melon, BM) 富含皂苷、黄酮类和多糖等多种活性成分, 具有降血糖、降脂和抗氧化性等功效, 可作为饲料添加剂应用到鱼类饲料中。为了探究苦瓜对鲤 (*Cyprinus carpio*) 糖脂代谢的影响, 本研究以鲤为研究对象, 以苦瓜粉 (Bitter melon powder, BMP) 作为饲料添加剂, 分别设置对照组 (C)、高糖组 (HG)、0.5%苦瓜粉添加组 (HG+0.5%BMP)、1%苦瓜粉添加组 (HG+1%BMP) 和 1.5%苦瓜粉添加组 (HG+1.5%BMP), 开展 8 周的养殖实验。结果表明, BMP 的添加降低了鲤血糖和血脂含量, 提高了鲤血清中总胆固醇 (total cholesterol, TC) 以及高密度脂蛋白胆固醇 (high density lipoproteins-cholesterol, HDL-C) 的含量, 此外, 添加 0.5%BMP 后可以显著降低鲤血清和肝胰脏中 MDA 的含量, 提升抗氧化能力, 并改善因高糖引起的鲤肠绒毛损伤。1.5%BMP 的添加可以减轻高糖饲料引起的鲤肝胰脏及肌肉组织中糖原和脂质的沉积; 糖脂代谢关键基因的表达结果也表明, 添加 BMP 后, 多个组织 (肝胰脏、肌肉、肠道和脂肪) 中糖酵解相关基因 (*gk*、*pk* 和 *pfk*) 的表达显著升高, 而糖原合成及糖异生关键基因 (*gys* 和 *g6pase*) 的表达量受到抑制; 此外, 脂质合成关键基因 (*fasn* 和 *ppary*) 的表达也显著降低。综上, BMP 的添加可提高鲤的抗氧化能力, 减弱鲤肝胰脏及肌肉组织中糖脂蓄积情况, 有助于恢复鲤肠道组织损伤, 同时, 还可调节鲤糖脂代谢紊乱。研究结果可为 BMP 添加剂的研发提供参考。

关键词: 鲤; 苦瓜粉; 生长性能; 抗氧化; 糖脂代谢

Effects of bitter melon powder on growth performance, glucose and lipid metabolism and related gene expression in common carp fed high-sugar diet

Haiying Fan^{1,2}, Ronghua Lu^{1,2}, Xianglin Cao^{1,2}, Xinxin Xu^{1,2}, Yuru Zhang^{1,2*},
(College of Fisheries, Henan Normal University, Xinxiang China 453007)

Abstract : Carbohydrate is one of the important energy substances in aquatic feed, but the ability of fish to use sugars is limited. When the sugar content in feed exceeds the standard, excessive sugar will be converted into fat, inducing insulin resistance, fatty liver and other metabolic diseases. Studies have shown that bitter melon (Bitter melon, BM) is rich in saponins, flavonoids and polysaccharides and other active ingredients, with hypoglycemic, lipid-lowering and antioxidant effects, can be used as feed additives applied to fish feed. In order to explore the effect of bitter melon on glucose and lipid metabolism of common carp (*Cyprinus carpio*), common carp was used as the research object in this study, and bitter melon powder (BMP) was used as feed additive. The control group (C), high glucose group (HG), 0.5 % bitter melon powder addition group (HG + 0.5 % BMP), 1 % bitter melon powder addition group (HG + 1 % BMP) and 1.5 % bitter melon powder addition group (HG + 1.5 % BMP) were set up to carry out an 8-week breeding experiment. The results showed that the addition of BMP reduced the content of blood glucose and blood lipid, and increased the content of TC and HDL-C in the serum of carp. In addition, the addition of 0.5 % BMP could significantly reduce the content of MDA in the serum and hepatopancreas of carp, improve the antioxidant capacity, and improve the damage of intestinal villi caused by high glucose. The addition of 1.5 % BMP could reduce the deposition of glycogen and lipid in hepatopancreas and muscle tissues of common carp caused by high sugar diet. The expression results of key genes in glycolipid metabolism also showed that the expression of glycolysis-related genes (*gk*, *pk* and *pfk*) in multiple tissues (hepatopancreas, muscle, intestine and fat) was significantly increased after adding BMP, while the expression of glycogen synthesis and gluconeogenesis key genes (*gys* and *g6pase*) were inhibited. In addition, the expression of key genes for lipid synthesis (*fasn* and *ppary*) was also significantly reduced. In summary, the addition of BMP can improve the antioxidant capacity of carp, reduce the accumulation of glucose and lipid in hepatopancreas and muscle tissues of carp, help to restore the intestinal tissue damage of carp, and regulate the disorder of glucose and lipid metabolism in carp. The research results can provide reference for the development of BMP additives.

Keywords : common carp; bitter melon powder; growth performance; antioxidant; glycolipid metabolism

海藻多糖改善过氧化氢应激对加州鲈肠道损伤²⁷

孙淼¹, 邓华辉¹, 秦仪波¹, 孙莹¹, 周萌¹, 林鑫¹, 黄燕华¹, 董焯玮¹, 游翠红^{1*}

(1 仲恺农业工程学院, 健康养殖创新研究院&动物科技学院, 广州 510225)

摘要: 【目的】海藻多糖具有抗氧化功能, 为探究海藻多糖对加州鲈 (*Micropterus salmoides*) 肠道损伤的修复作用, 【方法】本研究采用自提的海藻多糖, 以 0%、0.08%、0.14%、0.20%、0.26%、0.32% 水平与商品饲料拌食投喂加州鲈幼鱼 2 周, 胸鳍基部注射过氧化氢, 24 h 后测定血清和前肠的生化指标和酶活及前肠基因表达; 并且, 在人结肠腺癌细胞 Caco-2 中, 用过氧化氢处理再用海藻多糖治疗, 或先用海藻多糖预防再用过氧化氢处理, 测定 Caco-2 细胞的酶活和基因表达。【结果】各组的存活率、增重率、特定生长率、饲料系数没有显著性差异 ($P > 0.05$), 以 0.08% 组的生长性能最好。与对照组相比 (0%), 饲料中添加海藻多糖显著降低了血清的谷草转氨酶、免疫球蛋白 IgM、二胺氧化酶 (DAO)、内毒素和丙二醛 (MDA) 的含量 ($P < 0.05$), 显著增加了血清的超氧化物歧化酶 (SOD)、谷胱甘肽过氧化物酶 (GSH-Px) 活性 ($P < 0.05$); 0.08% 和 0.14% 组还增加了血清的过氧化氢酶 (CAT)、白蛋白含量及前肠的 SOD、GSH-Px 和脂肪酶活性 ($P < 0.05$), 降低了血清的谷丙转氨酶活性 ($P < 0.05$); 除开 0.32% 组外, 其他海藻多糖组还降低了前肠的髓过氧化物酶 (MPO) 含量; 饲料中添加海藻多糖显著提高了肠道紧密连接相关基因 *zo-1* 的表达 ($P < 0.05$), 降低了炎症因子 *il-8*、*tnf- α* 的表达 ($P < 0.05$); 0.08% 和 0.14% 组还增加了 *occludin*、*claudin-4*、*il-10* 的表达 ($P < 0.05$)。在 Caco-2 的治疗和预防过氧化氢应激实验中, 海藻多糖均能提高 Caco-2 的 SOD、GSH-Px、CAT 的活性 ($P < 0.05$), 降低 MDA 含量和活性氧 ROS 水平 ($P < 0.05$); 在预防实验中, 海藻多糖降低了 Caco-2 的炎症因子 *il-1 β* 、*il-6*、*il-8*、*nf- κ b* 的 mRNA 表达 ($P < 0.05$), 提高了 *occludin*、*claudin-1*、*zo-1*、*il-10* 的 mRNA 表达 ($P < 0.05$)。【结论】上述结果表明, 自提的海藻多糖以 0.08%~0.14% 水平添加到饲料中能够降低过氧化氢应激对加州鲈的肠道损伤, 通过提高抗氧化性能降低肠中 ROS 水平, 修复肠上皮细胞屏障。

关键词: 加州鲈; 海藻多糖; 过氧化氢应激; 肠道损伤

Seaweed polysaccharides improve the intestinal damage induced by hydrogen peroxide stress in largemouth bass (*Micropterus salmoides*)

Miao Sun¹, Huahui Deng¹, Yibo Qin¹, Ying Sun¹, Meng Zhou¹, Li Lin¹, Yanhua Huang¹, Yewei Dong¹, Cuihong You^{1*}

(1. Institute of Animal Health Breeding Innovation & College of Animal Science and Technology, Zhongkai College of Agricultural Engineering, Guangzhou, China 510225)

Abstract: [Objective] Seaweed polysaccharides have antioxidant function, and then the repairing effects of seaweed polysaccharides on intestinal damage were investigated in largemouth bass (*Micropterus salmoides*). [Methods] In this study, self-extracted seaweed polysaccharides were mixed with commercial feeds at 0 %, 0.08 %, 0.14 %, 0.20 %, 0.26 %, and 0.32 % levels to feed juvenile largemouth bass for 2 weeks, and then the fish were injected with hydrogen peroxide from the pectoral fin base. After 24 h, it was to measure the biochemistry parameters and enzyme activity both in serum and foregut as well as intestinal gene expression. Moreover, in the human colon adenocarcinoma cells Caco-2, self-extracted seaweed polysaccharides were used to heal hydrogen peroxide instress, or to prevent hydrogen peroxide instress, and then the enzyme activity and gene expression of Caco-2 cells were tested. [Results] There was no significant difference in survival rate, weight gain rate, specific growth rate and feed coefficient among all groups ($P > 0.05$), and the growth performance of 0.08 % group was the best. Compared with the control group (0 %), dietary supplementation of seaweed polysaccharides significantly decreased the contents of aspartate aminotransferase, immunoglobulin IgM, diamine oxidase, endotoxin and malondialdehyde (MDA) in serum ($P < 0.05$), but significantly increased the activities of superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) in serum ($P < 0.05$). Furthermore, the 0.08 % and 0.14 % groups also increased serum catalase (CAT) activity and albumin content as well as foregut SOD, GSH-Px and lipase activities ($P < 0.05$), but decreased serum alanine aminotransferase content ($P < 0.05$). Except for the 0.32 % group, other seaweed polysaccharide groups also reduced the level of myeloperoxidase (MPO) in the foregut ($P < 0.05$). In addition, dietary supplementation of seaweed polysaccharides significantly increased the expression of *zo-1* related to tight junction ($P < 0.05$), and decreased the expression of *il-8* and *tnf- α* associated with inflammation ($P < 0.05$). Moreover, the expression of *occludin*, *claudin-1* and *il-10* was also increased in 0.08 % and 0.14 % groups ($P < 0.05$). Both in the treatment and prevention experiments of hydrogen peroxide instress in Caco-2 cells, seaweed polysaccharides increased the activity of SOD, GSH-Px and CAT, and reduced the content of MDA and ROS. Furthermore, in the prevention experiment, seaweed polysaccharide reduced the expression of inflammatory factors *il-1 β* , *il-6*, *il-8* and *nf- κ b* in Caco-2, and increased the expression of *occludin*, *claudin-1*, *zo-1*, *il-10*. [Conclusion] The above results suggest that the addition of self-extracted seaweed polysaccharide in diets at an 0.08 % ~ 0.14 % level could reduce the intestinal damage caused by hydrogen peroxide stress. The mechanism may be associated with increment of the antioxidant enzyme activity to reduce ROS levels in intestine and to improve epithelial barrier.

Key words: largemouth bass; seaweed polysaccharide; hydrogen peroxide stress; intestinal damage

褐藻酸钠通过肝肠轴缓解高糖饲料诱导黄鳝健康损伤²⁸

余传启^{1,2}, 朱雯璐^{1,2}, 潘海涛^{1,2}, 张慧琳^{1,2}, 王文军^{1,2}, 刘云锋³, 王自蕊^{1,2}, 彭墨^{1,2}, 周秋白^{1,2*}

(1. 特种水产研究所、江西农业大学动物科学技术学院, 江西 南昌 330045; 2. 南昌市特色水生生物营养生理与健康养殖重点实验室, 江西 南昌 330045; 3. 青岛隆安生物科技有限公司, 山东 青岛 266000)

摘要:【目的】高糖饲料在水产养殖中较为常见, 然而, 这导致水产动物健康损伤; 为探索褐藻酸钠在缓解高糖饲料诱导水产动物健康损伤中的作用。【方法】本研究以黄鳝为研究对象, 通过分别投喂常规 (NC)、高糖 (HC)、高糖+0.5%褐藻酸钠 (HC-S) 饲料 56 天。【结果】结果表明, 与 HC 组比, HC-S 组的肝体指数、血清生化指标 (血糖、甘油三酯、转氨酶活性)、肝脏组织结构 (脂滴、糖原和胶原纤维含量) 均降低。肝脏转录组学分析显示, 与 NC 组比, HC 组解毒相关差异表达基因的表达下调; 同时, 与 HC 组比, LA 组与脂肪酸合成相关差异表达基因的表达上调。此外, 联合后肠内容物中宏基因组学和短链脂肪酸谱分析表明, 与 HC 组比, LA 组的乙酸浓度显著增加, 这与吉氏海杆菌丰度显著增加一致。【结论】总之, 褐藻酸钠通过缓解肝损伤和肠道菌群失调改善高糖饲料诱导黄鳝健康损伤。

关键词: 褐藻酸钠; 肝损伤; 肠道菌群失调; 高糖饲料。

Sodium alginate ameliorates healthy injury induced by high carbohydrate diets in *Monopterus albus* through gut-liver axis

Chuanqi Yu^{1,2}, Wenlu Zhu^{1,2}, Haitao Pan^{1,2}, Huilin Zhang^{1,2}, Wenjun Wang^{1,2}, Yunfeng Liu³, Zirui Wang^{1,2}, Mo Peng^{1,2}, Qiubai Zhou^{1,2*}

(1. Special fisheries research institute, College of Animal Science and Technology, Jiangxi Agricultural University, Nanchang 330045, China; 2. Key Laboratory of Featured Hydrobios Nutritional Physiology and Healthy Breeding, Nanchang 330045, China; 3. Qingdao Luoan Biotechnology Co., Ltd, Qingdao 266000, China)

Abstract: [Objective] High carbohydrate (HC) diets have become a conventional approach in modern aquaculture. However, this feeding strategy frequently compromises the health of high-value economic fish species. This study aims to explore the role of sodium alginate in alleviating aquatic animals' health damage caused by high carbohydrate diet. [Methods] In this study, *Monopterus albus* were fed normal diet (20 % carbohydrate, NC), high carbohydrate diet (32 % carbohydrate, HC), and high carbohydrate diets supplemented with 0.5 % SA (LA) for 56 days. [Results] Then our outcomes evinced that LA improves various health-related parameters, including reduction of hepatosomatic index (HSI), serum glucose, triglycerides, and aminotransferase levels, as well as the decrease in hepatic lipid droplets, glycogen, and collagen fiber content. Our transcriptomic analysis on liver tissue showed that detoxification-related differentially expressed gene (DEG) was down regulated in HC group than in NC group. In contrast, DEG linked to fatty acid synthesis increased in LA group versus HC group. A combined analysis of metagenomics and the short-chain fatty acids (SCFAs) profile in the posterior intestinal digesta indicated that LA diets greatly increased concentration of acetic acid. This effect was accompanied by a concurrent reduction in the abundance of the species *Marinobacter guineae* relative to HC diets. [Conclusion] sodium alginate has demonstrated a substantial enhancement in *Monopterus albus*' health by mitigating liver injury and ameliorating intestinal microbiota dysbiosis.

Key words: Sodium alginate; Liver injury; Intestinal microbiota dysbiosis; High carbohydrate diet;

黑水虻油替代鱼油对拟穴青蟹生长性能、抗氧化能力、脂质代谢和线粒体功能的影响

孙蓬^{1,2,3}, 杨宇航^{1,2,3}, 朱婷婷^{1,2,3}, 金敏^{1,2,3*}, 周歧存^{1,2,3*}

(1. 宁波大学, 海洋学院, 鱼类与甲壳动物营养研究室, 浙江 宁波 315211; 2. 水产生物技术教育部重点实验室浙江 宁波 315211; 3. 农业农村部绿色海水养殖重点实验室(省部共建)浙江 宁波 315211)

摘要:【目的】鱼油在全球范围内供不应求, 价格持续上涨, 这使水产饲料行业迫切的需要研究鱼油的替代来源。而黑水虻油(BSFO)富含月桂酸, 且被认为是水产饲料中潜在的脂质来源。因此, 本研究旨在评估BSFO替代鱼油对拟穴青蟹生长、抗氧化能力、脂质代谢和线粒体功能的影响。【方法】本研究共制作了五种等氮(约46.0%粗蛋白)和等脂(约10.0%粗脂肪)的实验饲料, BSFO替代饲料中鱼油的比例分别为0%、25%、50%、75%和100%。选取160只初始体重为 18.58 ± 0.02 g的拟穴青蟹, 置于蟹公寓循环水系统中进行为期八周的养殖实验。【结果】当BSFO替代鱼油不超过50%时, 对拟穴青蟹的增重率(PWG)、特定生长率(SGR)和饲料效率(FE)均无显著影响($P > 0.05$), 然而随着替代率从50%增加到100%, PWG和SGR显著降低($P < 0.01$)。当BSFO替代比例超过50%, 显著上调脂质合成相关基因的表达, 同时下调脂质分解相关基因的表达水平($P < 0.05$)。BSFO替代25%和50%鱼油组显著增强了拟穴青蟹的抗氧化能力, 具体表现为血淋巴和肝胰腺中的抗氧化以及免疫相关酶活性和代谢产物水平的显著提高, 肝胰腺中丙二醛(MDA)和蛋白质羰基(PC)含量的显著降低, 以及肝胰腺细胞凋亡指数的显著下降($P < 0.05$)。此外, 黑水虻幼虫油显著上调了肝胰腺中线粒体DNA拷贝数和能量代谢相关基因的表达水平($P < 0.05$)。BSFO替代25%和50%鱼油组肝胰腺线粒体更丰富, 而替代25%鱼油组ATP含量最高($P < 0.01$)。【结论】用BSFO替代鱼油不超过50%时, 对拟穴青蟹的生长无负面影响, 同时提高机体抗氧化和免疫能力, 增强线粒体功能。

关键词: 拟穴青蟹; 黑水虻油; 生长; 抗氧化; 脂质代谢; 线粒体功能

基金项目: 国家重点研发计划(2023YFD2402000); 国家自然科学基金(32072987); 国家虾蟹产业技术体系(CARS-48); 浙江省自然科学基金项目(LQ20C190005); 宁波大学王宽诚基金

通讯作者: 周歧存, E-Mail: zhouqicun@nbu.edu.cn; 金敏, E-Mail: jinmin@nbu.edu.cn

Effects of substituting fish oil with black soldier fly larvae oil on growth, antioxidant capacity, lipid metabolism, and mitochondrial function in *Scylla paramamosain*

Peng Sun^{1,2,3}, Yuhang Yang^{1,2,3}, Tingting Zhu^{1,2,3}, Min Jin^{1,2,3*}, Qicun Zhou^{1,2,3*}

(1. Laboratory of Fish and Shellfish Nutrition, Ningbo University, Ningbo 315211, PR China; 2. Key Laboratory of Aquacultural Biotechnology Ministry of Education, Ningbo University, Ningbo 315211, PR China; 3. Key Laboratory of Green Mariculture (Co-construction by Ministry and Province), Ministry of Agriculture and Rural, Ningbo 315211, PR China)

Abstract: [Objective] Due to a global shortage of fish oil (FO) and rising prices, it is critical that the aquafeed sector look for lipid alternatives. Whereas, black soldier fly oil (BSFO) is rich in lauric acid and has been recognized as a potential source of lipids in aquafeeds. Therefore, the present study aimed to evaluate the effects of substituting FO with BSFO on growth, antioxidant capacity, lipid metabolism, and mitochondrial function on the mud crab (*Scylla paramamosain*). **[Methods]** Five isonitrogenous (46.0% protein) and isolipidic (10.0% lipid) experimental diets were made to satisfy the protein and lipid requirements of juvenile mud crabs. FO was replaced by BSFO at 0% (BSFO0, control), 25% (BSFO25), 50% (BSFO50), 75% (BSFO75), and 100% (BSFO100), respectively. A total of 160 juvenile mud crabs (18.58 ± 0.02 g) were randomly divided into crab cell recirculating water system for an 8-week culture experiment. **[Results]** The results showed that there was no significant difference in percent weight gain (PWG), specific growth rate (SGR), or feed efficiency (FE) between the experimental and control groups when the proportion of BSFO replacing FO was not more than 50%, however, PWG and SGR significantly decreased as the percentage of substitution increased from 50% to 100% ($P < 0.01$). When the percentage of substitution is exceeded 50%, the expression levels of genes related to lipid synthesis and catabolism were significantly up- and down-regulated, respectively ($P < 0.05$). When 25% and 50% FO were replaced with BSFO, the antioxidant and immune responses of juvenile mud crabs were significantly enhanced, and antioxidant and immune-related enzyme activities and metabolite concentrations in the hemolymph and hepatopancreas were significantly increased, the concentration of malondialdehyde (MDA) and protein carbonyl (PC), and the apoptosis index in the hepatopancreas significantly decreased ($P < 0.05$). Moreover, mitochondrial function indexes in the hepatopancreas, such as mitochondrial DNA copy number and expression levels of energy metabolism-related genes, were significantly up-regulated. Hepatopancreas mitochondria were more abundant in BSFO replacement 25% and 50% FO groups, while ATP content was highest in 25% FO replacement groups ($P < 0.01$). **[Conclusion]** In summary, the results of the present study demonstrated that substituting no more than 50% of FO with BSFO (1.5% BSFO in the feed) does not negatively affect the growth performance of mud crabs and enhances the antioxidant and immune capacity of the hepatopancreas as well as mitochondrial function.

Key words: Mud crab; Black soldier fly oil; Growth; Antioxidant; Lipid metabolism; Mitochondrial function,

几种功能性物质对大菱鲆粪便稳定性和肠道健康的影响

廖兆凡¹, 麦康森^{1,2*}, 张彦娇^{1,2*}

(中国海洋大学农业农村部水产动物营养与饲料重点实验室, 海水养殖教育部重点实验室, 山东青岛, 266003; 2. 青岛海洋科学与技术国家实验室, 海洋渔业科学与食物产出过程功能实验室, 山东 青岛 266237)

摘要: 本研究以海水养殖鱼类大菱鲆幼鱼 (*Scophthalmus maximus L.*) 为研究对象, 通过在低鱼粉饲料 (42% 鱼粉) 中分别添加瓜尔胶、黄原胶、甘露寡糖以及腐殖酸钠, 研究其对大菱鲆幼鱼肠道健康以及粪便稳定性的影响。本论文主要研究内容和实验结果如下: 设计并制作了 6 种等氮等脂的饲料, 分别为: 鱼粉组 (PC) 包含 50% 的鱼粉, 低鱼粉组含 42% 的鱼粉 (NC), GG 组 (NC+0.3% 瓜尔胶), XTG 组 (NC+0.3% 黄原胶), SH 组 (NC+0.3% 腐殖酸钠) 和 MOS0.3 组 (NC+0.3% 甘露寡糖)。经过 35 天的养殖投喂后取样分析。实验结果显示, 各处理组大菱鲆的生长性能没有差别。为了研究粪便的稳定性, 在养殖第 21 和 28 天对养殖水体的粒径以及粪便进行取样分析, 结果显示, XTG 显著增加了第 21 天的水体的中值粒径; 在第 28 天, PC、GG 和 XTG 组显著增加了水体的中值粒径; 粪便成型率的情况, 第 21 和 28 天各个处理组相比于 NC 组, 成型率都有上升的趋势。为研究添加剂对大菱鲆肠道健康的影响, 在 35 天养殖实验结束后, 对大菱鲆肠道进行取样分析, 所有处理组的大菱鲆幼鱼后肠肠道上皮细胞完整、细胞核均位于细胞基底且排列整齐; 固有层均未出现显著增宽, 且固有层都未出现明显的炎性细胞浸润现象。肠道绒毛周长比以及肠道肌层厚度在各处理组间均无显著差异。与 NC 组相比, 所有处理组显著下调了促炎因子 IFN- γ 的表达量; 除 XTG 组外, 其余处理组显著下调了促炎因子 IL-1 β 的表达量; 所有处理组促炎因子 TNF- α 的表达量都显著低于 NC 组; PC 组和 MOS0.3 组显著上调了抑炎因子 IL-10 的表达量。GG 组显著上调了 Tricellulin 的表达水平; SH 组和 MOS0.3 组显著上调了 JAM-2 的表达水平; MOS0.3 显著上调了 Claudin-3 的表达水平。综上, 在饲料中添加 0.3% 黄原胶、瓜尔胶、腐殖酸钠、甘露寡糖能增加粪便的成型率, 其中黄原胶、瓜尔胶能够显著增强粪便的稳定性。同时, 上述添加剂并不会对大菱鲆幼鱼的肠道健康和生长造成负面影响, 而且甘露寡糖对大菱鲆幼鱼的肠道健康有一定促进作用。

关键词: 黄原胶; 瓜尔胶; 甘露寡糖; 肠道健康; 粪便稳定性; 大菱鲆

Effects of several functional additives on fecal stability and intestinal health of turbot

Zhaofan Liao¹, Kangsen Mai^{1,2*}, Yanjiao Zhang^{1,2*}

(Key Laboratory of Aquatic Animal Nutrition and Feed, Ministry of Agriculture and Rural Affairs, Key Laboratory of Marine Aquaculture, Ministry of Education, Ocean University of China, Qingdao, Shandong, 266003; 2. Functional Laboratory of Marine Fisheries Science and Food Production Processes, Qingdao National Laboratory of Marine Science and Technology, Qingdao 266237, Shandong, China)

Abstract : In this research, juvenile turbot (*Scophthalmus maximus L.*) was used to investigate the effects of 4 kinds of additives on the intestinal health and fecal stability of juvenile turbot in a low fishmeal diet (42% fishmeal contained). A total of 6 isonitrogenous and isolipidic experimental diets were formulated: fishmeal group (PC) containing 50% fishmeal, low fishmeal group containing 42% fishmeal (NC), GG (NC+0.3% guar gum), XTG (NC+0.3% xanthan gum), SH (NC+0.3% sodium humate), MOS0.15 (NC+0.15% mannan-oligosaccharide) and MOS0.3 (NC+0.3% mannan-oligosaccharide). Samples were taken and analyzed after 35 days of culture feeding. The results of the experiment showed that there was no difference in the growth performance of turbot among the treatment groups. Sampling of the particle size of the culture water as well as feces which were used to analyze the stability of the feces showed that PC, GG and XTG groups significantly increased the median particle size of the water; and in the case of the feces molding rate, there was a tendency to increase in the rate of molding for each of the treatment groups compared to the NC group. Based on the results of the intestinal sections, there were no significant differences between the treatments. Compared with the NC group, the expression of pro-inflammatory factor IFN- γ was significantly down-regulated; the expression of TNF- α was significantly lower in all treatment groups than that in NC; and the expression of IL-1 β was significantly up-regulated in PC and the MOS0.3 groups; SH and MOS0.3 groups significantly up-regulated the expression of JAM-2; MOS0.3 significantly up-regulated the expression of Claudin-3. In conclusion, the addition of 0.3% xanthan gum, guar gum, sodium humate, and mannan oligosaccharide to the feed could increase the rate of fecal molding, in which xanthan gum and guar gum could significantly enhance the stability of feces. At the same time, the above additives did not negatively affect the intestinal health and growth of juvenile turbot, and mannan-oligosaccharides could promote the intestinal health of turbot.

Keywords: Xanthan gum; Guar gum; Manna oligosaccharides; Intestinal health; Fecal stability; Turbot

姜黄素对赭曲霉毒素 A 和低氧应激联合导致的草鱼肝损伤的缓解作用

吴亮琴¹, 赵 飘¹, 吴 培¹, 姜维丹¹, 刘 杨¹, 马耀斌¹, 任红梅¹, 金小璇¹, 史合群²,
周小秋^{1*}, 冯 琳^{1*}

(1.四川农业大学动物营养研究所, 成都 611130; 2.广州科虎生物科技有限公司, 广州 510663)

摘要: 在渔业生产实践中, 水体缺氧是限制渔业生产的重要因素。此外, 赭曲霉毒素 A (OTA) 是一种广泛存在于水产饲料中的毒素。在实际生产中, 当饲料受到 OTA 污染时, 水生动物往往对低氧更加敏感。本研究探讨了 OTA 和低氧应激对草鱼肝脏的多重生物毒性, 并探究了姜黄素 (CUR) 对两者联合效应导致的草鱼肝损伤的缓解作用。试验选取 720 尾初始体重为 11.06 ± 0.05 g 的健康幼草鱼, 随机分配到 4 个实验组: 对照组 (不含 OTA 和 CUR)、1.2 mg/kg OTA 组、400 mg/kg CUR 组和 1.2 mg/kg OTA + 400 mg/kg CUR 组, 每个实验组设 3 个重复, 每个重复 60 尾鱼, 实验为期 60 d, 生长试验结束后每个处理选取 32 尾鱼, 分为常氧组 (18 尾) 和低氧组 (18 尾), 进行 96 小时的低氧胁迫实验。结果表明: CUR 通过减少草鱼肝组织空泡化和核偏移现象, 缓解了因 OTA 和低氧应激共同造成的组织病理学损伤, 这种损伤的缓解作用与线粒体途径的细胞凋亡有关, 即降低了促凋亡蛋白 Caspase 3、8、9、Bax 和 Apaf1 的表达 ($P < 0.05$), 增加了抗凋亡蛋白 Bcl-2 的表达 ($P < 0.05$); 并通过减少 Grp78 的水平来缓解了内质网应激 (ERS) ($P < 0.05$)。这可能是由于添加 CUR 通过提高过氧化氢酶 (CAT) 和谷胱甘肽 (GSH) 的水平 ($P < 0.05$) 增强了抗氧化能力, 确保了线粒体呼吸链复合物 I 和 II 的正常运作, 减少了活性氧 (ROS) 的大量产生 ($P < 0.05$), 从而缓解了细胞凋亡和 ERS。这项研究证实了 CUR 在缓解 OTA 和低氧应激共同导致的草鱼肝损伤的有效性, 姜黄素将作为一种潜在的天然产品, 为后续缓解生产中霉菌毒素和低氧造成的危害提供可行策略。

关键词: 姜黄素; 赭曲霉毒素 A; 低氧; 草鱼; 内质网应激; 细胞凋亡。

通讯作者: 周小秋, 教授, 博士生导师; 冯 琳, 教授, 博士生导师; E-mail: zhouxq@sicau.edu.cn (周小秋); fenglin@sicau.edu.cn (冯琳)

基金项目: 国家现代农业产业技术体系 (CARS-45); 国家自然科学基金项目 (32273144, 32072985); 国家重点研发计划“蓝色粮仓科技创新”重点专项 (2019YFD0900200)

姜黄素缓解慢性热应激下西伯利亚鲟心脏氧化应激、细胞凋亡和线粒体功能损伤

杨世勇¹, 陈前余¹, 王惠莉¹, 张玉杰¹, 陈晓航¹, 张振业¹, 杜小刚^{2*}

(1.四川农业大学动物科技学院, 四川 成都 611100; 2. 四川农业大学生命科学学院, 四川 雅安 625014)

摘要: 本研究旨在探讨西伯利亚鲟 (*Acipenser baerii*) 心脏热应激损伤机制及姜黄素的干预作用。本研究将 360 尾西伯利亚鲟 (114.69±4.48 g) 幼鱼分为 3 个组: C 组 (20°C)、HC 组 (28°C) 和 HM 组 (28°C+200 mg/kg 姜黄素), 其中 C 组及 HC 组投喂未添加姜黄素的饲料, HM 组投喂含 200 mg/kg 姜黄素的饲料。在第 41 d 开始对 HC 组及 HM 组进行慢性热应激处理, 按照 1°C/d 连续加热 8 d 直到水温达到 28°C, 维持该水温 12 d 后采集心脏。H&E 染色和透射电镜的结果发现, 与对照组 (C 组) 相比, HC 组心脏出现炎性细胞浸润、肌原纤维断裂、线粒体空泡化等病理损伤, 而 HM 组损伤明显减轻。免疫荧光结果显示, 与对照组相比, HC 组心脏中 ROS 水平极显著升高 ($p < 0.01$), 而 HM 组极显著降低 ($p < 0.01$)。此外, HC 组心脏中 SOD 活性和 MDA 含量极显著升高 ($p < 0.01$), 抗氧化酶 (CAT 和 GSH-Px) 活性显著降低 ($p < 0.05$), 而 HM 组抗氧化酶 (CAT 和 GSH-Px) 活性极显著升高 ($p < 0.01$), MDA 含量显著降低 ($p < 0.05$)。Tunel 免疫荧光结果显示, HC 组心肌细胞凋亡水平极显著升高 ($p < 0.01$), 而 HM 组极显著降低 ($p < 0.01$)。实时荧光定量 PCR 和免疫印迹的结果发现, HC 组心脏中线粒体凋亡途径相关基因 (*caspase-9*、*caspase-3* 和 *caspase-7*) 和 Caspase-3 蛋白水平极显著升高 ($p < 0.01$), Hsp90 蛋白极显著降低 ($p < 0.01$), 而 HM 组线粒体凋亡途径相关基因和 Caspase-3 蛋白水平极显著降低 ($p < 0.01$)。流式和酶活检测的结果发现, HC 组心脏 MMP、Ca²⁺Mg²⁺-ATP 酶活性及 ATP 含量显著降低 ($p < 0.05$), HM 组均显著升高 ($p < 0.05$)。与对照组相比, HC 组心脏线粒体生物合成相关基因 (*pgc-1 α* 和 *tfam*)、线粒体自噬相关基因 (*parkin* 和 *pink1*) 的 mRNA 和 Ampk 的蛋白水平显著升高 ($p < 0.05$), 而 HM 组均显著降低 ($p < 0.05$)。1.慢性热应激可导致西伯利亚鲟心脏结构损伤和氧化应激, 姜黄素可减轻慢性热应激引起的心脏损伤和氧化应激; 2.慢性热应激可通过促进线粒体途径细胞凋亡相关基因 (*caspase-9*、*caspase-3* 和 *caspase-7*) 和 Caspase-3 蛋白的表达, 同时抑制 Hsp90 蛋白的表达来促进心肌细胞凋亡, 而姜黄素可缓解慢性热应激诱导的细胞凋亡相关基因和蛋白的变化; 3.慢性热应激可导致西伯利亚鲟心脏出现线粒体功能障碍, 同时激活线粒体生物合成和线粒体自噬途径, 而姜黄素能发挥线粒体保护作用, 缓解热应激诱导的线粒体功能障碍, 同时调控线粒体生物合成和线粒体自噬途径以维持线粒体的稳定。

关键词: 热应激; 西伯利亚鲟; 心脏; 线粒体功能; 姜黄素。

Curcumin alleviates oxidative stress, apoptosis and mitochondrial impairment in the heart of Siberian sturgeon(*Acipenser baerii*) under chronic heat stress

Shiyong Yang¹

(1. Department of Fisheries, Sichuan Agricultural University, Chendu Sichuan 611100)

Abstract: The aim of this study was to investigate the mechanism of cardiac heat stress injury in Siberian sturgeon (*Acipenser baerii*) and the interventional role of curcumin. In this study, 360 juvenile Siberian sturgeon (114.69±4.48 g) were divided into three groups: C (20°C), HC (28°C), and HM (28°C+200 mg/kg curcumin), in which C and HC were fed diets without curcumin, and HM was fed diets containing 200 mg/kg curcumin. The HC and HM groups were subjected to chronic heat stress on the 41st day, and were heated at 1°C/d for 8 d until the water temperature reached 28°C, and the hearts were collected after maintaining the water temperature for 12 d. The results of H&E staining and transmission electron microscopy revealed that the hearts in the HC group showed pathological damage such as inflammatory cell infiltration, myofibrillar rupture, and mitochondrial vacuolization compared with the control group (group C), whereas the damage was significantly reduced in the HM group. Immunofluorescence results showed ROS levels were highly significantly elevated ($p < 0.01$) in the hearts of the HC group compared to the control group, whereas they were highly significantly reduced ($p < 0.01$) in the HM group. In addition, SOD activity and MDA content were highly significantly higher ($p < 0.01$) and antioxidant enzyme (CAT and GSH-Px) activities were significantly lower ($p < 0.05$) in the hearts of the HC group, whereas antioxidant enzyme (CAT and GSH-Px) activities were highly significantly higher ($p < 0.01$) and MDA content was significantly lower ($p < 0.05$) in the HM group. TUNEL immunofluorescence results showed that the level of cardiomyocyte apoptosis was highly significantly increased in the HC group ($p < 0.01$) and highly significantly decreased in the HM group ($p < 0.01$). The results of real-time fluorescence quantitative PCR and immunoblotting revealed that the levels of mitochondrial apoptosis pathway-related genes (*caspase-9*, *caspase-3*, and *caspase-7*) and Caspase-3 protein were highly significantly increased ($p < 0.01$) and the level of Hsp90 protein was highly significantly decreased ($p < 0.01$) in the hearts of the HC group, whereas in the hearts of the HM group, the levels of mitochondrial apoptosis pathway-related genes and caspase-3 protein were highly significantly reduced ($p < 0.01$). The results of flow and enzyme activity assays revealed that heart MMP, $\text{Ca}^{2+}\text{Mg}^{2+}$ -ATPase activity and ATP content were significantly lower in the HC group ($p < 0.05$) and significantly higher in the HM group ($p < 0.05$). The mRNA levels of mitochondrial biosynthesis-related genes (*pgc-1 α* and *tfam*) and Ampk protein and mitochondrial autophagy-related genes (*parkin* and *pink1*) were significantly higher in the heart of the HC group compared with the control group ($p < 0.05$). And all were significantly lower in the HM group compared to the HC group ($p < 0.05$). 1. Chronic heat stress can lead to heart structural damage and oxidative stress in Siberian sturgeon, and curcumin can alleviate chronic heat stress-induced heart

damage and oxidative stress; 2. Chronic heat stress promotes apoptosis by promoting the expression of apoptosis-associated genes (*caspase-9*, *caspase-3*, and *caspase-7*) and Caspase-3 proteins of the mitochondrial pathway, and simultaneously inhibiting the expression of Hsp90 protein expression to promote cardiomyocyte apoptosis, while curcumin alleviated chronic heat stress-induced changes in apoptosis-related genes and proteins; Chronic heat stress can lead to mitochondrial dysfunction in the heart of Siberian sturgeon and activate both mitochondrial biosynthesis and mitochondrial autophagy pathways, whereas curcumin exerts a mitochondrial protective effect, alleviates heat stress-induced mitochondrial dysfunction, and regulates mitochondrial biosynthesis and mitochondrial autophagy pathways in order to maintain the stability of mitochondria.

Key words: heat stress; Siberian sturgeon (*Acipenser baeri*); heart; mitochondrial function; curcumin

资助项目：四川省重点研发计划（2021YFYZ0015）、四川省自然科学基金（2022NSFSC0070）、国家现代农业产业
体系（SCCXTD-15）、四川省科技成果转化示范项目（2021ZHCG0065）

通讯作者：杜小刚，E-Mail: duxiaogang@sicau.edu.cn

酵母培养物通过改善中华绒螯蟹肝肠健康缓解慢性热应激

王松¹, 李雯¹, 王晓丹¹, 李二超^{1*}, 陈立侨^{1*}

(1. 华东师范大学生命科学学院, 上海 200241)

摘要: 全球气候变暖加剧了水生动物面临的热应激风险, 急需水产养殖业探索有效的缓解策略。酵母培养物(Yeast Culture, YC)因其在缓解热应激方面的潜力而备受关注。本研究旨在评估饲料添加 YC 对中华绒螯蟹(*Eriocheir sinensis*)幼蟹慢性热应激的影响。实验为期 6 周, 设置对照组(24 °C; 0 g/kg YC)和高温组(30 °C; 0、3.2、6.4 g/kg YC), 实验蟹初重 2.82 ± 0.01 g。结果表明, 慢性热应激显著降低了幼蟹存活率以及全蟹粗蛋白和粗脂肪水平而饲料添加 3.2 g/kg YC 能够显著缓解这些不利影响。进一步研究发现, 添加 YC 显著下调了热休克蛋白相关基因的表达, 同时提高抗氧化酶活性, 并有助于维护肠道围食膜的完整性。相关性分析显示, 幼蟹存活率与抗氧化能力和肠道健康相关指标显著正相关。实验还发现高温导致幼蟹肠道菌群网络结构紊乱, 而 YC 添加显著提高了菌群多样性和稳定性。转录组分析表明 YC 显著影响了丝氨酸蛋白酶、抗坏血酸和醛糖酸盐代谢通路相关基因的表达。菌群与转录组联合分析进一步揭示, 肝浆念珠菌属(*Candidatus_Hepatoplasma*)、红细菌科(*Rhodobacteraceae*)和气单胞菌属(*Aeromonas*)等可能参与幼蟹的抗氧化和免疫过程。综上, 饲料添加 3.2 g/kg YC 可通过提高抗氧化能力、调节免疫应答和改善肠道微生态, 缓解慢性热应激对中华绒螯蟹幼蟹的不利影响, 为水产养殖应对气候变暖提供了新的解决方案。

关键词: 饲料添加剂; 热应激; 死亡率; 免疫; 肠道菌群。

资助项目: 国家重点研发计划(2023YFD2402000)、国家自然科学基金项目(32072986)、财政部和农业农村部国家现代农业产业技术体系、上海市中华绒螯蟹产业技术体系(202404)

通讯作者: 李二超, E-mail: ecli@bio.ecnu.edu.cn; 陈立侨, E-mail: lqchen@bio.ecnu.edu.cn

Dietary yeast culture can protect against chronic heat stress by improving the survival, antioxidant capacity, immune response, and gut health of juvenile Chinese mitten crab (*Eriocheir sinensis*)

Song Wang¹, Wen Li¹, Xiaodan Wang¹, Erchao Li^{1,*}, Liqiao Chen^{1,*}

(1. School of Life Sciences, East China Normal University, 500 Dongchuan Road, Shanghai 200241, China)

Abstract: As global warming intensifies, aquatic species are increasingly threatened by heat stress, urging the aquaculture industry to explore innovative strategies to mitigate the adverse impact of thermal stress on animals. Supplementing diets with yeast culture (YC) has shown promising results in coping with heat stress. This study evaluated the effects of YC on the survival, biochemical responses, transcriptome, and intestinal microbiota of the Chinese mitten crab (*Eriocheir sinensis*) under chronic heat stress. Juvenile crabs were subjected to four conditions over 42 days: a control temperature of 24 °C and a high temperature of 30 °C supplemented with three YC doses: 0, 3.2, and 6.4 g/kg. Each group had six replicates of 30 crabs each. Chronic heat stress substantially reduced survival rates and increased molting frequency. However, YC supplementation significantly improved survival and antioxidant enzyme activities (SOD and GSH-Px) while reducing MDA levels, indicating a reduction in oxidative stress. The immune response metrics (PO and AKP activities) were comparable to those of the control group when YC was included in the diet. A significant correlation existed between the crab survival rate, antioxidant performance and gut health. Histological assessment revealed that YC maintained the integrity of the intestinal lining under heat stress. 16S rRNA sequencing revealed that YC ameliorated disruptions in the diversity and structure of the intestinal microbiota caused by high temperature. Transcriptomic analysis identified DEGs linked to serine-type peptidases and ascorbate and aldarate metabolism pathways. Significant correlations were detected between *Candidatus_Hepatoplasma*, *Rhodobacter*, *Aeromonas*, and genes related to antioxidant and immune responses. In conclusion, dietary YC at 3.2 g/kg effectively enhanced the resilience of *E. sinensis* to chronic heat stress by increasing survival rates and antioxidant capacity, restoring immune function, and maintaining gut health.

Key words: Feed additives; Thermal stress; Immunity; Mortality; Intestinal microbiota

芥酸在鱼类健康中的两面性

高文雅¹, 马丁菲¹, 黎强伟¹, 刘乐平¹, 徐亚隆¹, 吴成龙¹, 刘艳^{1*}

(1.湖州师范学院, 生命科学学院, 湖州 313000)

摘要: 菜籽油中的芥酸(EA)被认为对动物健康构成潜在威胁。然而, 近期研究揭示, 芥酸作为PPAR γ 的一种新型天然抑制剂, 其摄入特别是通过富含芥酸的植物油能够有效缓解由肥胖引发的代谢综合征。但在鱼类中, 有关芥酸的研究较为匮乏, 其在鱼类中的营养生理作用尚不清楚。鉴于此, 我们以罗非鱼作为实验对象, 旨在探究芥酸对鱼类健康及其代谢机制的影响。使用6种不同EA含量的正常脂肪水平饲料(0、3、6、12、20和27 g/kg)投喂罗非鱼8周, 结果发现: EA不影响鱼体生长, 以剂量依赖的方式增加组织脂肪含量, 并导致抗氧化能力下降, 高剂量EA(≥ 20 g/kg)引发肝损伤。此外, EA提高肝脏和肌肉中C18:2n-6、C20:1n-9和C22:1n-9含量, 降低C18:0和C16:0水平。EA含量为12、20和27 g/kg时, 脂肪自噬、脂肪分解和 β -氧化基因显著下调, 而甘油三酯合成基因上调。这表明高剂量EA(20 g/kg)阻碍脂肪利用, 引发氧化损伤, 对罗非鱼健康具有潜在危害。但在高脂饲料(HF, 10.5%脂肪水平)中添加EA(2、4、6、8 g/kg), 结果显示, 适量EA(6 g/kg)通过抑制PPAR γ 转录活性和蛋白水平能有效减轻高脂引起的体重增加、脂肪沉积及炎症反应, 同时上调脂肪分解基因表达, 抑制脂肪细胞分化、脂肪生成和炎症因子基因水平, 从而改善鱼类健康状况。然而, 更高剂量的EA(8 g/kg)并未进一步增强这种保护作用, 反而可能加剧高脂饲料的负面效应。综上所述, 芥酸对鱼类健康的影响与其含量和营养背景相关, 这些发现为不同芥酸含量的菜籽油在水产养殖中的应用提供了一定的参考。

关键词: 芥酸; 菜籽油; 脂肪蓄积; 炎症; 脂肪分化。

Both sides of erucic acid: its beneficial and toxic properties in fish

Wenya Gao, Dingfei Ma, Qiangwei Li, Leping Liu, Yalong Xu, Chenglong Wu, Yan Liu*

(College of Life Science, Huzhou University, Huzhou, Zhejiang 313000, China)

Abstract: Erucic acid (EA) in rapeseed oil has previously been flagged, as a potential health risk for animals. However, recent research has unveiled a new role for EA as a natural inhibitor of PPAR γ , suggesting that its consumption, particularly through EA-rich vegetable oils, may effectively mitigate obesity-related metabolic syndromes. Despite this, studies exploring EA's effects on fish remain limited, and its nutritional and physiological impacts on aquatic species remain unclear. To address this gap, we conducted an experiment using tilapia as our subjects to investigate the impact of EA on fish health and its underlying metabolic mechanisms. The fish were fed diets containing six different levels of EA (0, 3, 6, 12, 20, and 27 g/kg) at a normal fat content for eight weeks. Our findings revealed that EA had no adverse effects on fish growth but significantly increased the lipid contents in tissue in a dose-dependent manner and decreased antioxidant capacity. Notably, high EA doses (≥ 20 g/kg) caused liver damage. Furthermore, EA altered fatty acid profiles in the liver and muscle, increasing levels of C18:2n-6, C20:1n-9, and C22:1n-9 while decreasing C18:0 and C16:0 levels. When EA content reached 12, 20, and 27 g/kg, genes related to autophagy, lipolysis, and β -oxidation were significantly downregulated, while genes involved in triglyceride synthesis were upregulated. These findings suggest that high doses of EA (20 g/kg) hinder fat utilization and cause oxidative damage, posing potential health risks to tilapia. However, in a separate experiment with a high-fat diet (HF, 10.5% fat level), supplementing EA at certain levels (2, 4, 6, 8 g/kg) showed that an appropriate amount of EA (6 g/kg) could effectively reduce weight gain, fat deposition, and inflammation by inhibiting PPAR γ transcriptional activity and protein levels. This, in turn, upregulated the expression of lipolysis genes, inhibited adipocyte differentiation, lipogenesis, and inflammatory cytokine gene levels, thereby improving fish health. However, higher doses of EA (8 g/kg) did not further enhance this protective effect and may even exacerbate the negative impacts of high-fat diets. In conclusion, the effects of EA on fish health are contingent upon its content and nutritional context. These findings provide valuable insights for the application of rapeseed oil with varying EA content in aquaculture.

Key words: Erucic acid; Rapeseed oil; Lipid accumulation; Inflammation; Adipocyte differentiation

资助项目: 国家自然科学基金青年项目-芥酸对罗非鱼线粒体 β 氧化的影响及其调控机制的研究(32102805)

通讯作者: 刘艳, E-Mail: 02870@zjhu.edu.cn

金藻多糖对杂交鲟幼鱼 (*Acipenser baerii* Brandt ♀ × *A. schrenckii* Brandt ♂) 生长性能、鱼体营养成分、血清指标及肠道菌群的影响

邢薇¹, 徐冠玲¹, 李铁梁¹, 马志宏¹, 姜娜¹, 郁欢欢¹, 罗琳^{1*}
(北京市农林科学院水产科学研究所 渔业生物技术北京重点实验室, 北京 100068)

摘要: 旨在研究金藻多糖对杂交鲟幼鱼生长性能、鱼体营养成分、血清指标和肠道菌群的影响。选用 270 尾杂交鲟幼鱼, 随机分为 3 组, 每组设置 3 个重复, 每个重复放 30 尾鱼。各组分别饲喂在基础饲料中添加 0%、0.3%和 0.6%金藻多糖。试验期为 84d。JZ-1 和 JZ-2 组的 FCR 显著低于 JZ-0 组 ($P<0.05$); JZ-2 组的 CF 和 FE 显著性高于 JZ-0 ($P<0.05$); SR、SGR、WGR、VSI、HIS 在各组间无显著差异 ($P>0.05$)。JZ-1 和 JZ-2 组的全鱼和肝脏粗脂肪含量显著低于 JZ-0 组的 ($P<0.05$)。与 JZ-0 组相比, JZ-1 组和 JZ-2 组血清中 AST 和 LZM 活性显著升高 ($P<0.05$); JZ-2 组 ALT 和 GSH-PX 活性显著升高 ($P<0.05$)。MiseqPE300 测序结果显示, 添加金藻多糖的各试验组肠道菌群的 Chaol、Observed species、PD whole tree 和 Shannon 指数显著高于 JZ-0 组, NMDS 结果显示 JZ-1 和 JZ-2 与 JZ-0 在肠道微生物组成上存在显著差异; 试验组肠道菌群中梭杆菌门和放线菌门的比例降低, 厚壁菌门和拟杆菌门的比例增加; 狭义梭菌属、分节丝状菌属丰度增加。从经济效益的角度考虑, 饲料中添加 0.3%的金藻多糖较好。

关键词: 杂交鲟; 金藻多糖; 生长性能; 血清指标; 肠道菌群。

Effect of dietary polysaccharides from *Prymnesium parvum* on growth performance, body composition, serum index and intestinal microflora of juvenile hybrid sturgeon (*Acipenser baerii* Brandt ♀ × *A. schrenckii* Brandt ♂)

Xing Wei¹, Xu Guan-Ling¹, Li Tie-Liang¹, Ma Zhi-Hong¹, Jiang Na¹, Yu Huan-Huan¹, Luo Lin^{1*}

(1. Fisheries Science Institute, Beijing Academy of Agriculture and Forestry Sciences, Beijing Key Laboratory of Fishery Biotechnology, Beijing China 100068)

Abstract: This study was conducted to determine the effects of polysaccharides from *Prymnesium parvum* on growth performance, body composition, serum index and intestinal microflora of hybrid sturgeon. A total of 270 juvenile hybrid sturgeons were randomly assigned to 3 groups with 3 replicates per group and 30 fish per replicate. Fish in the 3 groups were fed the basal diets supplemented with 0%(JZ-0, control group), 0.3%(JZ-1) and 0.6%(JZ-2) polysaccharides from *Prymnesium parvum*. The experiment lasted for 84 days. The results showed that the feed conversion rate in JZ-1 and JZ-2 group was significantly lower than that in JZ-0 group ($P < 0.05$); the condition factor and Feed efficiency in JZ-2 group were significantly higher than those in JZ-0 group ($P < 0.05$); no significant differences were found in the survival rate, specific growth rate, weight gain rate, viscerasomatic index and hepatosomatic index among groups ($P > 0.05$). The whole body and liver lipid content in JZ-1 and JZ-2 fish groups were lower than that in JZ-0 group. Compared with the JZ-0 group, the activities of aspartate aminotransferase and lysozyme in JZ-1 and JZ-2 groups were significantly increased; the activities of alanine aminotransferase and glutathione peroxidase in JZ-2 group were significantly increased. The MiseqPE300 sequence assays showed that the Chao 1 index, Observed species index, PD whole tree index and Shannon index of intestinal bacteria in experimental groups were higher than those in JZ-0 group; NMDS analysis showed that, there were difference in diversity of intestinal microbiota in JZ-1, JZ-2 and JZ-0 groups; The proportion of Fusobacteria and Actinobacteria were decreased, whereas the proportions of Firmicutes and Bacteroidetes were increased in experimental groups; *Clostridium_sensu_stricto_1* and *Candidatus_Arthromitus* were increased in experimental groups. Combined with this study and from the perspective of economic benefits, 0.3% of polysaccharides from *Prymnesium parvum* was better added to the feed.

Key words: hybrid sturgeon (*Acipenser baerii* Brandt ♀ × *A. schrenckii* Brandt ♂); growth performance; polysaccharides from *P. parvum*; serum biochemical indexes; intestinal bacteria

基金项目：北京市农林科学院青年科研基金项目 (QNJJ201912)；国家自然科学基金 (32002397)；北京自然科学基金 (6222010)。

通讯作者：罗琳，E-mail: luo_lin666@sina.com。

菌体蛋白替代鱼粉对合方鲫生长性能、生理生化及肌肉品质的影响研究

金克岚¹, 肖扬波², 毛庄文², 刘长军^{1*}, 刘臻¹, 唐建洲^{2,3*}

(1. 湖南科技大学生命科学与健康学院, 湖南长沙 411201; 2. 长沙学院生物与化学工程学院, 水生动物营养与品质调控湖南省重点实验室, 湖南长沙 410022; 3. 渔美康生物科技有限公司 湖南岳阳 414100)

摘要: 鱼粉生产能力无法满足水产养殖业的需求, 用菌体蛋白 (SCP) 代替鱼粉具有重要的研究价值。本研究使用了由 0%、25%、50%、75% 和 100% 菌体蛋白 (SP0 作为对照组, 分别为 SP25、SP50、SP75 和 SP100) 代替鱼粉蛋白制成的实验饲料, 所有原料均具有相同的脂质和蛋白质含量, 对合方鲫进行 74d 生长试验, 研究对合方鲫生长性能、生理生化特性、肌肉质量以及生长和肽转运相关基因的影响。结果显示, 各组的存活率均为 100%, 总抗氧化能力均无显著变化 ($P>0.05$); 除 SP50 组肌肉粘附值最高且显著高于对照组外, 其他组无显著变化 ($P>0.05$)。SP75 组合方鲫的终末体重显著增加 ($P<0.05$), 特殊生长速率最大。SP75 组未增加合方鲫的额外氨基酸脱氨作用, 未增加总氮排放, 血浆中过氧化氢酶、超氧化物歧化酶和溶菌酶活性无显著差异 ($P>0.05$), SP75 组可显著增加 GH、IGF、PepT1 和 LAT2 基因表达水平。这些数据表明, SP75 组效果最好, 可以降低饲料成本, 并且不会对合方鲫造成不利影响。

关键词: 菌体蛋白; 鱼粉; 合方鲫; 肌肉质地。

资助项目: 湖南省水产产业技术体系 (HARS-06)

通讯作者: 唐建洲, E-Mail: Z20050711@ccsu.edu.cn

The Effect of Single-Cell Protein Substitution of Fishmeal on the Growth Performance, Physiological and Biochemical Properties, and Muscle Quality of Hefang Crucian Carp (*Carassius auratus cuvieri*♀×*Carassius auratus red var*♂)

Kelan Jin¹, Yangbo Xiao², Zhuangwen Mao², Changjun Liu^{1*}, Zhen Liu¹, Jianzhou Tang^{2, 3*}

(1. School of Life and Health Sciences, Hunan University of Science and Technology, Xiangtan China 411201; 2. Hunan Provincial Key Empirical Laboratory of Animal Nutrition and Quality Control, School of Biological and Chemical Engineering, Changsha University, Changsha China 410022; 3. Yumeikang Biotechnology Co., Ltd. Yueyang China 414100)

Abstract: Fish meal production capacity cannot meet the demands of the aquaculture industry. The substitution of bacterial protein (SCP) for fishmeal is of great research value. This study used experimental feeds made with 0%, 25%, 50%, 75%, and 100% single-cell protein (SP0 as control group, SP25, SP50, SP75, and SP100, respectively) replacing fishmeal protein, all formulated to have equal lipid and protein content. Conducting a 74-day growth experiment on Hefang crucian carp revealed the effects on the growth performance, physiological and biochemical characteristics, muscle quality of the fish, and the growth and peptide transport-related genes of Hefang crucian carp. The results showed that the survival rate was 100% in all groups, none of the groups changed its total antioxidant capacity ($P > 0.05$); Except for the SP50 group, which had the highest muscle adhesion value and was significantly higher than the control group, and there was no significant change in the other groups ($P > 0.05$). The terminal body weight of the SP75 combination was significantly increased ($P < 0.05$) and had the maximum specific growth rate. The SP75 group did not increase the additional amino acid deamination of Hefang crucian carp, did not increase the total nitrogen emission, there was no significant difference in the activities of catalase, superoxide dismutase and lysozyme in plasma ($P > 0.05$), and the SP75 group could significantly increase *GH*, *IGF*, *PepT1* and *LAT2* Gene expression levels. These data indicated that the SP75 group had the best effect and could reduce the feed cost without adversely affecting the Hefang crucian carp.

Keywords: Single-cell protein; Fishmeal; Hefang crucian carp; Muscle texture

苦瓜皂苷促进鲤鱼饲料中高糖节约蛋白质作用的有效性评价

范泽¹, 吴迪¹, 李晋南¹, 李晨辉¹, 王连生^{1*}

(1. 中国水产科学研究院黑龙江水产研究所, 黑龙江省水生动物病害与免疫重点实验室, 黑龙江 哈尔滨 150070)

(2.

摘要: 为探讨鲤鱼幼鱼饲料中添加苦瓜皂苷(Momordica charantia saponins, MCS)促进高糖对蛋白质节约的可行性, 在前期研究的基础上, 设计了蛋白碳水化合物比(P/C)为 32%P/40%C、30%P/43%C、28%P/46%C、28%P/46%C 添加 0.16% MCS (28%P/46%C+MCS)的 4 组饲料。在高糖低蛋白饲料中添加 MCS 对鲤鱼生长性能的影响与肠道健康密切相关。补充 MCS 可以增强肠道消化的代偿作用, 促进蛋白质和碳水化合物的消化。此外, 补充 MCS 可通过增强肠屏障功能逆转肠通透性的上升趋势, 从而重新激活抗氧化能力和抗炎能力。同时, 添加 MCS 可使肠道菌群结构更有利于生长和肠道健康。综上, 在 28%P/46%C 组中添加 0.16%MCS 可促进鲤鱼饲料中高糖的蛋白质节约作用, 降低饲料中 5%的豆粕用量, 同时降低饲料中 4%的粗蛋白质, 且不影响鲤鱼的生长和免疫能力。

关键词: 苦瓜皂苷; 蛋白质节约作用; 鲤鱼; 生长; 补偿作用; 肠道健康。

资助项目: 国家自然科学基金青年科学基金项目(32302969); 黑龙江水产研究所基本科研业务费专项资金(HSY202111Q; HSY202408Q); 中国水产科学研究院基本科研业务费资助(2023TD60); 财政部和农业农村部: 国家现代农业产业技术体系资助。

通讯作者: 王连生, E-Mail: wangliansheng@hrfri.ac.cn。

***Momordica charantia* saponins administration in low-protein-high-starch diet improves growth, blood biochemical, intestinal health and microflora composition of juvenile common carp (*Cyprinus carpio*)**

Ze Fan¹, Di Wu¹, Jinnan Li¹, Chenhui Li¹, Liansheng Wang^{1*}

(1.Key Laboratory of Aquatic Animal Diseases and Immune Technology of Heilongjiang Province, Heilongjiang River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Harbin 150070, PR China)

Abstract: An 8-week feeding trial was conducted to explore the feasibility of *Momordica charantia* saponins (MCS) administration to facilitate the protein-sparing action of high carbohydrate in diets for juvenile common carp (*Cyprinus carpio*) with initial mass of 5.41±0.02 g. Based on our previous study, four diets with different the ratio of protein and carbohydrate (P/C ratio) were designed: 32%P/40%C, 30%P/43%C, 28%P/46%C, 28%P/46%C supplemented with 0.16% MCS (28%P/46%C+MCS). Each diet treatment was divided into 3 replicates. Results revealed that 30%P/43%C group increased growth performance and intestinal digestion, decreased intestinal inflammation, and optimized the intestinal microflora compared to 32%P/40%C group, which presented the stronger protein-sparing action of high carbohydrate. But if the P/C ratio reduced to 28%P/46%C or less, the saving action would be restrained. However, compared to the 30%P/43%C and 28%P/46%C groups, 28%P/46%C+MCS group significantly elevated growth performance and activities of digestive enzymes and antioxidative enzymes, whilst the opposite trend occurred in the contents of glucose, triglyceride, total cholesterol, low density lipoprotein cholesterol, blood urea nitrogen, glutamic oxalacetic transaminase, glutamic-pyruvic transaminase and malondialdehyde. In addition, 28%P/46%C+MCS group markedly upregulated the expressions of GH/IGF axis genes, genes involved in protein synthesis, antioxidant genes and anti-inflammatory cytokine, whilst the opposite trend occurred in the the expressions of pro-inflammatory cytokines. 28%P/46%C +MCS group obtained the remarkably higher *Enterococcus* proportion and lower *Lactococcus* proportion compared to the 30%P/43%C and 28%P/46%C groups, whereas the opposite occurred in 30%P/43%C group, which indicated that there existed differences in the improvement mechanism on intestinal microflora composition between MCS and appropriate P/C ratio. Overall, 0.16% MCS administration in a 28%P/46% diet could facilitate the protein-sparing action of high carbohydrate in common carp feed, which could decrease the 5% dosage of soybean meal and synchronously reduce the 4% crude protein of diets without affecting the growth and immune ability for common carp.

Keywords: *Momordica charantia* saponins (MCS); Protein-sparing action; Common carp (*Cyprinus carpio*), Growth performance; Compensatory effect; Intestinal health

螺旋藻替代鱼粉对黄鳝生长性能、抗氧化及免疫力的影响

陈希环, 周秋白*, 黄浩, 胡运松, 陈恺文

(江西农业大学动物科学技术学院, 江西南昌, 330045)

摘要: 为探明黄鳝 (*Monopterus albus*) 饲料中螺旋藻替代鱼粉的适宜比例, 本试验以含 50% 鱼粉的基础饲料作为对照组, 再用的螺旋藻粉等蛋白替代基础饲料中 10%、20%、30%、40%、50%、60% 鱼粉, 喂养黄鳝 [(20.72 ± 0.04) g] 60d。结果: 1. 黄鳝的终末均重、增重率、特定生长率和蛋白质沉积率均随螺旋藻替代比例的升高呈下降的趋势, 饲料系数呈上升的趋势; 替代 50% 和 60% 鱼粉组终末均重、增重率、特定生长率和蛋白质沉积率显著低于对组 ($p < 0.05$), 饲料系数显著高于对照组 ($p < 0.05$)。2. 随着替代鱼粉比例升高, 黄鳝 T-AOC、SOD 活力呈上升趋势, CAT 活力呈先升后降的趋势, MDA 呈先将后升趋势; 替代 40%、50%、60% 鱼粉组黄鳝 T-AOC、SOD 活力均显著高于对照组 ($p < 0.05$); 替代 5% 鱼粉组 CAT 活力最高, 且显著高于对照组和替代 50%、60% 鱼粉组 ($p < 0.05$); 替代 30%、40%、50% 和 60% 鱼粉组黄鳝 MDA 显著低于对照组 ($p < 0.05$)。3. 随着替代比例升高, 黄鳝血清 LZM、ACP、AKP、IgM、C3 均随着螺旋藻替代比例升高呈先升后降的趋势; 与对照组比, 替代 20%、30%、和 40% 鱼粉组 LZM、AKP 均显著升高 ($p < 0.05$); 各替代组 ACP 均显著高于对照组 ($p < 0.05$); 替代 10%、20%、30%、和 40% 鱼粉组 IgM、C3 显著高于对照组 ($p < 0.05$); 替代 60% 鱼粉组 IgM、C3 显著低于对照组 ($p < 0.05$)。结果表明: 螺旋藻替代鱼粉适宜比例为 10%–40%。

关键词: 螺旋藻替代鱼粉; 黄鳝; 生长性能; 抗氧化能力; 免疫能力。

资助项目: 国家现代农业产业体系专项资金 (CARS-46)

通讯作者: 周秋白, 男, 博士, 教授 水产动物营养与饲料 手机号: 13065180718 E-Mail: zhouqiubai@163.com

迷迭香酸抑制伊丽莎白菌感染诱导的牛蛙炎症反应的作用机制³⁰

朱波¹, 麦康森², 胡毅^{1*}

(1.湖南农业大学水产学院, 湖南 长沙 410128; 2.中国海洋大学海水养殖重点实验室(教育部)、水产动物营养与饲料重点实验室(农业农村部), 山东 青岛 266003)

摘要: 为深入探讨牛蛙“歪头病”的病症、发病机制及其防控策略, 本研究运用多组织转录组学综合分析结合病理观察, 确认了该病的核心病变位于脑组织, 并鉴定了 Toll 样受体 (TLRs) 与核因子 κ B (NF- κ B) 等炎症信号通路的显著激活。此外, 通过体外抗菌试验和治疗试验, 筛选出迷迭香酸作为潜在的免疫调节剂。经过为期八周的饲喂试验后, 进行伊丽莎白菌感染测试, 表明迷迭香酸能够显著减少疾病发生率。通过对感染前后脑的转录组学对比分析, 确认迷迭香酸有效抑制了 TLR/MYD88/NF- κ B 信号通路的活化, 从而减弱了炎症反应, 降低了疾病的发病率。体外细菌感染细胞模型实验的结果与体内试验一致, 且当使用抑制剂靶向干预 MYD88 基因表达时, 由细菌感染引发的炎症因子表达显著下降, 进一步验证了上述结论。综上所述, 本研究表明了伊丽莎白菌感染牛蛙引发脑部炎症反应的具体机制, 并揭示了迷迭香酸通过抑制 TLR/MYD88/NF- κ B 信号传导路径, 减轻炎症, 减少疾病发生, 展示了其在预防和控制牛蛙歪头病方面的潜在应用价值。

关键词: 伊丽莎白菌; 细菌感染; 炎症; 牛蛙; 脑膜炎; 迷迭香酸。

资助项目: 无

通讯作者: 胡毅, E-Mail: huyi740322@163.com

The Mechanism of Rosmarinic Acid in Inhibiting the Inflammatory Response Induced by *Elizabethkingia* Infection in Bullfrogs

Bo Zhu¹, Kangsen Mai², Yi Hu^{1, *}

(1. Fisheries College, Hunan Agricultural University, Changsha China 410128; 2. Key Laboratory of Mariculture (Ministry of Education and), and Key Laboratory of Aquaculture Nutrition and Feed (Ministry of Agriculture and Rural Affairs), Ocean University of China, Qingdao China 266003)

Abstract: To thoroughly investigate the symptoms, pathogenesis, and prevention strategies of “head tilt disease” in bullfrogs, this study employs a multi-tissue transcriptomic analysis integrated with pathological observations. The results confirm that the disease's primary lesions are localized in brain tissue and identify significant activation of inflammatory signaling pathways, such as Toll-like receptors (TLRs) and nuclear factor kappa B (NF- κ B). Furthermore, through in vitro antibacterial and therapeutic tests, rosmarinic acid was identified as a potential immune modulator. After an eight-week feeding trial followed by an *Elizabethkingia* infection challenge, rosmarinic acid was found to significantly reduce disease incidence. Comparative transcriptomic analysis of brain tissue before and after infection confirmed that rosmarinic acid effectively inhibited the activation of the TLR/MYD88/NF- κ B signaling pathway, thereby mitigating inflammatory responses and reducing disease incidence. In vitro experiments using a cell model of *Elizabethkingia* infection corroborated the in vivo findings; targeted inhibition of MYD88 gene expression resulted in a marked decrease in infection-induced inflammatory factor expression, further validating the conclusions. In summary, this study elucidates the specific mechanism by which *Elizabethkingia* infection induces brain inflammation in bullfrogs and demonstrates that rosmarinic acid reduces inflammation and disease incidence by inhibiting the TLR/MYD88/NF- κ B signaling pathway, highlighting its potential application in preventing and controlling head tilt disease in bullfrogs.

Key words: *Elizabethkingia*; bacterial infection; inflammation; bullfrog; meningitis; rosmarinic acid.

棉籽粕替代鱼粉饲料中添加青蒿素对卵形鲳鲹生长性能、消化酶活性、脂代谢和菌群的影响

林芷炫^{1,2,3}, 潘玲^{1,2}, 谢瑞涛⁴, 刘泓宇^{1,2,3*}, 谭北平^{1,2,3}, 董晓慧^{1,2,3}, 迟淑艳^{1,2,3}, 杨奇慧^{1,2,3}, 章双^{1,2,3}, 邓君明^{1,2,3}, 周小秋⁵

(1.广东海洋大学, 水产学院, 水产动物营养与饲料实验室, 广东 湛江 524088; 2.广东省水产动物精准营养与高效饲料工程技术研究中心, 广东 湛江 524088; 3.农业部华南水产与畜禽饲料重点实验室, 广东 湛江 524088; 4.广东恒兴饲料实业股份有限公司, 广东 湛江 524088; 5.四川农业大学动物营养研究所, 四川 成都 625014)

摘要: 青蒿素是具有抗疟疾作用的植物提取成分。本研究旨在探讨在棉籽粕(CSM)替代高比例鱼粉饲料中添加青蒿素对卵形鲳鲹生长、脂代谢和肠道微生物群的影响。本实验共配制了五种日粮, 包括对照组(CM, CSM替代16%的鱼粉)和实验组(CA0、CA2、CA4和CA8, CSM替代36%的鱼粉, 分别添加0%、0.20%、0.40%和0.80%的青蒿素)。将375尾卵形鲳鲹(初始体重为 22.45 ± 0.07 克)随机分为五组, 每组三份, 在水箱中饲养8周。结果表明, CA8组提高了卵形鲳鲹最终体重、增重率和特定生长率, 降低血清中甘油三酯、总胆固醇和高密度脂蛋白胆固醇的水平。在肝脏中, 饲料中添加青蒿素可减轻高浓度CSM替代鱼粉日粮诱导的肝细胞空泡化和脂质沉积, 降低脂肪生成相关酶的活性, 提高脂肪分解相关酶的活性。在肠道中, CA8组显著提高肠道消化酶(胰蛋白酶、脂肪酶和淀粉酶)的活性。补充0.8%的青蒿素能显著提高卵形鲳鲹肠道微生物群的多样性和稳定性, 同时还能减少与高CSM水平相关的潜在有害弧菌的数量。综上所述, 补充0.8%的青蒿素可通过提高脂质代谢、肠道消化酶活性和调节肠道微生物群来减轻CSM替代高比例鱼粉饲料对卵形鲳鲹生长、脂质代谢和肝脏健康的负面影响。

关键词: 卵形鲳鲹; 棉籽粕; 肠道菌群; 青蒿素。

基金项目: 广东省普通高校重点科研项目(2024ZDZX2085)、广东省现代化海洋牧场适养品种核心技术攻关项目(2024-MRB-00-001)、国家海水鱼产业技术体系(CARS-47)

通讯作者: 刘泓宇, 教授, 博士生导师, E-Mail: liuhyu@gdou.edu.cn

Artemisinin supplementation improves growth, lipid metabolism, and intestinal microbiota of Golden pompano (*Trachinotus ovatus*) fed cottonseed meal diets

Zhixuan Lin^{1,2,3}, Ling Pan^{1,2}, Ruitao Xie⁴, Hongyu Liu^{1,2,3*}, Beiping Tan^{1,2,3}, Xiaohui Dong^{1,2,3}, Shuyan Chi^{1,2,3}, Qihui Yang^{1,2,3}, Shuang Zhang^{1,2,3}, Junming Deng^{1,2,3}, Xiaoqiu Zhou⁵

1.Laboratory of Aquatic Animal Nutrition and Feed, Fisheries College, Guangdong Ocean University, Zhanjiang 524088, PR China; 2.Aquatic Animals Precision Nutrition and High Efficiency Feed Engineering Research Centre of Guangdong Province, Zhanjiang, Guangdong, 524088, PR China; 3.Key Laboratory of Aquatic, Livestock and Poultry Feed Science and Technology in South China, Ministry of Agriculture, Zhanjiang 524088, PR China; 4.Guangdong Evergreen Feed Industry Co. Ltd, Zhanjiang, 524088, PR China; 5.Animal Nutrition Institute, Sichuan Agricultural University, Chengdu 625014, PR China

Abstract: This study aimed to investigate the effect of artemisinin supplementation to high cottonseed meal (CSM) diet on the growth, lipid metabolism and intestinal microbiota of golden pompano (*Trachinotus ovatus*). Five diets were formulated, including the control (CM, with CSM replacing 16% of fishmeal) and experimental groups (CA0, CA2, CA4, and CA8, with CSM replacing 36% of fishmeal and supplemented with 0%, 0.20%, 0.40%, and 0.80% of artemisinin, respectively). 375 fishes (initial weight 22.45 ± 0.07 g) were randomized into five groups of triplicates each and fed in tanks for 8 weeks. Results indicated that 0.8% artemisinin improved final weight, weight gain rate and specific growth rate, reduced the serum lipid levels under the condition of 36% fishmeal replaced with CSM. In the liver, artemisinin supplementation alleviated hepatocyte vacuolization and lipid deposition induced by the high level CSM replacement fishmeal diet, reduced the activity of lipogenesis-related enzymes and increased lipolysis-related enzyme activity. In the intestine, supplementation with 0.8% artemisinin significantly increased the activities of intestinal digestive enzymes. Supplementation with 0.8% artemisinin significantly increased the diversity and stability of the intestinal microbiota of the golden pompano, while also reducing the abundance of potentially harmful *Vibrio* associated with high CSM levels. In conclusion, 0.8% artemisinin supplementation mitigated the negative effects of high CSM diets on growth, lipid metabolism, and liver health in golden pompano by enhancing lipid metabolism, intestinal digestive enzyme activity, and modulating intestinal microbiota.

Keywords: Artemisinin; *Trachinotus ovatus*; cottonseed meal; intestinal microbiota

评价人工合成虾青素和藻源虾青素对饲喂高脂饲料的卵形鲳鲹生长特性、脂质代谢和肝脏健康的影响³¹

郭昱才¹, 赵伟^{1*}, 牛津^{1*}

(中山大学生命科学院生物防治国家重点实验室、广东省水生经济动物重点实验室和南方海洋科学与工程广东省重点实验室, 广东 珠海 510275)

摘要: 水产养殖中过量摄入脂肪在促进生长、降低饲料成本的同时, 也会引起鱼类肝脏脂肪变性、炎症、氧化应激和免疫功能障碍。虾青素是一种有效的抗氧化剂, 有可能减轻高脂饮食带来的负面影响。本研究旨在探讨人工合成虾青素和藻源虾青素对高脂饲料下卵形鲳鲹生长性能、脂质代谢和肝脏健康的影响及其分子机制。分别饲喂 8 周的正常脂质饲料 (CF)、高脂饲料 (HL)、HL+合成虾青素饲料 (HL+S) 和 HL+藻源虾青素饲料 (HL+A)。与 HL 饲料相比, 饲料中添加人工虾青素或藻类虾青素均能显著提高卵形鲳鲹的生长性能和存活率。此外, 两种虾青素提高了谷胱甘肽还原酶活性和高密度脂蛋白水平, 并降低了血清中总胆固醇、总甘油三酯和低密度脂蛋白含量。此外, 合成虾青素和藻源虾青素都能有效减轻肝脏中过多的脂质积累。在抗氧化能力方面, 补充虾青素可显著增强 Nrf2/Keap-1 信号通路, 提高抗氧化酶活性。此外, 虾青素刺激先天免疫反应, 合成虾青素在抑制炎症反应方面表现出优越的功效, 而藻源虾青素从根本上增强了卵形鲳鲹的免疫能力, 最终提高了鱼体抗逆性。综上所述, 在高脂肪饲料中添加合成虾青素或藻类衍生虾青素可以减轻高脂肪饲料对卵形鲳鲹的不良影响, 如生长迟缓、抗氧化能力降低和先天免疫反应受损。此外, 这些虾青素来源对维持鱼的脂质代谢平衡和促进肝脏健康有有益的影响。

关键词: 高脂饲料; 虾青素; 脂质积累; 抗氧化能力; 免疫能力; 肝脏健康。

资助项目: 南方海洋科学与工程广东省重点实验室 (SML2023SP236)、国家自然科学基金 (32172982; 32303014)、广东省基础与应用基础研究基金 (2023A1515012627; 2024A1515010444)、巴斯夫, 中国 (88348178)
通讯作者: 牛津, E-Mail: niuj3@mail.sysu.edu.cn; 赵伟, E-Mail: zhaow66@mail.sysu.edu.cn

Evaluating the impact of synthetic and algal-sourced astaxanthin on growth characteristics, lipid metabolism, and hepatic health in *Trachinotus ovatus* fed a high-fat diet

Yucai Guo¹, Wei Zhao^{1*}, Jin Niu^{1*}

(1. State key Laboratory of Biocontrol, Guangdong Provincial Key Laboratory for Aquatic Economic Animals and Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), School of Life Sciences, Sun Yat-Sen University, Guangzhou 510275, Guangdong Province, PR China)

Abstract : While excessive lipid intake in aquaculture is used to enhance growth and reduce feed costs, it can also induce liver steatosis, inflammation, oxidative stress, and immune dysfunction in fish. Astaxanthin, a potent antioxidant, exhibits potential in alleviating these negative effects of high-lipid diets. This study aimed to investigate the diverse functions and the underlying molecular mechanisms of synthetic and algal-sourced astaxanthin on the growth performance, lipid metabolism and liver health of juvenile *Trachinotus ovatus* fed high-lipid diets. *T. ovatus* were fed for 8 weeks with normal lipid diet (CF), high lipid diet (HL), HL+synthetic astaxanthin (HL+S), and HL+ algal-sourced astaxanthin (HL+A). Compared to the HL diet, the incorporation of either synthetic or algal-sourced astaxanthin into the feed markedly enhanced the growth performance and survival rate of *T. ovatus*. Besides, two sources of astaxanthin led to an increase in glutathione reductase activity and high-density lipoprotein levels, as well as a reduction in total cholesterol, total triglyceride, and low-density lipoprotein content in serum. Moreover, both synthetic and algal-sourced astaxanthins effectively mitigated excessive lipid accumulation in the liver. In terms of antioxidant capacity, astaxanthin supplementation significantly augmented Nrf2/Keap-1 signaling pathways and elevated the activity of antioxidant enzymes. Furthermore, astaxanthin stimulated innate immune responses, with synthetic astaxanthin demonstrating a superior efficacy in suppressing inflammatory responses, whereas algal-sourced astaxanthin fundamentally bolstered the immune competence of *T. ovatus*, ultimately leading to a diminished stress resistance in the organism. In summary, supplementation of either synthetic or algal-derived astaxanthin to the high-fat diet of *T. ovatus* mitigated the adverse consequences of high-fat feeding, such as growth retardation, reduced antioxidant capacity, and impaired innate immune responses. Additionally, these astaxanthin sources had beneficial impacts on maintaining lipid metabolic balance and promoting liver health in the fish.

Key words : High-fat diet; Astaxanthin; Lipid accumulation; Antioxidant status; Immunity; Liver health

全植物蛋白饲料中添加肌酸提高了克氏原螯虾生长性能和肌肉生长

田娟¹, 李薪源¹, 刘洋洋¹, 张健敏¹

(中国水产科学研究院长江水产研究所, 湖北 武汉 430223)

摘要: 为探究全植物蛋白饲料中添加肌酸对克氏原螯虾 (*Procambarus clarkii*) 生长性能和肌肉生长的影响, 在基础饲料中分别添加 0(对照组)、2.50、5.00、10.00、15.00 和 20.00 g/kg 的一水肌酸, 饲喂克氏原螯虾 [初始体质量(5.86±0.04) g] 8 周。结果显示: 克氏原螯虾增重率、特定生长率、蛋白质效率、蛋白质沉积率、饲料系数、全虾粗蛋白含量、肌肉粗蛋白含量、硬度、咀嚼性、总羟脯氨酸含量、直径<40 μm 肌纤维比例和肌纤维密度均随饲料肌酸添加量的增加呈显著的二次多项式变化趋势, 且均在 5.00 g/kg 组显著高于对照组。腹部含肉率、总必须氨基酸和总结氨基酸含量均随饲料肌酸添加量的增加呈显著的线性和二次多项式变化趋势, 且均在 5.00 g/kg 组显著高于对照组。与对照组相比, 肌酸添加水平为 2.50 和 5.00 g/kg 时显著上调了肌肉蛋白质合成的 TORC1 通路关键基因 (*igf-1*、*pi3k*、*akt*、*tor* 和 *s6k1*) 的相对表达量; 肌酸添加水平为 5.00 g/kg 时显著下调了肌肉蛋白质降解的泛素-蛋白酶体系统关键基因 (*ub*、*psma2*、*psmc1* 和 *murfl*) 和自噬-溶酶体系统关键基因 (*atg16l1*、*atg5*、*beclin1* 和 *atg12*) 的相对表达量; 肌酸添加水平为 5.00 g/kg 时显著上调了肌肉胶原蛋白合成的 TGFβ/Smad 通路关键基因 (*tgf-β1*、*smad6*、*smad3*、*smad4* 和 *colla1*) 的相对表达量; 肌酸添加水平为 5.00 g/kg 时显著上调了肌肉发育关键基因 (*mef2a* 和 *mef2b*) 的相对表达量, 显著下调 *mstn* 的相对表达量。综上所述, 本试验条件下外源添加肌酸能够提高克氏原螯虾的生长性能和饲料利用率, 促进蛋白质沉积和肌肉生长, 并提高肌肉品质。以饲料系数、增重率、特定生长率和腹部含肉率进行折线回归分析得肌酸的最适添加量为 4.29-5.66 g/kg。

关键词: 克氏原螯虾; 肌酸; 生长性能; 蛋白质沉积; 胶原蛋白合成; 肌肉生长。

Creatine supplementation to all-plant-protein diets improved the growth performance and muscle growth of the red swamp crayfish (*Procambarus clarkii*)

Juan Tian¹, Xinyuan Li¹, Yangyang Liu¹, Jianmin Zhang¹

(Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Wuhan China 430223)

Abstract: To investigate the effect of creatine addition to all-plant-protein diets on the growth performance and muscle growth of crayfish (*Procambarus clarkii*), creatine monohydrate was added to the basal diet at 0 (control), 2.50, 5.00, 10.00, 15.00, and 20.00 g/kg, and was fed to crayfish (5.86±0.04 g) for 8 weeks. The results showed that the weight gain rate, specific growth rate, protein efficiency, protein deposition rate, feed coefficient, crude protein content of whole body, crude protein content of muscle, hardness, chewability, total hydroxyproline content, proportion of myofibres <40 µm in diameter and density of myofibres showed a significant quadratic polynomial trend with the increase of dietary creatine supplementation, and all of them were significantly higher in the 5.00 g/kg group than in the control group. Abdominal flesh content, total essential amino acids and total amino acids showed significant linear and quadratic polynomial trends with the increase in dietary creatine addition and all were significantly higher in the 5.00 g/kg group than in the control group. The relative expression of key genes of TORC1 pathway for muscle protein synthesis (*igf-1*, *pi3k*, *akt*, *tor*, and *s6k1*) was significantly up-regulated at the creatine addition levels of 2.50 and 5.00 g/kg compared to the control group; and the key genes of ubiquitin-proteasome system for muscle protein degradation (*ub*, *psma2*, *psmc1*, and *murfl*) and autophagy-lysosome system (*atg16l1*, *atg5*, *beclin1*, and *atg12*) for muscle protein degradation were significantly down-regulated at 5.00 g/kg, and the relative expression of the key genes in the TGFβ/Smad pathway (*tgf-β1*, *smad6*, *smad3*, *smad4*, and *collagen*) for muscle collagen synthesis was significantly up-regulated at 5.00 g/kg; the relative expression of key genes of muscle development (*mef2a* and *mef2b*) was significantly up-regulated and the relative expression of *mstn* was significantly down-regulated at the level of 5.00 g/kg of creatine addition. In conclusion, exogenous addition of creatine could improve the growth performance and feed utilisation of crayfish, promote protein deposition and muscle growth, and improve muscle quality. Linear regression analyses of feed coefficient, weight gain rate, specific growth rate and abdominal flesh content rate showed that the optimal amount of dietary creatine was 4.29-5.66 g/kg.

Key words: Creatine; *Procambarus clarkii*; Growth performance; Collagen synthesis; Protein deposition; Muscle development

桑叶多糖可减轻高淀粉饲料对大口黑鲈肝脏损伤和淀粉代谢紊乱的影响³²

肖琴琴^{1,2}, 周勇华¹, 周罗璟¹, 毛庄文¹, 曹申平¹, 何志敏¹, 瞿符发¹, 刘臻^{1*}, 唐建洲^{1*}

(1. 长沙学院生物与化学工程学院, 水生动物营养与品质调控湖南省重点实验室, 湖南 长沙 410022;

2. 湖南师范大学生命科学学院, 淡水鱼类发育生物学国家重点实验室, 湖南 长沙 410081)

摘要: 桑叶多糖 (MLP) 是从桑叶中提取的化合物, 具有抗氧化、抗炎、降血糖和降脂等药用价值。为了研究桑叶多糖对高淀粉饲料诱导的肝脏损伤与淀粉代谢紊乱的影响, 本实验配制了 6 种不同淀粉水平 (LS、HSM0、HSM2、HSM4、HSM6、HSM8) 的饲料。在池塘中饲养的大口黑鲈 (*Micropterus salmoides*) 被随机分配到六个组中, 每组三个平行。饲养六周后, 收集血液和肝脏样本, 进行酶学、组织病理学、超微显微镜和转录组学分析, 以探究高淀粉饲料对大口黑鲈肝脏损伤的影响。结果表明, 高淀粉水平对大口黑鲈的生长性能有一定的抑制作用, 但在高淀粉饲料中添加适量的 MLP 可促进大口黑鲈的生长。肝胰脏指数 (HSI)、血清葡萄糖 (GLU) 和胰蛋白酶水平显著升高 ($P<0.05$), 胰蛋白酶和胰岛素水平显著升高 ($P>0.05$)。肌糖原积累也显著减少。组织病理学观察显示, 适量添加 MLP 可以减轻高淀粉饮食引起的肝细胞严重空泡化, 显著刺激肝脏己糖激酶 (HK) 和丙酮酸激酶 (PK) 的活性。葡萄糖代谢下调酶果糖-1,6-二磷酸酶 (FBPase)、磷酸烯醇丙酮酸羧激酶 (PEPCK) 和葡萄糖-6-磷酸酶 (G6Pase) 活性也显著改变 ($P<0.05$)。转录组学分析发现, HSM0 组和 HSM4 组之间存在 3879 个差异表达基因 (deg), 其中大多数差异表达基因显著富集于与葡萄糖代谢、淀粉代谢和胰岛抵抗相关的信号通路。基因表达分析用于验证转录组研究结果。桑叶多糖可改善 HF 日粮对大口黑鲈的生长性能和肝脏损伤, 并且改善大口黑鲈血清生化指标, 减少 HF 日粮诱导的大口黑鲈肝糖原积累, 减轻 HF 饲料引起的炎症。此外, 添加 MLP 通过调节碳水化合物代谢的关键酶, 并通过 PI3K/Akt 信号通路和胰岛素抵抗来减轻高淀粉饲料对大口黑鲈肝损伤的作用中起关键作用。

关键词: 大口黑鲈; 碳水化合物代谢; 酶活性; 转录组; PI3K/Akt 信号通路; 胰岛素抵抗。

资助项目: 湖南省现代农业产业技术体系 (HARS-06)

通讯作者: 唐建洲, E-Mail: Z20050711@ccsu.edu.cn

Mulberry leaf polysaccharide alleviates liver damage and starch metabolism disorder in Largemouth bass induced by a high-starch diet

Qinqin Xiao^{1, 2}, Yonghua Zhou¹, Luoqing Zhou¹, Zhuangwen Mao¹, Shenping Cao¹, Zhimin He¹, Fufa Qu¹, Zhen Liu^{1*}, Jianzhou Tang^{1*}

(1. Hunan Provincial Key Laboratory of Nutrition and Quality Control of Aquatic Animals, Changsha University, Changsha 410022, China; 2. State Key Laboratory of Developmental Biology of Freshwater Fish, College of Life Sciences, Hunan Normal University, Changsha, Hunan, China)

Abstract: Mulberry leaf polysaccharides (MLP) are compounds extracted from mulberry leaves that are scientifically validated to exhibit medicinal value, such as antioxidative, anti-inflammatory, hypoglycemic, and lipid-lowering effects. To study the effects of mulberry leaf polysaccharide on liver injury and starch metabolism disorder induced by high starch diet. Diets with varying starch levels (LS, HSM0, HSM2, HSM4, HSM6, HSM8) were formulated. Largemouth bass (*Micropterus salmoides*) raised in ponds were randomly assigned to one of six groups and fed one of the six diets over an eight-week period. Subsequent collection of blood and liver samples allowed for enzymological, histopathological, ultramicroscopic, and transcriptomic analyses to explore the effects of a high starch diet on liver damage in largemouth bass. [Results] Results indicated that a high starch level has a certain inhibitory effect on the growth performance of largemouth bass, but adding the right amount of MLP to high-starch feed can promote their growth. However, there were significant increases in the hepatopancreas index (HSI), serum glucose (GLU), and trypsin levels ($P < 0.05$), and increases in trypsin ($P < 0.05$) and insulin levels ($P > 0.05$). There was also a significant reduction in muscle glycogen accumulation. Histopathological observations revealed that moderate MLP supplementation mitigated severe vacuolation of liver cells induced by a high starch diet, significantly stimulating the activities of liver hexokinase (HK) and pyruvate kinase (PK). The glucose metabolism lower activities of fructose-1,6-diphosphatase (FBPase), phosphoenolpyruvate carboxykinase (PEPCK), and glucose-6-phosphatase (G6Pase) were also significantly altered ($P < 0.05$). Transcriptomic analysis identified 3879 differentially expressed genes (DEGs) between the HSM0 group and the HSM4 group, with most DEGs significantly enriched in the signaling pathways related to glucose metabolism, starch metabolism, and islet resistance. Gene expression analysis was used to validate the transcriptome findings. Mulberry leaf polysaccharide can improve the growth performance and liver damage of largemouth bass on HF diet, improve serum biochemical indices, reduce liver glycogen accumulation induced by HF diet, and alleviate inflammation induced by HF diet. In addition, the addition of MLP plays a key role in alleviating the effects of high-starchy diet on liver damage in sea bass by regulating key enzymes in carbohydrate metabolism and through the PI3K/Akt signaling pathway and insulin resistance.

Key words: *Micropterus salmoides*; Carbohydrate metabolism; Enzyme activity; Transcriptomics; PI3K/Akt signaling pathway; Insulin resistance.

桑叶提取物对鳊脾、肾、鳃结构及功能的影响³³

王文洁¹, 陈琪琪¹, 周达¹, 翟旭亮³, 薛洋³, 汪福保⁴, 陈拥军¹, 何远法¹,
刘海平¹, 赵敏^{2*}, 罗莉^{1*}

(1.西南大学水产学院, 西部(重庆)科学城种质创制大科学中心, 淡水鱼类资源与生殖发育教育部重点实验室, 重庆 400715; 2.山东新希望六和集团有限公司, 山东 青岛, 266061; 3.重庆市水产技术推广总站, 重庆 400400; 4.佛山市南海区杰大饲料有限公司, 广东 佛山 528211)

摘要: 为探究饲料中添加桑叶提取物(MLE)对鳊(*Sinipeca chuatsi*)脾、肾、鳃结构及功能的影响, 在基础饲料中分别添加 0g/kg、2.5g/kg、5.0g/kg、7.5g/kg 和 10.0g/kg 的 MLE, 配制成 5 种等氮等脂的饲料饲喂初始重为(47.82±0.19)g 的鳊, 分别记为 D1、D2、D3、D4 和 D5 处理组, 每组设 3 个重复, 每个重复 15 尾鱼。8 周饲养试验结束后测定脾脏、头肾、鳃组织的抗氧化、免疫指标、组织结构及血液指标变化。结果显示:(1)添加 MLE 后, 鳊脾脏、头肾、鳃和血浆中的免疫球蛋白 M (IgM)、总抗氧化能力(T-AOC)和总超氧化物歧化酶(T-SOD)活性均呈上升趋势, D4 组达到最高值, 同时, 丙二醛(MDA)均呈下降趋势, 其中 D4 组值最佳;(2)鳊脾脏骨髓细胞数量、头肾淋巴细胞数量和鳃丝末端杯状细胞数量的增多, 同时使鳃丝排列更为紧密, 鳃小叶长度更长; 随着 MLE 水平的升高, 鳊全血白细胞数(WBC)先升后降, 在 D3 组达到最高, 较对照组增高 121.40%, 总蛋白(TP)、溶菌酶(LZM)与碱性磷酸酶(AKP)水平先升后降, 在 D4 组达到最大值, 分别较对照组升高 33.76%、8.57%、40.38%。综上可知, MLE 可改善鳊脾脏、头肾、鳃组织发育, 提高机体的抗氧化与免疫能力, 添加量为 7.5g/kg 时效果最佳。本研究可为桑叶提取物在水产养殖中的合理使用提供指导, 提高水产养殖的效益, 促进水产养殖业的可持续发展。

关键词: 鳊; 桑叶提取物; 抗氧化; 免疫能力; 组织发育。

资助项目: 新希望六和集团项目, 重庆市生态渔产业技术体系项目, 重庆市水产科技创新联盟项目

通讯作者: 罗莉, E-Mail:luoli1972@163.com

Effects of mulberry leaf extract on the structure and function of spleen, kidney and gill of *Siniperca chuatsi*

Abstract: To explore the effects of adding mulberry leaf extract (MLE) to feed on the structure and function of spleen, kidney and gill of *Siniperca chuatsi*, 0 g/kg, 2.5 g/kg, 5.0 g/kg, 7.5 g/kg and 10.0 g/kg of MLE were added to the basal feed respectively to prepare five isonitrogenous and isolipidic feeds. *Siniperca chuatsi* with an initial weight of (47.82 ± 0.19) g were fed and recorded as treatment groups D1, D2, D3, D4 and D5 respectively. Each group had three replicates, and each replicate had 15 fish. After the 8-week feeding experiment, the changes of antioxidant, immune indexes, tissue structure and blood indexes of spleen, head kidney and gill tissues were determined. The results showed that: (1) After adding MLE, the immunoglobulin M (IgM), total antioxidant capacity (T-AOC) and total superoxide dismutase (T-SOD) activities in the spleen, head kidney, gill and plasma of *Siniperca chuatsi* all showed an upward trend, and reached the highest value in group D4. At the same time, malondialdehyde (MDA) showed a downward trend, and the value of group D4 was the best; (2) The number of white pulp cells in the spleen of *Siniperca chuatsi*, the number of lymphocytes in the head kidney and the number of goblet cells at the end of gill filaments increased. At the same time, the gill filaments were arranged more closely and the length of gill lobules was longer. With the increase of MLE level, the number of white blood cells (WBC) in the whole blood of *Siniperca chuatsi* first increased and then decreased, reaching the highest in group D3, which was 121.40% higher than that of the control group. The levels of total protein (TP), lysozyme (LZM) and alkaline phosphatase (AKP) first increased and then decreased, and reached the maximum in group D4, which were 33.76%, 8.57% and 40.38% higher than those of the control group respectively. In conclusion, MLE can improve the development of spleen, head kidney and gill tissues of *Siniperca chuatsi* and improve the antioxidant and immune capacity of the body. When the addition amount is 7.5 g/kg, the effect is the best. This study can provide guidance for the rational use of mulberry leaf extract in aquaculture, improve the efficiency of aquaculture and promote the sustainable development of aquaculture industry.

Key words: *Siniperca chuatsi*; mulberry leaf extract; anti-oxidation; immune capacity; Tissue development

沙葱黄酮对乌鳢生长、抗氧化和肝糖代谢的作用

刘云卓¹, 李沐阳^{1*}, 王桂芹²

(1.黑龙江八一农垦大学动物科技学院, 大庆 163319; 2.吉林农业大学动物科技学院, 长春 130118)

摘要:【目的】本试验旨在研究饲料添加沙葱黄酮 (AMRF) 对乌鳢生长、抗氧化和免疫功能及肝糖代谢的作用。【方法】选取体重相近的乌鳢 400 尾, 随机分为 4 组 (每组 5 个重复, 每个重复 20 尾): 对照组 (CN 组) 饲喂基础饲料, 试验组在基础饲料中分别添加 10、20 和 40 mg/kg 的 AMRF, 试验期 8 周。【结果】结果表明: 1) 饲料添加 AMRF 可显著提高乌鳢的体增重 (WG) 和特定生长率 (SGR) ($P < 0.05$)。2) 饲料添加 10、20 或 40 mg/kg 的 AMRF 可显著降低乌鳢血清皮质醇 (COR)、谷草转氨酶 (AST) 和谷丙转氨酶 (ALT) 含量 ($P < 0.05$)。3) 饲料添加 10、20 或 40 mg/kg 的 AMRF 可显著提高乌鳢肝脏超氧化物歧化酶 (SOD)、谷胱甘肽过氧化物酶 (GPx) 和过氧化氢酶 (CAT) 活性。4) 饲料添加 10、20 或 40 mg/kg 的 AMRF 可显著提高乌鳢血清溶菌酶 (LZM) 活性、补体 C3 (C3)、免疫球蛋白 (IgM) 含量 ($P < 0.05$)。5) 饲料添加 10、20 或 40 mg/kg 的 AMRF 可显著提高肝糖原合成酶活性及 pAMPK 和 Beclin-1 蛋白表达。【结论】由此可见, 饲料中添加 AMRF 可促进乌鳢的生长、抗氧化、免疫及肝糖代谢。

关键词: 沙葱黄酮; 乌鳢; 抗氧化; 肝糖代谢。

资助项目: 国家自然科学基金项目 (32273150)

通讯作者: 李沐阳, 教授, 硕士生导师, E-mail: muyangli_hbau@163.com

水飞蓟素对幼草鱼肠道免疫功能的影响和机制³⁵

加峰¹, 韦丽^{1,2,3}, 姜维丹^{1,2,3}, 吴培^{1,2,3}, 马耀斌^{1,2,3}, 刘杨^{1,2,3}, 周小秋^{1,2,3}, 冯琳^{1,2,3*}

(1. 四川农业大学动物营养研究所, 四川 成都, 611130; 2. 鱼类营养与安全生产重点实验室, 四川 成都, 611130; 3. 动物抗病营养农业部、教育部、四川省重点实验室, 四川 成都, 611130)

摘要: 【目的】本文旨在研究水飞蓟素 (SLM) 对幼草鱼肠道免疫能力的影响及其机制。【方法】选择 2160 尾健康草鱼 (均重 24.2 ± 0.1 g) 进行 10 周的生长试验, 试验设置了 0 (基础饲料)、20、40、60、80 和 100 mg/kg 6 个水平的 SLM 饲料组。生长试验结束后, 测定幼草鱼生长性能, 随后进行嗜水气单胞菌攻毒试验探究 SLM 对幼草鱼肠道免疫能力的影响及其机制。【结果】结果显示: 1) 20-100 mg/kg SLM 显著提高幼草鱼增重百分比、采食量和饲料效率 ($P < 0.05$), 降低肠炎发病率。2) 饲料添加 20-80 mg/kg SLM 提高幼草鱼肠道 LZ、ACP 的活性和补体 C3、C4 和 IgM 的含量。此外, 饲料中添加 40-80 mg/kg SLM 上调抗菌肽相关基因 *hepcidin*、*LEAP-2A*、*LEAP-2B*、 *β -defensin-1* 和 *Mucin-2* 的 mRNA 水平。3) 饲料中添加 20-80 mg/kg SLM 上调抗炎细胞因子 (如 *TGF- β 1*、*TGF- β 2*、*IL-4/13A*、*IL-10* 和 *IL-11*) 的 mRNA 水平, 下调促炎细胞因子 (如 *IFN- γ 2*、*IL-6*、*IL-8* (除了前、中肠)、*IL-12p40* 和 *IL-15*) 的 mRNA 水平。4) 饲料中添加 20-100 mg/kg SLM 上调幼草鱼前、中、后肠 *JAK1*、*JAK2*、*JAK3*、*STAT3b1*、*STAT3b2* 和 *STAT6* 的 mRNA 水平, 并下调 *STAT1*、*TYK2* 和 *STAT4* 的 mRNA 水平。【结论】综上所述, 饲料中添加 60 mg/kg SLM 能够提高幼草鱼生长性能, 并通过 JAKs/STATs 信号途径调控幼草鱼肠道炎症细胞因子的表达, 进而改善肠道免疫能力。根据 PWG 和肠炎发病率确定幼草鱼饲料中 SLM 的最适添加量分别为 57.63、56.73 mg/kg。

关键词: 水飞蓟素; 幼草鱼; 免疫功能; 肠道; JAKs/STATs。

通讯作者: 冯琳, 教授, 博士生导师; E-mail: fenglina@sicau.edu.cn;

基金项目: 国家现代农业产业技术体系专项基金 (CARS-45); 国家自然科学基金优秀青年基金项目 (31922086); 国家重点研发计划“蓝色粮仓科技创新”重点专项 (2019YFD0900200)。

水飞蓟素缓解伏马毒素 B1 诱导的幼草鱼肝胰腺损伤的可能性

机制：促进线粒体自噬

陈代宇¹, 姜维丹^{1,2,3}, 吴培^{1,2,3}, 刘杨^{1,2,3}, 马耀斌^{1,2,3}, 周小秋^{1,2,3*}, 冯琳^{1,2,3*},
(1.四川农业大学动物营养研究所, 四川成都 611130; 2.鱼类营养与安全生产重点实验室, 四川成都 611130; 3.动物抗病营养农业部、教育部、四川省重点实验室, 四川成都 611130)

摘要: 伏马菌素(Fumonisin, FUM)是镰刀菌属真菌产生的次生毒性代谢物, 广泛存在于玉米、小麦和水稻等植物性饲料原料中, 其中 FUM B1 (FB1)是 28 种 FUM 类似物中毒性最大、含量最多的毒素。多数动物的肝脏是 FB1 主要的靶器官。水飞蓟素 (Silymarin, SIL) 由于其抗氧化和抗炎功能而被广泛应用于缓解肝脏损伤的研究中。本试验旨在探究饲料中添加 SIL 是否能缓解 FB1 对草鱼的肝胰腺损伤。720 尾幼草鱼 (10.92 ± 0.01 g) 被随机分配到对照组、FB1 组、SIL 组和 FB1+SIL 组中, 每组 3 个重复, 每个重复 60 尾鱼。四组分别饲喂基础饲料 (不添加 FB1 和 SIL)、添加 4 mg/kg FB1、60 mg/kg SIL 饲料和 4 mg/kg FB1+60 mg/kg SIL 饲料, 饲喂 30 d。结果显示:1) FB1 导致幼草鱼肝胰腺中的鞘脂代谢紊乱。2) FB1 导致幼草鱼肝胰腺炎性浸润、细胞坏死形成坏死灶、细胞空泡变性、肿胀、脂滴增多和纤维化水平增加, 同时伴随着线粒体肿胀、结构紊乱和线粒体嵴断裂。SIL 缓解了上述 FB1 造成的肝胰腺损伤。3) FB1 降低了幼草鱼肝胰腺的抗氧化酶活性水平, 提高了幼草鱼肝胰腺的活性氧自由基、丙二醛、蛋白质羰基和 8-OHdG 水平。SIL 对该变化有缓解作用。4) FB1 降低了幼草鱼肝胰腺的脂肪酸 β-氧化关键酶的表达水平, 增加了肝胰腺甘油三酯和脂肪酸水平。SIL 缓解了这些变化。5) 在 FB1+SIL 组中观察到了线粒体自噬的发生, 线粒体自噬的关键分子 (Paikin) 的水平提高, 同时线粒体损伤得到了缓解。综上所述, SIL 可能是通过提高线粒体自噬、缓解线粒体损伤, 进而缓解 FB1 诱导幼草鱼肝胰腺氧化损伤和脂肪变性。本研究探索了天然植物化合物 SIL 对缓解 FB1 诱导的幼草鱼肝脏毒性的作用, 为今后 SIL 用于水产饲料添加剂的开发提供新的思路和试验依据。

关键词: 肝胰腺脂肪变性; 脂肪酸 β-氧化; 线粒体功能障碍; 线粒体自噬。

基金项目: 国家自然科学基金优秀青年科学基金 (31922086); 国家重点研发计划“蓝色粮仓科技创新”重点专项 (2019YFD0900200, 2018YFD0900400); 国家现代农业产业技术体系 (CARS-45); 四川省科技计划 (2019YFN0036)

通信作者: 周小秋, 教授, 博士生导师, E-mail: zhouxq@sicau.edu.cn; 冯琳, 教授, 博士生导师, E-mail: fenglin@sicau.edu.cn

饲料氯化胆碱对用鱮幼鱼生长性能、抗氧化性能和肠道功能的影响

陈莉莉^{1,3}, 王诚洁¹, 张黎明², 段丽¹, 宋文哲¹, 黄峰^{1*}, 田娟^{1,3*}

(1. 武汉轻工大学动物营养与饲料科学重点实验室, 湖北 武汉 430223; 2. COFCO 饲料(荆州)有限公司, 湖北 荆州 434300; 3. 中国水产科学院研究院长江水产研究所, 湖北 武汉 4302231)

摘要: 为探究氯化胆碱对鱮幼鱼生长性能、抗氧化性能和肠道功能的影响, 配制 6 组含不同水平氯化胆碱的饲料: 0(对照组)、2、4、6、8 和 10 g/kg, 饲养鱮幼鱼(初始体质量为 1.77±0.20g) 66 天。结果表明, 饲料中添加 6 g/kg 氯化胆碱可提高鱮幼鱼的增重率(WGR)和特定生长率(SGR) ($P<0.05$)。添加氯化胆碱(4~10 g/kg)可降低鱮幼鱼血清甘油三酯、总胆固醇和葡萄糖含量 ($P<0.05$)。与对照组相比, 饲料中添加氯化胆碱(6~10g/kg)可显著降低血清丙二醛含量。当氯化胆碱添加水平为 6 g/kg 时, 血清中过氧化氢酶和超氧化物歧化酶活性显著升高 ($P<0.05$)。添加氯化胆碱(6~10 g/kg)显著提高肠道消化酶活性 ($P<0.05$)。饲料中添加氯化胆碱对鱮幼鱼肠道微生物丰度无影响。综上所述, 饲料中添加氯化胆碱(4~10g/kg)可显著提高鱮幼鱼的生长性能、抗氧化能力和消化能力。通过二次曲线回归模型分析 WGR、SGR 与饲料氯化胆碱添加水平的关系, 得出鱮幼鱼对氯化胆碱的需要量分别为 6.51 和 6.62 g/kg。

关键词: 氯化胆碱; 鱮幼鱼; 生长性能; 消化能力; 肠道微生物。

Effects of dietary choline chloride on growth performance, antioxidant properties, and intestinal function of juvenile bighead carp (*Aristichthys nobilis*)

Lili Chen^{1,3}, Chengjie Wang¹, Liming Zhang², Li Duan¹, Wenzhe Song¹, Feng Huang^{1,*} and Juan Tian^{3,*}

(1. Hubei Key Laboratory of Animal Nutrition and Feed Science, Wuhan Polytechnic University, Wuhan 430223, Hubei; 2. COFCO Feed (Jingzhou) Co., Ltd., Gongan, Jingzhou 434300, Hubei; 3. Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Wuhan 430223, Hubei)

Abstract: To investigate the effects of choline chloride on growth performance, antioxidant properties, and intestinal function of juvenile bighead carp (*Aristichthys nobilis*), fish with an average weight of 1.77 ± 0.20 g were fed with different dietary choline chloride supplementation concentrations: 0 g/kg (control), 2 g/kg, 4 g/kg, 6 g/kg, 8 g/kg and 10 g/kg for 66 days. The results indicated that dietary choline chloride supplementation at 6 g/kg improved the weight gain rate (WGR) and specific growth rate (SGR) ($P < 0.05$). Dietary choline chloride supplementation (approximately 4-10 g/kg) decreased serum in serum triglycerides, total cholesterol and glucose levels of juvenile bighead carp ($P < 0.05$). Malondialdehyde level was significantly lower than the control group when choline chloride supplementation ranged from 6 to 10g/kg. When choline chloride supplementation was at 6 g/kg, the activities catalase and superoxide dismutase were significantly higher than the control group ($P < 0.05$). The levels of choline chloride supplementation (approximately 6-10 g/kg) increased the activity of intestinal digestive enzymes and enhanced the intestinal digestibility of juvenile bighead carp ($P < 0.05$). In addition, choline chloride levels did not affect the abundance of intestinal microorganisms and there was no significant difference in the dominant phylum and genus among six groups. Overall, choline chloride supplementation (4-10 g/kg) could significantly improve the growth performance, antioxidant capacity, and digestive enzyme activity of juvenile bighead carp. Furthermore, broken-line regression analysis has identified 6.51 and 6.62 g/kg as the optimal levels of dietary choline chloride for juvenile bighead carp based on growth performance.

Keywords: choline chloride; juvenile bighead carp; growth performance; digestive capacity; intestinal flora

饲料纳米氧化锰通过 mtROS 依赖性 Hsf1^{Ser326} 磷酸化引发黄颡鱼肝脏脂毒性和线粒体自噬³⁷

赵涛

(西北农林科技大学动物科技学院, 陕西杨凌, 712100)

摘要: 锰 (Mn) 是维持脊椎动物正常代谢的必需元素。纳米二氧化锰 (MnO₂ NPs) 具有独特的物理和化学性质, 在生物和生物医学应用中显示出巨大的潜力, 也是水产饲料潜在的新型锰源。然而, 其对水产动物和细胞代谢的潜在影响知之甚少。因此, 本研究利用营养学、组织学、分子生物学和细胞生物学等技术和方法结合在体与离体细胞试验探究了饲料 MnO₂ NPs 水平对黄颡鱼肝脏脂质代谢的影响及其分子机制。结果表明, 饲料过量 MnO₂ NPs 会增加黄颡鱼肝脏和线粒体 Mn 含量, 促进肝脏脂肪生成, 抑制脂肪分解和脂肪酸 β-氧化过程, 引发脂毒性。同时, 过量 MnO₂ NPs 引发肝脏线粒体氧化应激, 损害线粒体功能, 破坏线粒体动力学并激活线粒体自噬。重要的是, 我们发现 mtROS 激活的热休克因子 1 (Hsf1) 在 Ser326 残基处的磷酸化介导 MnO₂ NPs 诱导的肝脏脂毒性和线粒体自噬。机制上, MnO₂ NPs 诱导的肝脏脂毒性和线粒体自噬是通过 mtROS 诱导的 Hsf1 磷酸化促进其核易位, 进一步增强其与 *plin2/dgat1* 和 *bnip3* 启动子的 DNA 结合能力实现。总之, 本研究结果揭示了 mtROS 诱导的线粒体功能障碍和 Hsf1^{S326} 磷酸化介导 MnO₂ NPs 诱导的肝脏脂毒性和线粒体自噬的新机制, 这不仅为新型矿物元素纳米颗粒对鱼类肝毒性的影响提供了新的见解, 也为纳米矿物元素在水产饲料中的安全应用提供了参考资料。

关键词: 纳米二氧化锰; 肝毒性; 线粒体氧化应激; 线粒体自噬; 脂毒性。

资助项目: 国家重点研发计划 (2018YFD0900400); 中央高校基本科研业务费专项资金 (2662023SCP001)。本研究内容详见: Zhao T, Zheng H, Xu JJ, Pantopoulos K, Xu YC, Liu LL, Lei XJ, Kotzamanis YP, Luo Z. MnO₂ nanoparticles trigger hepatic lipotoxicity and mitophagy via mtROS-dependent Hsf1^{Ser326} phosphorylation. *Free Radic Biol Med*, 2024, 210: 390-405.
报告作者: 赵涛, E-Mail: zhaotao2024@nwafu.edu.cn

MnO₂ nanoparticles trigger hepatic lipotoxicity and mitophagy in yellow catfish *Pelteobagrus fulvidraco* via mtROS-dependent Hsf1Ser326 phosphorylation

Tao Zhao

(College of Animal Science and Technology, Northwest A&F University, Yangling, Shaanxi, 712100, China)

Abstract: Manganese (Mn) is an essential element for maintaining normal metabolism in vertebrates. Mn dioxide nanoparticles (MnO₂ NPs) have unique physical and chemical properties, show great potential in biological and biomedical applications, and are also a potential novel source of Mn for aquatic feeds. However, little is known about its potential effects on aquatic animals or cell metabolism. Therefore, present study used nutritional, histological, molecular biology, and cell biology techniques and methods combined with *in vivo* and *in vitro* experiments to explore the effects of dietary MnO₂ NPs levels on hepatic lipid metabolism in yellow catfish and its molecular mechanisms. We found that, excessive MnO₂ NPs intake increased hepatic and mitochondrial Mn content, promoted hepatic lipotoxic disease and lipogenesis, and inhibited hepatic lipolysis and fatty acid β -oxidation. Moreover, excessive MnO₂ NPs intake induced hepatic mitochondrial oxidative stress, damaged mitochondrial function, disrupted mitochondrial dynamics and activated mitophagy. Importantly, we uncovered that mtROS-activated phosphorylation of heat shock factor 1 (Hsf1) at Ser326 residue mediated MnO₂ NPs-induced hepatic lipotoxic disease and mitophagy. Mechanistically, MnO₂ NPs-induced lipotoxicity and mitophagy were via mtROS-induced phosphorylation and nucleus translocation of Hsf1 and its DNA binding capacity to *plin2/dgat1* and *bnip3* promoters, respectively. Overall, our findings uncover novel mechanisms by which mtROS-mediated mitochondrial dysfunction and phosphorylation of Hsf1^{S326} contribute to MnO₂ NPs-induced hepatic lipotoxicity and mitophagy, which not only provide new insights into the effects of metal oxides nanoparticles on hepatotoxicity in fish, but also provides references for the safe application of nano-mineral elements in aquatic feeds.

Key words: Mn dioxide nanoparticles; Hepatotoxicity; Mitochondrial oxidative stress; Mitophagy; Lipotoxicity

饲料添加阿魏酸对中华绒螯蟹幼蟹生长性能、糖代谢及脂质代谢的影响

贺佳琪³⁸, 李二超¹, 陈立侨^{1*}, 王晓丹^{1*}

(1.华东师范大学, 生命科学学院, 水生动物营养与环境健康实验室, 上海 200241)

摘要: 【目的】阿魏酸是一种植物酚酸, 具有促生长、调节糖脂代谢等作用。本研究旨在探讨阿魏酸对中华绒螯蟹幼蟹生长和糖脂代谢的影响。【方法】将 960 只健康的幼蟹 (0.50 ± 0.02 g) 随机分为 6 组, 投喂对照饲料 (35% 鱼粉) 或 5 种不同阿魏酸浓度的饲料 (15% 鱼粉, 0、40、80、160、320mg/kg), 每组 4 个平行, 养殖 56 天。【结果】与低鱼粉对比, 添加 80 和 160mg/kg 阿魏酸可以显著提高幼蟹的增重率和特定生长率, 并降低饲料系数。适量的阿魏酸可显著促进脂肪合成过程和脂肪酶活性, 从而显著提高了全蟹粗脂肪含量, 并因此显著增加了血清中甘油三酯、胆固醇和高密度脂蛋白的含量, 同时降低了血清中谷草转氨酶 (AST) 含量和肝胰腺中丙二醛 (MDA) 含量。饲料添加适量阿魏酸, 还显著提高了肝胰腺中糖酵解 (丙酮酸激酶, PK 和己糖激酶, HK) 和糖异生 (磷酸烯醇丙酮酸羧激酶, PEPCK) 相关酶的活性, 下调了肝胰腺中糖原合成酶 (GS) 和糖原分解酶 (GP) 基因的表达。【结论】研究表明, 饲料中添加 80-160mg/kg 阿魏酸时, 可以通过促进幼蟹糖酵解、糖异生等糖代谢途径和脂肪合成过程, 从而促进粗脂肪积累, 进而促进生长。

关键词: 中华绒螯蟹; 阿魏酸; 糖代谢; 脂代谢。

资助项目: 国家重点研发计划 (2023YFD2402000); 国家自然科学基金项目 (32072986); 财政部和农业农村部国家现代农业产业技术体系; 上海市中华绒螯蟹产业技术体系 (202404)

通讯作者: 陈立侨, E-Mail: lqchen@bio.ecnu.edu.cn ; 王晓丹, E-Mail: xdwang@bio.ecnu.edu.cn

Effects of ferulic acid on growth performance, glucose metabolism and lipid metabolism of juvenile Chinese mitten crab, *Eriocheir sinensis*

Jiaqi He¹, Erchao Li¹, Liqiao Chen¹, Xiaodan Wang^{1*}

(1. East China Normal University, School of Life Sciences, Laboratory of Aquaculture Nutrition and Environmental Health, Shanghai China 200241)

Abstract: [Objective] Ferulic acid is a kind of plant phenolic acid, which can promote growth and regulate glucose and lipid metabolism. The aim of this study was to investigate the effects of ferulic acid on the growth and metabolism of juvenile *Eriocheir sinensis*. [Methods] 960 juvenile crabs (0.50 ± 0.02 g) were randomly divided into 6 groups and fed either a control diet (35% fish meal) or one of 5 diets containing different concentrations of ferulic acid (15% fish meal, 0, 40, 80, 160, 320 mg/kg). The crabs were randomly assigned to 24 aquariums, with 40 crabs per aquarium, and the feeding trial lasted for 56 days. [Results] Compared with the low fish meal group, 80 and 160mg/kg dietary ferulic acid could significantly improve the weight gain rate and specific growth rate of juvenile crabs, and reduced the feed coefficient. Moderate ferulic acid significantly increased the crude fat content and fat enzyme activity of the whole crab and promoted the expression of fatty acid synthesis-related genes. Ferulic acid can significantly increased the content of triglycerides, cholesterol and high-density lipoprotein in the serum, reduced the content of serum aspartate transaminase (AST) and malondialdehyde (MDA) in the hepatopancreas, but did not change the glucose content in the serum. Adding an appropriate amount of ferulic acid to the feed also significantly increased the activity of related enzymes for glucose metabolism (pyruvate kinase, PK and hexokinase, HK) and gluconeogenesis (phosphoenolpyruvate carboxykinase, PEPCK) in the hepatopancreas, and downregulated the expression of glycogen synthase (*GS*) and glycogen-degrading enzyme (*GP*) genes in the hepatopancreas. [Conclusion] The results have shown that the addition of 80-160mg/kg ferulic acid in the diet can promote the accumulation of crude fat and promote the growth of juvenile crabs by promoting glycolysis, gluconeogenesis and other glucose metabolic pathways and fat synthesis processes.

Key words : *Eriocheir sinensis*; Ferulic acid; Glucose metabolism; Lipid metabolism

饲料中添加 L-谷氨酸对大口黑鲈生长性能、肌肉生长相关基因表达及肠道健康的影响

姜非凡¹ 黄文庆² 周萌¹ 高红燕¹ 黄燕华^{1*39}

(1. 仲恺农业工程学院动物科技学院健康养殖创新研究院 广东广州 510225; 2. 广州飞禧特生物科技有限公司广东广州 510640)

摘要【目的】本研究探讨了 L-谷氨酸(Glu)水平对大口黑鲈生长性能、肌肉组成、肌肉生长发育相关基因表达的影响以及肠道健康的影响。

【方法】试验选取 525 尾大口黑鲈, 随机分为 5 个组, 每组 3 个重复, 每个重复放养 35 尾。实验日粮分为对照组以及分别添加 0.2%、0.4%、0.6%和 0.8%的谷氨酸的实验组, 配制成 5 种等氮等脂实验饲料。

【结果】结果表明, 添加谷氨酸提高了最终体重 (FBW) 和增重百分比 (PWG) 以及摄食量 (FI) 和肥满度 CF(g/cm³), 在 0.4%谷氨酸组达到最高。降低了饲料转化率 (FCR)。提高了鱼体粗蛋白以及粗脂肪的含量。肌肉组成方面, 提高了肌纤维的平均面积, 降低了肌纤维的密度。提高了总氨基酸的含量以及谷氨酸、天冬氨酸、亮氨酸、缬氨酸、丙氨酸和甘氨酸 6 种鲜味氨基酸的含量。基因表达方面, 添加谷氨酸后 4E-BP1、FoxO3a、MuRF-1、Atrogin-1 mRNA 表达水平低于对照组, PI3K、AKT、TOR、S6K1、MyoD、MyoG、Myf5、mRNA 表达水平高于对照组。肠道消化能力方面, 谷氨酸提高了淀粉酶, 脂肪酶以及蛋白酶的活性, 提高了大口黑鲈肠道的绒毛高度、绒毛宽度和肌层厚度。上述结果表明, 谷氨酸促进了鱼类生长、肌肉发育和肠道消化吸收能力。

【结论】综上所述, 我们的研究结果表明, Glu 对大口黑鲈的生长性能、肌肉发育和肠道消化都有好处。以生长性能为指标, 谷氨酸的适宜添加量为 0.4%, 以肌肉发育为指标, 谷氨酸的适宜添加量为 0.6%。

关键词: 谷氨酸; 大口黑鲈; 肌肉; 肠道健康。

资助项目³⁹ *:广东省教育厅创新团队项目、功能饲料与动物免疫调节创新团队(2020KCXTD019)
通讯作者黄燕华, *huangyanhua@zhku.edu.cn

Effects of Dietary L-glutamic acid on the Growth Performance, Gene Expression Associated with Muscle Growth-Related Gene Expression, and Intestinal Health of Juvenile Largemouth Bass (*Micropterus salmoides*)

Feifan Jiang¹, Wenqing Huang², Meng Zhou¹, Hongyan Gao¹, and Yanhua Huang^{1,*}

(¹ Institute of Animal Health Breeding Innovation, College of Animal Science and Technology, Zhongkai College of Agricultural Engineering, Guangzhou 510225, China;

² Guangzhou Fishtech Biotechnology Co., Ltd., Guangzhou 510640, China;)

Abstract:[Objective] The present research examined the impact of L-glutamic acid (Glu) supplementation on the growth performance, muscle composition, gene expression correlated with muscle growth, and intestinal health of largemouth bass.

[Methods] There were 525 fish in total, which were distributed randomly into five groups. Each group had three replicates, and each replicate consisted of 35 fish. Groups with control and experimental diets were assigned glutamic acid amounts of 0.2%, 0.4%, 0.6%, and 0.8%.

[Results] The findings demonstrated that glutamic acid supplementation enhanced growth performance, feed intake (FI), and condition factor (CF), with the best value being attained at 0.4% Glu. The mean muscle fiber area was increased and the muscle fiber density was decreased in the 0.6% Glu group. The levels of total amino acids and specific amino acids, such as glutamic acid, aspartic acid, leucine, valine, alanine, and glycine, were shown to be higher in the 0.6% Glu group. In the 0.6% Glu group, the mRNA expression levels of atrogen-1, murf-1, foxo3a, and 4e-bp1 were decreased compared to the control group. Conversely, the mRNA expression levels of myf5, myog, myod, s6k1, tor, akt, and pi3k were increased in the 0.6% Glu group compared to the control group. The 0.4% Glu group had higher intestinal amylase, lipase, and protease activities and greater villus height, villus width, and muscle thickness.

[Conclusion] In summary, Glu can support largemouth bass growth, muscular development, intestinal digestion, and absorption.

Keywords: glutamic acid; largemouth bass; muscle; intestinal health

饲料中添加当归脂溶性提取物对鲤生长、体成分、代谢与抗氧化能力的影响

李华涛^{1*}, 徐静¹, 王苗苗^{40,2}, 黄晓兰¹, 刘海静¹, 李江¹, 杨奇慧³, 陈岗富¹
(1. 内江师范学院生命科学学院, 长江上游鱼类资源保护与利用四川省重点实验室, 四川 内江 641100; 2. 江苏海洋大学海洋科学与水产学院, 江苏 连云港 222000; 3. 广东海洋大学水产学院, 广东 湛江 524088)

摘要: 【目的】探索当归脂溶性提取物 (FSE) 对鲤生长、体成分、代谢与抗氧化能力的影响。【方法】使用石油醚和乙酸乙酯萃取出 FSE, 将不同浓度的 FSE 添加入饲料; 投喂鲤 15 d 后, 测定以上指标。【结果】投喂 FSE 显著降低了鲤的增重、特定生长率、肥满度 (CF)、胴体含脂量、脂肪沉积率、氨排放率、血浆总氨基酸和高密度脂蛋白、肝胰脏和鳃丙二醛以及肌肉 H₂O₂ 含量; 显著提高了鲤胴体蛋白含量、蛋白质沉积率 (PPV)、氧消耗率、O:N 比、血浆总蛋白和低密度脂蛋白含量以及肝胰脏、肌肉、鳃或红细胞的 Na⁺,K⁺-ATP 酶、谷丙转氨酶、谷草转氨酶、乳酸脱氢酶、肌酸激酶、抗超氧阴离子、抗羟自由基、超氧化物歧化酶、过氧化氢酶和谷胱甘肽过氧化物酶活性以及红细胞还原型谷胱甘肽含量。以上结果说明, FSE 具有显著的减肥和肉质改良作用, 能够提高鱼体脂肪和糖类的分解代谢、ATP 的消耗和蛋白质的合成, 降低其蛋白质的分解代谢, 改善鱼体酶型抗氧化剂的活性和非酶抗氧化剂含量, 从而抑制了组织器官活性氧的产生和脂质氧化。基于 CF 和 PPV 的折线回归分析显示, FSE 在饲料中的适宜添加量为 12.03 g kg⁻¹。【结论】FSE 能改善鱼体的营养代谢和抗氧化能力, 因而降低了鱼体的脂肪沉积和增重。为开发具有减肥功能的鱼饲料添加剂提供候选原料。**关键词:** 当归脂溶性提取物; 鲤; 增重; 体成分; 代谢; 抗氧化。

基金项目: 四川省科技计划项目 (2018JY0214); 大学生创新创业项目 (X2021207)

*通信作者: 李华涛, 教授, 博士, E-mail: lihuatao666@163.com

The effects of dietary fat soluble extract of *Angelica sinensis* on the growth, body composition, metabolism, and antioxidant capacity of *Cyprinus carpio* var. Jian

LI Huatao^{1*}, XU Jing¹, WANG Miaomiao^{1,2}, HUANG Xiaolan¹, LIU Haijing¹, LI Jiang¹, YANG Qihui³, CHEN Gangfu¹

(1. Key Laboratory of Sichuan Province for Fishes Conservation and Utilization in the Upper Reaches of the Yangtze River, College of Life Sciences, Neijiang normal university, Neijiang 641110, China; 2. School of Marine Science and Fisheries, Jiangsu Ocean University, Lianyungang 222000, China; 3. College of Fisheries, Guangdong Ocean University, Zhanjiang 524088, China)

Abstract: This study explored the effects of fat soluble extract of *Angelica sinensis* (FSE) on the growth, body composition, metabolism, and antioxidant capacity in Jian carp (*Cyprinus carpio* var. Jian). Firstly, FSE was obtained by extraction with petroleum ether and ethyl acetate. Then, the experimental diets were formulated by adding FSE to the basal diet. Jian carps were fed with diets containing different levels of FSE for 15 d. The results showed that dietary FSE decreased the weight gain, special growth rate, condition factor (CF), fat content in carcass, fat deposition rate and ammonia excretion rate as well as the content of total amino acids and high-density lipoprotein in the plasma, malondialdehyde in hepatopancreas and gills and H₂O₂ in muscles, and increased the protein content in carcass, protein deposition rate (PPV), oxygen consumption rate, O:N ratio and the content of total protein and low-density lipoprotein in the plasma as well as the activities of Na⁺,K⁺-ATPase, alanine aminotransferase, aspartate aminotransferase, lactate dehydrogenase, creatine kinase, anti-superoxide anion, anti-hydroxyl radical, superoxide dismutase, catalase and glutathione peroxidase and the content of reduced glutathione in the hepatopancreas, gills, muscles or erythrocytes of carp. These results indicated that FSE has significant weight loss and meat quality improvement effects, can enhance the catabolism of body fat and carbohydrates, ATP consumption and protein synthesis, reduce the catabolism of protein, and improve the enzymatic antioxidant activity and non-enzymatic antioxidant content, thereby inhibiting the production of reactive oxygen species and lipid oxidation in tissues and organs of fish. According to the broken-line regression analysis based on CF and PPV, the appropriate concentration of FSE is estimated to be 12.03 g kg⁻¹ diet. In summary, FSE can improve the nutritional metabolism and antioxidant capacity, thereby reducing fat deposition and weight gain in fish. This study provides candidate raw materials for the development of fish feed additives with weight loss functions.

Keywords: Fat soluble extract of *Angelica sinensis*; Carp; Weight gain; Body composition; Metabolism; Antioxidant

饲料中添加发酵吊笼养殖附着物替代海泥对刺参生长的影响

贾建鑫^{1,2}, 王瑞瑶^{1,2}, 李娅宁^{1,2}, 吴思润^{1,2}, 李永超^{1,2}, 高昌盛^{1,2}

(1. 大连海洋大学, 大连 116023; 2. 辽宁省贝类良种繁育工程技术研究中心, 大连 116023)

摘要: 在悬浮网箱培养过程中, 定期清洗去除网箱中的附生生物防止笼子下沉而造成经济损失是不可避免的。然而, 清洗后许多附着物会脱落悬浮网箱堆积在潮汐中, 造成环境污染和资源浪费。此外, 海参 (*Apostichopus japonicus*) 是沉积食物生物, 在它们生长的不同阶段经常需要通常添加海泥。然而, 长期的海泥挖掘会破坏海洋环境。因此, 为促进刺参养殖业的可持续发展, 开发一种替代海参饲料中海泥的新型原料是十分重要的。本研究旨在探索以发酵吊笼养殖附着物为替代物 (FASC) 的可行性。在饲料中分别添加不同浓度的 FASC (0、25、50、75、100%) 喂养刺参 60 天。结果表明, 100% FASC 海泥代替组显著提高了海参的生长, 降低了饲料系数, 显著提高了肠道消化酶活性, 改善了肠道结构, 丰富了肠道微生物群的多样性。此外, 与对照组相比 100% FASC 海泥代替组生长基因 *mapk-7* 和 *fgfr-1* 的表达量也有了显著增加, 而生长负调节基因 *gdf-8* 则被抑制。结果表明, FASC 有潜力作为日本刺参的新原料。

关键词: 刺参; 消化酶; 发酵吊笼养殖附着物; 肠结构。

Effect of dietary fermented attachments of suspension cage to feed instead of sea mud on growth of *Apostichopus japonicus*

Jianxin Jia^{1,2}, Ruiyao Wang^{1,2}, Yaning Li^{1,2}, Sirun Wu^{1,2}, Yongchao Li^{1,2}, Changsheng Gao^{1,2}

(1. Dalian Ocean University, Dalian 116023; 2. Engineering and Technology Research Center of Shellfish Breeding in Liaoning Province, Dalian Ocean University, Dalian 116023)

Abstract: In the suspension cage culture process, regular cleaning to remove epiphytic organisms from the cage is essential to prevent economic losses due to the sinking of the cage. However, after cleaning, many of attachments from the suspension cage accumulate in the tidal flats, causing environmental pollution and resource wastage. Moreover, because sea cucumbers (*Apostichopus japonicus*) are sedimentary food organisms, sea mud is typically added to their feed to varying degrees. However, long-term excavation of sea mud can destroy the marine environment. Therefore, developing an alternative new raw feed material to replace sea mud in sea cucumber feed is necessary to promote sustainable development of the *A. japonicus* aquaculture industry. The aim of this study was to explore the feasibility of using fermented attachments of suspension cage (FASC) as a raw feed material for *A. japonicus*. Different FASC concentrations (0, 25, 50, 75, and 100 %) were used in *A. japonicus* feed for 60 d. Replacing Sea mud with 100 % FASC significantly improved sea cucumber growth, reduced the feed coefficient, significantly increased the activity of intestinal digestive enzymes, improved intestinal structure, and enriched intestinal microbiome diversity. Furthermore, expressions of growth genes *mapk-7* and *fgfr-1* significantly increased in the 100 % FASC treatment compared with that in the control, and that of negative growth regulator gene *gdf-8* was inhibited. The results suggested the potential of FASC as a new raw feed material for *A. japonicus*.

Keywords: *Apostichopus japonicus*; digestive enzyme; fermented attachments suspension cage; intestinal structure

饲料中添加发酵石榴皮多酚对凡纳滨对虾血清生化、免疫、肝胰脏健康和抗病力的影响⁴¹

余宙霖¹, 刘广业¹, 李思杰¹, 洪宇聪², 周萌^{1*}, 谭小红^{1*}

(1.仲恺农业工程学院, 广东 广州 510225; 2.广东越群海洋生物科技股份有限公司, 广东 揭阳 515500)

摘要:【目的】研究饲料中添加发酵石榴皮多酚对凡纳滨对虾 (*Litopenaeus vannamei*) 生长性能、血清生化、抗氧化能力、免疫力、肝胰脏健康和抗病力的影响。【方法】选择初始体重为 (2.92 ± 0.09) g 的凡纳滨对虾 300 尾, 随机分为 5 组, 每组 3 个重复, 每个重复 20 尾虾。配制了发酵石榴皮多酚含量分别为 0% (FP0 组)、0.015% (FP1 组)、0.030% (FP2 组)、0.060% (FP3 组) 和 0.120% (FP4 组) 的 5 种等脂肪 ($8.50 \pm 0.08\%$) 等蛋白 ($42.43 \pm 0.11\%$) 的 5 种试验饲料进行饲喂, 养殖试验为期 45 天。【结果】各组之间对虾的增重率 (WGR)、特定生长率 (SGR) 和饲料系数 (FCR) 均无显著差异 ($P > 0.05$), 但添加发酵石榴皮多酚组的对虾存活率 (SR) 显著高于 FP0 组 ($P < 0.05$)。与 FP0 组相比, FP3 和 FP4 组对虾血清生化指标中总蛋白 (TP) 和球蛋白 (GLB) 的含量显著升高 ($P < 0.05$), 血尿素氮 (BUN) 的含量显著降低 ($P < 0.05$)。与 FP0 组相比, FP3 和 FP4 组对虾肝胰腺和血清的超氧化物歧化酶 (SOD)、过氧化氢酶 (CAT)、碱性磷酸酶 (AKP)、酸性磷酸酶 (ACP) 和溶菌酶 (LZM) 活性显著升高 ($P < 0.05$)。FP2 组对虾肝胰腺和血清的谷胱甘肽过氧化物酶 (GSH-Px)、总抗氧化能力 (T-AOC) 和酚氧化酶 (PO) 活性也显著高于 FP0 组 ($P < 0.05$)。添加发酵石榴皮多酚组的对虾肝胰腺和血清中丙二醛 (MDA) 的含量均显著低于 FP0 组。此外, 与 FP0 组相比, FP3 和 FP4 组对虾肝胰腺的抗氧化和免疫相关基因 (SOD、CAT、GST、LZM、ProPO、Pen3、Crustin、Imd、Toll 和 Relish) 的表达水平显著上调 ($P < 0.05$)。另外, 增加饲料中发酵石榴皮多酚的添加水平可以使对虾肝胰脏的肝小体排列更加紧密, 星状结构更加清晰, 参与营养物质吸收的 B 细胞数目增多。溶藻弧菌攻毒结果表明, 添加发酵石榴皮多酚组的对虾在攻毒 7 天后的累计存活率均显著高于 FP0 组 ($P < 0.05$), 其中 FP3 组累计存活率最高。【结论】饲料中添加发酵石榴皮多酚可以在不影响凡纳滨对虾生长性能的前提下, 增强其抗氧化能力和免疫力, 改善其肝胰脏健康, 并提高其对溶藻弧菌感染的抵抗力。
关键词: 凡纳滨对虾; 发酵石榴皮多酚; 抗氧化; 免疫力; 抗病力; 溶藻弧菌。

资助项目: 广东茂名滨海新区海洋渔业产业园项目 (0835-220FA8102621)、广东省重点建设学科科研能力提升工程 (2022ZDJS022)、广东省重点领域科技发展计划 (2021B0202050002)、广东省普通高校创新团队项目 (2020KCXTD019)、广东省农业科技发展资源环境保护管理项目 (2022KJ115)。

通讯作者: 周萌, E-Mail: zhoumeng@zhku.edu.cn

谭小红, E-Mail: tanxiaohong@zhku.edu.cn

Effects of dietary fermented pomegranate peel polyphenols on serum biochemistry, immunity, hepatopancreatic health and disease resistance in white shrimp (*Litopenaeus vannamei*)

Zhoulin Yu¹, Guangye Liu¹, Sijie Li¹, Yucong Hong², Shuyan Zhao², Meng Zhou^{1*},
Xiaohong Tan^{1*}

(1. Innovative Institute of Animal Healthy breeding, College of Animal Sciences and Technology, Zhongkai University of Agriculture and Engineering, Guangzhou China 510225; 2. Guangdong Yuequn Biotechnology Co., Ltd, Jieyang China 515500)

Abstract: [Objective] In order to investigate the effects of dietary fermented pomegranate peel polyphenols (FPPP) on growth performance, serum biochemistry, antioxidant capacity, immunity, hepatopancreatic health and disease resistance in white shrimp (*Litopenaeus vannamei*). [Methods] A total of 300 shrimps with an initial body weight of (2.92 ± 0.09) g were randomly divided into 5 groups with 3 replicates per group and 20 shrimps per replicate. Five isoproteic ($42.43 \pm 0.11\%$) and isolipidic ($8.50 \pm 0.08\%$) experimental diets were formulated, which contained 0% (FP0), 0.015% (FP1), 0.030% (FP2), 0.060% (FP3) and 0.120% (FP4) FPPP, respectively. The experiment lasted for 45 days. [Results] There were no significant variations in weight gain rate (WGR), specific growth rate (SGR) and feed conversion rate (FCR) of shrimp in all treatment groups ($P > 0.05$), but the survival (SR) of shrimp was significantly higher in all groups with the addition of FPPP ($P < 0.05$). Compared with FP0 group, the contents of total protein (TP) and globulin (GLB) in serum biochemical indexes of FP3 and FP4 groups were significantly increased, and the content of blood urea nitrogen (BUN) was significantly decreased ($P < 0.05$). Compared with FP0 group, the activities of superoxide dismutase (SOD), catalase (CAT), alkaline phosphatase (AKP), acid phosphatase (ACP) and lysozyme (LZM) in hepatopancreas and serum of FP3 and FP4 groups were significantly increased ($P < 0.05$). Similarly, the activities of glutathione peroxidase (GSH-Px), total antioxidant capacity (T-AOC) and phenoloxidase (PO) in hepatopancreas and serum of FP2 group were significantly higher than those of FP0 group ($P < 0.05$). The content of malondialdehyde (MDA) in hepatopancreas and serum of shrimp in FPPP-added groups was significantly lower than that of FP0 group ($P < 0.05$). In addition, compared with FP0 group, the expression levels of SOD, CAT, GST, LZM, ProPO, Pen3, Crustin, Imd, Toll and Relish genes were significantly up-regulated in the hepatopancreas of shrimp in FP3 and FP4 groups ($P < 0.05$). Furthermore, increasing the addition level of FPPP resulted in a more compact hepatosomal arrangement of the shrimp's hepatopancreas, a more visible star-shaped lumen structure, and a significantly higher number of B cells. The results of *Vibrio alginolyticus* challenge showed that the cumulative survival rate of shrimp in FPPP-added groups was significantly higher than that in FP0 group after 7 days of challenge ($P < 0.05$), and the cumulative survival rate of FP3 group was the highest. [Conclusion]

Adding FPPP to the feed can enhance its antioxidant capacity and immunity, improve its hepatopancreatic health, and increase its resistance to *Vibrio alginolyticus* infection without affecting the growth performance of *Litopenaeus vannamei*.

Key words: *Litopenaeus vannamei*; Fermented pomegranate peel polyphenols; Antioxidation; Immunity; Disease resistance; *Vibrio alginolyticus*

饲料中添加甘露寡糖促进大菱鲆幼鱼皮肤创伤愈合

潘金桃¹, 陈枳初², 余桂娟¹, 孔瑶瑶¹, 艾庆辉^{1,3}, 麦康森^{1,3}, 张彦娇^{1,3*}

(1. 中国海洋大学水产养殖营养与饲料农业部重点实验室, 海水养殖教育部重点实验室, 青岛 266003; 2. 福建农林大学海水养殖育种国家重点实验室, 福建省海洋生物技术重点实验室; 3. 青岛海洋科技中心海洋渔业科学与食品生产工艺实验室, 山东青岛 266237)

摘要: 本试验旨在研究在饲料中添加甘露寡糖 (MOS) 对大菱鲆幼鱼皮肤创面愈合过程的影响。本实验共设计两种饲料, 即对照组 (CON) 及在对照组基础上添加 0.16% MOS (MOS)。每个处理 3 个重复, 每个重复 20 尾鱼。30 天养殖实验结束后, 对缸内所有鱼进行称重、计数, 并随机选取 4 尾鱼用于取样, 剩余的鱼则用活检穿孔器在鱼体表进行创伤处理。创伤后的鱼继续按照之前的投喂方式投喂相对应处理的饲料, 并在创伤后第 1、3、7 天再次取样。图像分析结果显示, MOS 可以显著促进大菱鲆创口面积收缩。基因表达结果显示, MOS 上调了促炎因子 *il-1 β* 和 *tnf- α* 的表达, 下调了抗炎因子 *tgf- β 1* 和 *il-10* 的表达; 上调了与再上皮化相关的基因 (*mmp-9*、*fgf2*、*tgf- β 1*、*rock1*) 以及新组织形成和重塑相关的基因 (*fn1*、*lamb2*、*coll- α* 、*vegf*) 的表达。组织学结果显示, MOS 能够促进再上皮、细胞增殖、胶原沉积以及血管再生。此外, 饲料中添加 MOS 改变了大菱鲆皮肤的微生物群落组成, 降低了 *Rolstonia*, *Pseudomonas*, 和 *Aeromonas* 的丰度, 上调了 *Pseudoalteromonas luteoviolacea* 和 *Shewanella colwellianav* 的丰度。综上所述, 饲料中添加甘露寡糖 (0.16%) 可促进大菱鲆幼鱼皮肤创口再上皮和炎性细胞募集, 促进 ECM 生物合成和血管生成, 改变皮肤微生物群落, 最终促进皮肤创面愈合过程。

关键词: 皮肤创伤恢复; 甘露寡糖; 再上皮; 皮肤菌群; 大菱鲆。

The supplementation of mannan oligosaccharide promotes the skin wound healing of juvenile turbot, *Scophthalmus maximus*

Jintao Pan ¹, Zhichu Chen ², Guijuan Yu ¹, Yaoyao Kong ¹, Qinghui Ai ^{1,3}, Kangsen Mai ^{1,3},
Yanjiao Zhang ^{1,3*}

(1. The Key Laboratory of Aquaculture Nutrition and Feed (Ministry of Agriculture), The Key Laboratory of Mariculture (Ministry of Education), Ocean University of China, Qingdao 266003, China; 2. State Key Laboratory of Mariculture Breeding, Key Laboratory of Marine Biotechnology of Fujian Province, Fujian Agriculture and Forestry University; 3. Laboratory for Marine Fisheries Science and Food Production Processes, Qingdao Marine Science and Technology Center, Qingdao, Shandong 266237, China)

Abstract: A 30-day feeding trial was conducted to investigate the effects of the supplementation of mannan oligosaccharide (MOS) in the diet on the skin wound healing process of juvenile turbot (*Scophthalmus maximus*). Two groups of diets were formulated, the control diet (CON) and the control diet supplemented with 0.16% MOS (MOS), which were fed to the turbot separately. Each group had 3 replicates, with 20 fish per replicate. At the end of the feeding trial, all the fish were weighed and counted. Then four fish per tank were randomly selected for sampling, and the skin of the rest fish was wounded by a biopsy punch. The wounded fish continued to be fed as usual with the same diets respectively, and then sampled again at the 1, 3, and 7 day(s) post wounding (dpw). The results by image analysis showed that the wound closure rate of wounded fish was significantly improved by the supplementation of MOS. As for the results of gene expression, dietary MOS promoted the expression of pro-inflammatory factors (*il-1 β* & *tnf- α*) and decreased the expression of anti-inflammatory factors (*tgf- β 1* & *il-10*). It also enhanced the expression of genes related to re-epithelialization (*mmp-9*, *fgf2*, *tgf- β 1*, *rock1*), as well as new tissue formation and remodeling (*fn1*, *lamb2*, *coll- α* , *vegf*). Furthermore, dietary MOS promoted re-epithelialization, cell proliferation, collagen deposition, and angiogenesis according to the histomorphological observation. In addition, the supplementation of MOS modified the communities of skin microbiota, decreasing the abundance of *Rolstonia*, *Pseudomonas*, and *Aeromonas*, while increasing the abundance of *Pseudoalteromonas luteoviolacea* and *Shewanella colwellianav*. In conclusion, the supplementation of MOS (0.16%) can promote the re-epithelialization and the recruitment of inflammatory cells, stimulate ECM biosynthesis and angiogenesis, modify the communities of skin microbiota, and ultimately promote the skin wound healing process.

Keywords: Skin wound healing; Mannan oligosaccharide; Re-epithelialization; Skin microbiota; Turbot.

通讯作者: 张彦娇, **E-Mail:** yanjiaozhang@ouc.edu.cn

基金项目: 国家自然科学基金 (32273143, 31872577), 国家海水鱼产业技术体系 (CARS-47)

饲料中添加谷氨酸可增强急性碱度胁迫下尼罗罗非鱼的抗氧化能力、氨解毒能力和离子调节能力

王敏旭, 李二超, 黄雨星, 刘伟, 陈立侨, 王晓丹*

(华东师范大学生命科学学院, 上海 200241)

摘要:【目的】盐碱水养殖是提高盐碱水综合利用能力和缓解淡水危机的重要途径。谷氨酸(Glu)作为一种安全的营养素,被认为是鱼类不可或缺的氨基酸之一。已有许多研究表明Glu在鱼类生长、饲料利用和肠道健康方面具有重要作用,但是其在氨代谢、离子调节和抗氧化方面的潜在益处尚未见报道。故本实验研究了饲料中添加L-谷氨酸对急性碳酸盐碱度胁迫下尼罗罗非鱼离子调节、氨解毒和抗氧化能力的影响。【方法】270尾鱼(6.06 ± 0.12 g)分别饲喂Glu添加量为0%、1.5%和3.0%的3种饲料,试验持续45 d。饲喂试验结束后,将罗非鱼分别置于淡水(对照)或53.57 mmol/l碳酸盐碱水中处理24 h。【结果】饲料中添加谷氨酸不仅提高了罗非鱼的增重和肥满度,还促进了氨转化为无毒物质的3个反应。碱度胁迫24 h后,添加15 g/kg Glu的罗非鱼鳃离子转运能力显著高于对照组($p < 0.05$)。此外,15 g/kg Glu添加组罗非鱼的鳃结构完整,而其他组罗非鱼的鳃结构受损。饲料中添加15 g/kg Glu显著提高了尿素和谷氨酰胺合成相关基因的表达。此外,15 g/kg Glu添加组罗非鱼的氨排泄能力和抗氧化能力最高($p < 0.05$)。【结论】饲料中添加谷氨酸除了能促进尼罗罗非鱼的生长外,还能改善尼罗罗非鱼的耐碱性,防止急性碳酸盐碱胁迫引起的氧化损伤、离子毒性和氨中毒。本研究可为谷氨酸在盐碱水养殖中的应用提供科学依据,并进一步促进盐碱水资源的开发利用。

关键词: 谷氨酸; 氨代谢; 碱度胁迫; 离子调节; 尼罗罗非鱼。

资助项目: 国家自然科学基金(No. 32172946), 中国科协第八届青托工程项目(2022QNRC001), 上海市青年科技启明星计划, 中央高校基本科研业务费专项资金
通讯作者: 王晓丹, E-mail: xdwang@bio.ecnu.edu.cn

Dietary supplementation with glutamate enhanced antioxidant capacity, ammonia detoxification and ion regulation ability in Nile tilapia (*Oreochromis niloticus*) exposed to acute alkalinity stress

Minxu Wang, Erchao Li, Yuxing Huang, Wei Liu, Liqiao Chen, Xiaodan Wang*

(School of Life Sciences, East China Normal University, Shanghai 200241, China)

Abstract: [Objective] Saline-alkali aquaculture is an important way to improve the comprehensive utilization capacity of alkaline water and alleviate the fresh water crisis. Glutamate (Glu) , as a safe nutrient, is considered to be one of the essential amino acids in fish. This study investigated the effects of dietary L-glutamate on ion regulation, ammonia detoxification and antioxidant capacity in Nile tilapia (*Oreochromis niloticus*) exposed to acute carbonate alkalinity stress. [Methods] A total of 270 fish (6.06 ± 0.12 g) were fed three different dietary Glu supplements 0%, 1.5%, and 3.0% for 45 days. After the feeding trial, the fish were exposed to fresh water (control) or 53.57 mmol/l carbonate alkaline water for 24 h. [Results] The results showed that dietary Glu not only improved the weight gain and condition factors of tilapia but also promoted three reactions in which ammonia was converted into nontoxic substrates. After 24 h of alkalinity stress, tilapia fed a 15 g/kg Glu-supplement diet had considerably higher ion transport capacity in their gills compared to the control group ($p < 0.05$). Moreover, the gill structure of tilapia in the 15 g/kg Glu-supplement group was intact, while the structures in the other groups were impaired. Dietary Glu supplementation (15 g/kg) significantly increased the expression of genes related to urea and glutamine (Gln) synthesis. Additionally, the ammonia excretion capacity and antioxidant capacity were greatest in tilapia in the 15 g/kg Glu-supplement group ($p < 0.05$). [Conclusion] These results indicated that in addition to promoting the growth of Nile tilapia, dietary Glu supplementation ameliorate the alkalinity tolerance of Nile tilapia and prevent oxidative damage, ionic toxicity and ammonia poisoning caused by acute carbonate alkalinity stress. This study can provide scientific basis for the application of glutamate in saline-alkali water culture, and further promote the development and utilization of saline-alkali water resources.

Key words: Glutamate; Ammonia metabolism; Alkalinity stress; Ion regulation; *Oreochromis niloticus*.

饲料中添加几丁质对中华绒螯蟹幼蟹生长性能，抗氧化能力， 免疫和脂质代谢的影响

王涵¹，何龙¹，王晓丹¹，李二超¹，陈立侨^{1*}

(1. 华东师范大学生命科学学院，上海 200241)

摘要:【目的】本研究旨在探究饲料中添加几丁质对中华绒螯蟹幼蟹生长性能，抗氧化能力，免疫和脂质代谢的影响。【方法】试验配置了 5 种纯化饲料，分别添加 0%，0.4%，0.8%，1.6%和 3.2%几丁质。选取初始体重为 0.50 ± 0.01 g 的幼蟹进行了为期 8 周的养殖试验。【结果】线性回归分析表明，幼蟹的增重率随饲料中的几丁质含量增加而降低($P < 0.05$)，饲料中添加 3.2%几丁质显著降低了幼蟹的增重率和特定生长率($P < 0.05$)；饲料中添加 0.4%几丁质降低了幼蟹肠道 MDA 含量($P < 0.05$)，并提高了肠道抗氧化酶 (SOD,GPX 和 T-AOC) 的活性($P < 0.05$)；几丁质提高了幼蟹肠道免疫相关基因 (*toll*, *myd88*, *relish*, *litaf* 和 *ilf2*) 的表达量($P < 0.05$)；饲料中添加 3.2%几丁质降低了幼蟹的总脂含量以及血清甘油三酯、总胆固醇和高密度脂蛋白含量($P < 0.05$)；饲料中添加 3.2%几丁质降低了幼蟹肝胰腺脂肪合成基因 (*fas* 和 *srebp*) 的表达量($P < 0.05$)，提高了脂肪分解相关基因 (*cpt1* 和 *cpt2*) 的表达量($P < 0.05$)。【结论】综上所述，饲料中添加几丁质会造成幼蟹生长性能下降，促使免疫反应的发生。饲料中添加 0.2%几丁质可以促进肠道抗氧化能力，然而当饲料中几丁质含量达到 3.2% 时，会造成机体脂质代谢紊乱。因此，我们建议饲料中几丁质的含量不应超过 1.6%。
关键词: 几丁质；中华绒螯蟹；生长性能；脂质代谢。

资助项目：国家重点研发计划 (2023YFD2402000)、国家自然科学基金项目(32072986)、财政部和农业农村部国家现代农业产业技术体系、上海市中华绒螯蟹产业技术体系 (202404)

通讯作者：陈立侨，E-Mail: lqchen@bio.ecnu.edu.cn

Effects of dietary Chitin on growth performance, antioxidant capacity, immunity and lipid metabolism of juvenile Chinese Mitten crab, *Eriocheir sinensis*

Han Wang¹, Long He¹, Xiaodan Wang¹, Erchao Li¹, Liqiao Chen^{1*}

(1 School of Life Sciences, East China Normal University, 500 Dongchuan Road, Shanghai, 200241, China)

Abstract: [Objective] The aim of this study was to investigate the effects of dietary chitin on growth performance, antioxidant capacity, immunity and lipid metabolism of juvenile Chinese mitten crab. [Methods] Five purified feeds were added with 0 %, 0.4 %, 0.8 %, 1.6 % and 3.2 % chitin, respectively. An 8-week experiment was conducted on juvenile crab with an initial body weight of 0.50 ± 0.01 g. [Results] Linear regression analysis showed that the weight gain rate of crabs decreased with the increase of dietary chitin content ($P < 0.05$), and the addition of 3.2% chitin significantly decreased the weight gain rate and specific growth rate of juvenile crabs ($P < 0.05$). The contents of intestinal MDA were decreased ($P < 0.05$), and the activities of intestinal antioxidant enzymes (SOD, GPX and T-AOC) were increased ($P < 0.05$) in crabs fed diet with 0.2% chitin. The expression levels of intestinal immune-related genes (*toll*, *myd88*, *relish*, *litaf* and *ilf2*) were increased by chitin ($P < 0.05$). The total lipid content and the contents of TG, TCHO and HDL in serum were decreased by 3.2% chitin supplementation ($P < 0.05$). 3.2% dietary chitin decreased the expression levels of fat synthesis genes (*fas* and *srebp*) in hepatopancreas ($P < 0.05$), and increased the expression levels of lipolysis related genes (*cpt1* and *cpt2*) ($P < 0.05$). [Conclusion] In conclusion, the addition of chitin can reduce the growth performance and promote immune response. 0.2 % dietary chitin can promote intestinal antioxidant capacity. When the content of chitin in the diet reaches 3.2 %, the lipid metabolism will be disturbed. Therefore, we recommend that the content of chitin in feed should not exceed 1.6%.

Key words: Chitin; *Eriocheir sinensis*; Growth performance; Lipid metabolism

饲料中添加烟酸对盐度胁迫下尼罗罗非鱼的生长、渗透调节能力和糖代谢的影响

晏雨茜^{1*}，王敏旭，范晋铨，刘伟，陈立侨¹，李二超¹，王晓丹^{1*}

(1. 华东师范大学生命科学学院，上海 200241)

摘要：【目的】本实验旨在探究饲料中添加烟酸对盐度胁迫下尼罗罗非鱼的生长、渗透调节能力和糖代谢的影响。【方法】设计 5 种不同烟酸添加量的饲料，饲料中烟酸含量实测值为 3.33、12.18、33.98、94.28、275.23 mg/kg，选取初重为 1.8g±0.03 的尼罗罗非鱼开展为期 8 周的养殖实验。【结果】在饲料中添加烟酸可显著提高盐度胁迫下罗非鱼的增重率、特定生长率和肥满度，也能显著提高全鱼粗蛋白和粗脂肪含量。投喂 12.18-94.28 mg/kg 烟酸显著提高鳃的离子转运能力并且影响鳃的渗透压。鳃组织切片结果显示，饲料中添加 12.18-275.33 mg/kg 烟酸可以减轻盐度胁迫对鳃组织结构的破坏。进一步结果表明，罗非鱼摄入的烟酸主要积累在肝脏和鳃中，提高了烟酸代谢通路的活动，继而提高了产物 NADH 的含量和 NAD⁺/NADH 的比例。饲料中添加 94.28 mg/kg 烟酸可以显著上调 Sirt1-Glut1-HK 通路，从而影响糖酵解、TCA 和糖异生活活动使得肝脏中葡萄糖含量降低，丙酮酸和 ATP 含量增多。

【结论】综上，饲料中适量的烟酸可以促进烟酸代谢，帮助机体有效应对盐度造成的氧化损伤，同时通过激活 Sirt1-Glut1-HK 通路调控糖代谢过程，为离子转运提供充足的能量，从而帮助罗非鱼更好地适应盐度变化，提高盐度胁迫下罗非鱼的生长。基于增重率和特定生长率的回归分析，盐度胁迫下尼罗罗非鱼饲料中最适烟酸的添加量为 151.67-171.73 mg/kg。

关键词：烟酸；尼罗罗非鱼；盐度胁迫；糖代谢。

Effects of dietary niacin supplementation on growth, osmotic regulation, and carbohydrate metabolism of Nile tilapia under salinity stress

Yuxi Yan¹, Minxu Wang, Jinqian Fan, Wei Liu, Liqiao Chen¹, Erchao Li¹, Xiaodan Wang^{1*})

(1. School of Life Sciences, East China Normal University, Shanghai 200241, China)

Abstract: [Objective] The aim of this experiment was to investigate the effects of dietary niacin supplementation on the growth, osmoregulatory capacity, and carbohydrate metabolism of Nile tilapia (*Oreochromis niloticus*) under salinity stress. [Methods] In this experiment, five diets with varying niacin concentrations were prepared, with practical niacin levels of 3.33, 12.18, 33.98, 94.28, and 275.23 mg/kg. Nile tilapia with an initial weight of 1.8 ± 0.03 g were selected for an 8-week feeding trial. [Results] The results indicated that the dietary niacin significantly increased the weight gain, specific growth rate, and condition factor of tilapia. Furthermore, niacin supplementation also increased the crude protein and crude fat contents of tilapia. 12.18-94.28 mg/kg dietary niacin significantly improved the ion transport capacity of the gills which is a main part of the osmoregulation. Histological analysis of gill revealed that dietary niacin at concentrations ranging from 12.18 to 275.33 mg/kg relieved structural damage induced by salinity stress in gills. Dietary Niacin mainly accumulated in the liver and gill, activating the niacin metabolism pathway. As a result, fish fed with dietary niacin got high level of NADH, $NAD^+/NADH$ than those in the control group. The addition of 94.28 mg/kg niacin affected the glycolysis, TCA cycle and gluconeogenesis processes through Sirt1-Glut1-HK pathway. In addition, content of liver glucose decreased, while pyruvate and ATP contents increased. [Conclusion] Optimal dietary niacin could improve the growth performance of Nile tilapia under salinity stress by activating the Sirt1-Glut1-HK pathway to regulate carbohydrate metabolism, as well as enhancing ion transport capacity to resist osmosis stress. Based on regression analysis of weight gain rate and specific growth rate, the optimal dietary niacin for Nile tilapia under salinity stress is 151.67-171.73 mg/kg.

Key words: Niacin; Nile tilapia; Salinity stress; Carbohydrate metabolism.

饲料中添加栀子对大口黑鲈生长性能、抗氧化能力、炎症反应和 GLP-1R/AKT/Nrf2 通路的影响⁴²

张志伟^{1,2}, 刘昊昆¹, 韩冬^{1,3}, 金俊琰¹, 杨云霞¹, 朱晓鸣^{1,3}, 解绶启^{1,2,3}

(1. 中国科学院水生生物研究所, 湖北 武汉 430072; 2. 中国科学院大学, 北京 100049; 3. 湖北水产动物营养与饲料工程研究中心, 湖北 武汉 430072)

摘要: 药食两用性物质栀子是茜草科植物栀子 (*Gardenia jasminoides* Ellis) 的干燥果实, 具有抗氧化和抗炎等作用。为研究栀子作为水产饲料添加剂的作用, 本实验设计了含栀子 0、2、4、6 和 8g/kg 的 5 组等氮等脂饲料, 以大口黑鲈 (*Micropterus salmoides*) (35±0.51 g) 为养殖对象, 进行 7 周的养殖实验。结果表明: 饲料中添加 4g/kg 和 6g/kg 栀子提高了大口黑鲈的生长性能 ($P<0.05$)。4g/kg 添加的处理组肝脏中活性氧 (ROS) 和 MDA 水平降低 ($P<0.05$), 表明栀子具有抗氧化作用。进一步发现: 4g/kg 和 6g/kg 的栀子添加提高了肝脏 GLP-1R 的表达 ($P<0.05$), 进一步激活 PI3K/AKT 信号通路, Nrf2 被磷酸化的 AKT 激活并促进下游抗氧化基因 (SOD、HO-1) mRNA 相对表达量升高 ($P<0.05$)。此外, 6g/kg 添加的处理组肠道绒毛长度和宽度增加 ($P<0.05$)。4g/kg 添加的处理组肝脏中促炎因子表达量降低、抗炎因子表达量升高 ($P<0.05$), 表明栀子具有抗炎作用。然而, 饲料中添加 8g/kg 栀子体现出一定的负面作用, 如血浆谷丙转氨酶含量增加 ($P<0.05$) 以及肝细胞肿胀和细胞核塌缩。综上所述: 饲料中添加栀子可以提高大口黑鲈生长性能和抗炎能力, 并通过 GLP-1R/AKT/Nrf2 通路提高抗氧化能力。

关键词: 栀子; 大口黑鲈; 生长性能; 抗氧化能力; 炎症反应; GLP-1R/AKT/Nrf2。

资助项目: 国家重点研发计划 (2023YFD2400600), 国家自然科学基金面上项目 (32473179)
通讯作者: 刘昊昆, E-Mail: liuhaokun@ihb.ac.cn

Effects of dietary *Gardenia jasminoides* Ellis fruit on growth performance, antioxidant capacity, inflammatory response and GLP-1R/AKT/Nrf2 pathway of largemouth bass (*Micropterus salmoides*)

Zhiwei Zhang^{1,2}, Haokun Liu¹, Dong Han¹, Junyan Jin¹, Yunxia Yang¹, Xiaoming Zhu^{1,3},
Shouqi Xie^{1,2,3}

(1. Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China; 2. University of Chinese Academy of Sciences, Beijing 100049, China; 3. Hubei Engineering Research Center for Aquatic Animal Nutrition and Feed, Wuhan 430072, China)

Abstract: Gardenia constitutes a type of medicinal and edible substance. It is the dried fruit of the rubiaceae plant *Gardenia Jasminoides* Ellis and possesses antioxidant and anti-inflammatory effects. In order to study the function of gardenia as an aquatic feed additive, 5 groups of iso-nitrogen and iso-lipid feeds containing 0, 2, 4, 6 and 8g/kg of gardenia were designed in this experiment, and *Micropterus salmoides* (35 ± 0.51 g) were cultured for 7 weeks. The results showed as follows: Adding 4g/kg and 6g/kg gardenia increased the growth performance of largemouth bass ($P < 0.05$). The levels of reactive oxygen species (ROS) and MDA in liver of 4g/kg supplemented group were decreased ($P < 0.05$), indicating that gardenia has antioxidant effect. It was further found that the supplementation of 4g/kg and 6g/kg gardenia increased the expression of liver GLP-1R ($P < 0.05$), further activated the PI3K/AKT signaling pathway, and Nrf2 was activated by phosphorylated AKT and promoted the mRNA relative expression of downstream antioxidant genes (SOD, HO-1) to increase ($P < 0.05$). In addition, the length and width of intestinal villi were increased in the 6g/kg supplemented group ($P < 0.05$). The expression of pro-inflammatory factor decreased and the expression of anti-inflammatory factor increased in the liver of 4g/kg supplemented group ($P < 0.05$), indicating that gardenia has anti-inflammatory effect. However, dietary supplementation of 8g/kg gardenia showed some negative effects, such as increased plasma glutamic-pyruvic transaminase content ($P < 0.05$), hepatocyte swelling and nuclear collapse. Conclusion: Adding gardenia in diet can improve the growth performance and anti-inflammatory ability of largemouth bass, and enhance the antioxidant ability through GLP-1R/AKT/Nrf2 pathway.

Key words: Gardenia jasminoides; largemouth bass; Growth performance; Antioxidant capacity; Inflammatory response; GLP-1R/AKT/Nrf2

高糖营养背景下，L-肉碱对黄鳢生长性能、抗氧化力和脂肪代谢的影响

徐路遥¹，李加敏¹，彭墨^{1,2*}

(江西农业大学，江西 南昌，330045)

摘要：【目的】本文旨在探究 L-肉碱对黄鳢生长性能、抗氧化能力和脂肪代谢的积极作用。

【方法】实验选用初始体重为 $17.09 \pm 0.14\text{g}$ 的黄鳢 960 尾，随机分至 16 个网箱。实验鱼分别投喂对照饲料(15% α 淀粉)、高糖饲料(35% α 淀粉)、高糖饲料分别额外添加 1.2‰和 2.4 ‰L-肉碱的另外 2 种饲料 (HC/LLC 组和 HC/HLC 组)，实验周期为 8 周。【结果】本研究结果表明，高糖增加了黄鳢肝脏的脂肪含量，引起了脂肪沉积，降低了黄鳢肝脏的抗氧化能力。高糖饲料中添加 L-肉碱提升了黄鳢的生长性能，具体表现为终末体重(FBW)、增重率(WGR)、特定生长率(SGR)显著提高 ($P < 0.05$)。抗氧化方面，高糖饲料中添加 L-肉碱提高了黄鳢肝脏 T-AOC、T-SOD 和 CAT 的活性，减少了 MDA 的含量。脂肪沉积方面，高糖饲料中添加 L-肉碱缓解了黄鳢肝脏损伤，减少了肝脏的脂肪含量。线粒体方面，高糖饲料中添加 L-肉碱显著上调与线粒体脂肪酸 β 氧化相关基因 *ppara*、*pgc1a* 和 *cpt1* 的 mRNA 相对表达水平，显著下调黄鳢肝脏与脂质分解代谢相关基因 *fas* 和 *acc* 的 mRNA 相对表达水平。内质网应激方面，高糖饲料中添加 L-肉碱显著下调黄鳢肝脏 *grp78*、*ire1* 和 *atf6* 的 mRNA 相对表达水平。

【结论】综上所述，添加 L-肉碱可提高黄鳢生长性能，缓解高糖饲喂造成的肝脏脂肪异常沉积现象，并促进其肝脏健康。因此，本研究认为，饲料中添加 L-肉碱对黄鳢来讲是一种积极的营养调控策略。

关键词：黄鳢；L-肉碱；高糖；生长性能；抗氧化能力；脂质代谢。

Under the background of high-carbohydrate nutrition, the effects of L-carnitine on the growth performance, antioxidant capacity, and lipid metabolism of rice field eel (*Monopterus albus*)

Luyao Xu¹, Jiamin Li¹, Mo Peng^{1,2*}

(*Jiangxi Agricultural University, Nanchang 330045*)

Abstract: [Objective] This study aims to explore the positive effects of L-carnitine on growth performance, antioxidant capacity, and fat metabolism in rice field eel. [Methods]: A total of 960 rice field eels with an initial body weight of 17.09 ± 0.14 g were randomly assigned to 16 cages. The experimental fish were fed four different diets: a control diet (15% α -starch), a high-carbohydrate diet (35% α -starch), and two high-carbohydrate diets supplemented with 1.2‰ and 2.4‰ L-carnitine (HC/LLC group and HC/HLC group). The experimental period lasted for 8 weeks.[Results]: The results of this study indicated that high-carbohydrate diets increased the lipid content in the liver of rice field eels, causing lipid deposition and reducing the antioxidant capacity of the liver. The addition of L-carnitine to high-carbohydrate diets improved the growth performance of rice field eels, as evidenced by significant increases in final body weight (FBW), weight gain rate (WGR) and specific growth rate (SGR) ($P < 0.05$). In terms of antioxidant capacity, L-carnitine supplementation in high-carbohydrate diets enhanced the activities of T-AOC, T-SOD and CAT in the liver of rice field eels, while reducing the content of MDA. Regarding lipid deposition, L-carnitine supplementation alleviated liver damage and reduced the lipid content in the liver. At the mitochondrial level, L-carnitine supplementation significantly upregulated the mRNA expression levels of genes related to mitochondrial fatty acid β -oxidation (*ppara*, *pgc1a* and *cpt1*) and downregulated the mRNA expression levels of genes related to lipid catabolism (*fas* and *acc*) in the liver of rice field eels. In terms of endoplasmic reticulum stress, L-carnitine supplementation significantly downregulated the mRNA expression levels of *grp78*, *ire1* and *atf6* in the liver of rice field eels fed high-carbohydrate diets.[Conclusion]: In summary, the addition of L-carnitine improved the growth performance of rice field eels, alleviated abnormal lipid deposition in the liver caused by high-carbohydrate feeding, and promoted liver health. Therefore, this study suggests that the inclusion of L-carnitine in diets is a positive nutritional regulation strategy for rice field eels.

Key words: rice field eel; L-carnitine; high-carbohydrate diets; growth performance; antioxidant ability; lipid metabolism

乌苏里拟鲮对 14 种动物性蛋白源表观消化率的研究

陶胜强¹, 杨雨虹^{1*}

(东北农业大学、动物科学技术学院, 黑龙江省 哈尔滨市 150000)

摘要:【目的】本研究探讨了乌苏里拟鲮对白鱼粉、猪血浆蛋白粉、猪血球蛋白粉、宠物级鸡肉粉、饲料级鸡肉粉、马肉骨粉、牛肉骨粉、国产鸡肉粉、美国鸡肉粉、酶解羽毛粉、蛋白肽粉、肠膜粉、全鸡蛋粉和水解鸡肝粉 14 种蛋白源的干物质、粗蛋白、粗脂肪、能量、磷和氨基酸表观消化率的影响。【方法】试验选取初始体重为 5.0 ± 0.50 g 的乌苏里拟鲮, 随机放置于水族箱中, 每个水族箱 30 尾鱼, 每组设三个重复。试验饲料由 70%基础饲料和 30%试验原料组成, 选择三氧化二铬 (Cr_2O_3) 作为外源指示剂。【结果】结果显示乌苏里拟鲮对 14 种动物蛋白源干物质的表观消化率数值范围为 24.12%~87.58%, 依次为动物蛋白肽粉 (87.58%) > 国产鸡肉粉 (81.72%) > 饲料级鸡肉粉 (79.61%) > 美国鸡肉粉 (77.87%) > 全蛋粉 (77.63%) > 水解鸡肝粉 (77.38%) > 血浆蛋白粉 (72.69%) > 白鱼粉 (70.74%) > 酶解羽毛粉 (69.23%) > 血球蛋白粉 (67.54%) > 肠膜蛋白粉 (62.54%) > 牛肉骨粉 (61.80%) > 宠物级鸡肉粉 (59.25%) > 马骨粉 (24.12%)。粗蛋白表观消化率数值范围为 71.14% ~ 97.57%, 其中动物蛋白肽粉 (97.57%) 粗蛋白表观消化率显著高于其他原料 ($P < 0.05$)。各饲料原料的氨基酸表观消化率与粗蛋白表观消化率变化趋势基本一致。乌苏里拟鲮对动物蛋白肽粉和白鱼粉的赖氨酸和蛋氨酸等必需氨基酸及总氨基酸的表观消化率均处在较高水平, 而马骨粉和宠物级鸡肉粉的总氨基酸的表观消化率处于较低水平。粗脂肪的表观消化率数值范围为 59.53%~96.91%, 其中牛肉骨粉 (96.91%) 的粗脂肪表观消化率显著高于其他原料 ($P < 0.05$), 而酶解羽毛粉 (59.53%) 和饲料级鸡肉粉 (62.02%) 处于较低水平。原料总能表观消化率数值范围为 64.31%~98.06%, 乌苏里拟鲮对白鱼粉 (96.99%) 和动物蛋白肽粉 (96.45%) 的总能利用较好, 而对马骨粉 (64.31%) 总能利用较差。各种原料的总磷表观消化率除血浆蛋白粉 (77.73%) 和饲料级鸡肉粉 (73.08%) 外总体较低, 在 24.52%~67.04% 之间。【结论】白鱼粉和动物蛋白肽粉是乌苏里拟鲮饲料中较为理想的蛋白源, 血浆蛋白粉、血球蛋白粉、饲料级鸡肉粉、国产鸡肉粉、美国鸡肉粉、全蛋粉和水解鸡肝粉的干物质、粗蛋白及氨基酸表观消化率较高, 营养组成较为均衡, 是乌苏里拟鲮饲料中替代鱼粉的良好选择。酶解羽毛粉虽然粗蛋白表观消化率较高, 但其必需氨基酸尤其是赖氨酸和蛋氨酸含量低, 或可通过添加晶体氨基酸成为替代鱼粉的备用蛋白源。然而马骨粉、宠物级鸡肉粉、牛肉骨粉和肠膜蛋白粉等因其干物质、粗蛋白和氨基酸的表观消化率较差或灰分含量过高等原因不适宜应用于乌苏里拟鲮饲料。

关键词: 乌苏里拟鲮; 表观消化率; 动物蛋白源。

Apparent Digestibility of Fourteen Animal Protein Ingredients for *Pseudobagrus ussuriensis*

Shengqiang Tao¹, Yuhong Yang^{1*}

(1. College of Animal Science and Technology, Northeast Agricultural University, Harbin 150030)

Abstract: [Objective] In this study, we investigated apparent digestibility of dry matter, crude protein, crude lipid, gross energy, phosphorus and amino acids on white fish meal(WFM), blood plasma meal(BPM), blood cell meal(BCM), pet-food grade poultry by-product meal(PPBM), feed-grade poultry by-product meal(FPBM), China poultry by-product meal(CPBM), American poultry by-product meal(APBM), horse bone meal(HBM), beef meat and bone meal(BMBM), enzymatic feather meal(EFM), hydrolyzed chicken liver meal(HCLM), dried porcine solubles(DPS), whole egg meal(WEM) and protein peptide meal(PPM). [Methods] The test was conducted by selecting *Ussuriopsis* with an initial body weight of 5.0 ± 0.50 g. The fish were randomly placed in aquariums with 50 fish per aquarium and three replicates in each group. The test diets of the experiment consisted of 70% control diet and 30% test ingredients, with 0.5% chromic oxide (Cr_2O_3) used as the inert marker. [Results] The results were as follows: the dry matter apparent digestibility of 14 animal protein ingredients for *Pseudobagrus ussuriensis* ranged from 24.12% to 87.58%, in the order of PPM (87.58%) > CPBM (81.72%) > FPBM (79.61%) > APBM (77.87%) > WEM (77.63%) > HCLM (77.38%) > BPM (72.69%) > WFM (70.74%) > EFM (69.23%) > BCM (67.54%) > DPS (62.54%) > BMBM (61.80%) > PPBM (59.25%) > HBM (24.12%). The protein apparent digestibility values ranged from 71.14% to 97.57%, where PPM (97.57%) was significantly higher than other test ingredients ($P < 0.05$). Simultaneously, amino acid (AA) availability values generally demonstrated similar patterns as the ADC values for crude protein in the test ingredients. The essential amino acid (EAA) availability such as lysine and methionine and total amino acids availability of PPM and WFM are at a high level for *Pseudobagrus ussuriensis*, while HBM and PPBM are at a low level. The lipid apparent digestibility values ranged from 59.53% to 96.91%, where BMBM was significantly higher than other test ingredients ($P < 0.05$), while EFM and FPBM were at a low level. The gross energy apparent digestibility values ranged from 64.31% to 98.06%, the gross energy apparent digestibility of WFM and PPM was good, but HBM was poor. The apparent digestibility of phosphorus of test ingredients was lower in the range from 24.52% to 67.04% except BPM (77.73%) and FPBM (73.08%). [Conclusion] WFM and PPM were the most desirable protein feedstuffs for *Pseudobagrus ussuriensis*, while BPM, BCM, FPBM, CPBM, APBM, WEM, and HCLM may be good sources of available protein and amino acids, and promising substitutes for fishmeal in diets for *Pseudobagrus ussuriensis*. EFM may be good protein source with crystal amino acid supplementation. However, HBM, PPBM, BMBM and DPS may not be good alternative protein sources due to either their poor digestibility of dry matter, crude protein and availability of AAs or their large amounts of ash.

Keywords: *Pseudobagrus ussuriensis*; apparent digestibility; animal protein ingredient

岩藻多糖激活 Sirt1 调控 Perk-Eif2 α -Atf4 轴缓解高脂诱导的海水鱼肝脂质沉积

金敏^{1,2,3*}, 赵文丽^{1,2,3}, 鲍阳光^{1,2,3}, 竺嘉运^{1,2,3}, 成皓^{1,2,3}, 植心妍^{1,2,3}, 朱婷婷^{1,2,3}, 孙蓬^{1,2,3}, 周歧存^{1,2,3*}

(1. 宁波大学, 海洋学院, 鱼类与甲壳动物营养研究室, 浙江 宁波 315211; 2. 水产生物技术教育部重点实验室浙江 宁波 315211; 3. 农业农村部绿色海水养殖重点实验室(省部共建)浙江 宁波 315211)

摘要:【目的】随着高脂饲料的普及, 脂肪沉积和脂肪肝变性已成为最为常见的代谢性疾病。岩藻多糖是一种具有降脂活性的天然硫化多糖。为探讨岩藻多糖缓解高脂饲料诱导的和海水鱼肝脏脂肪沉积的分子调控机制, 本实验以黑鲷为研究对象, 构建了体内和体外脂肪肝模型。

【方法】在体内实验中, 配制了 4 种不同的等氮饲料, 分别为对照组(脂肪水平: 12.37%, Control)、高脂组(脂肪水平: 18.62%, HFD)、高脂组分别添加 0.50%和 1.00%岩藻多糖(HFD + F1 和 HFD + F2)组, 进行为期 8 周的黑鲷幼鱼养殖实验。在体外实验 1 中, 分别用 OA (200 μ M)、OA 加岩藻多糖(FUC, 100 μ g)孵育黑鲷肝细胞; 在体外实验 2 中, 设置 3 个处理组孵育黑鲷肝细胞, 分别为 Control 组、OA (200 μ M)、OA 加 Perk 抑制剂组 GSK2606414 (GSK); 在体外实验 3 中, 设置 4 个处理组, 分别为: OA 组、OA+FUC 组、OA+FUC 并转染 NC siRNA 组和 OA+FUC 并转染 sirt1 siRNA (sisirt1) 组。采用生化指标、基因表达(qPCR)、组织学、透射电镜、免疫荧光、Western blot、免疫共沉淀等方法评价肝脏脂质沉积、脂质代谢、Sirt1 和 Perk-Eif2 α -Atf4 通路, 并确定 Sirt1 与 Perk 之间的蛋白相互作用。

【结果】在体内实验中, 岩藻多糖可显著减轻高脂诱导的血清和肝脏脂肪沉积。此外, HFD 显著激活了 Perk-Atf4-Eif2 α 通路, 抑制了 Ppar α 的核易位和脂肪分解基因的表达, 并促进了 Ppar γ 的核易位和脂肪合成基因的表达。而岩藻多糖的添加显著激活了 Sirt1 表达, 并逆转了这些变化, 从而显著缓解了 HFD 诱导的肝脏脂肪积累。体外 FUC 肝细胞实验的结果与体内结果一致。利用 GSK2606414 (GSK) 特异性抑制肝细胞中 Perk 通路, 与 OA 组相比, 显著促进了 Ppar α 核易位, 抑制了 Ppar γ 核易位; 而在细胞转染实验中, 与 OA 组相比, 岩藻多糖显著抑制了 Perk-ATF4-eIF2 α 通路, 并通过调控 Ppar α /Ppar γ 的核易位缓解肝细胞脂肪沉积, 而 Sirt1 敲低后, 岩藻多糖的这些调控作用消失。【结论】综上所述, 岩藻糖聚糖通过激活 Sirt1, 抑制 Perk-Eif2 α -Atf4 轴, 调控 Ppar α (促进) 和 Ppar γ (抑制) 核易位缓解高脂诱导的黑鲷肝脏脂肪沉积。本研究结果为提高饲料脂质利用率提供了新的思路, 为绿色多糖添加剂在水产饲料中的应用提供了理论支持。

关键词: 岩藻多糖; Sirt1; Perk-Eif2 α -Atf4 轴; 核易位; 脂肪沉积。

Fucoidan Reduces Hepatic Lipid Accumulation in black seabream by Activating Sirt1 to Modulate the Perk-Eif2 α -Atf4

Pathway

Min Jin^{1,2,3*}, Wenli Zhao^{1,2,3}, Yangguang Bao^{1,2,3}, Jiayun Zhu^{1,2,3}, Hao Chen^{1,2,3}, Xinyan Zhi^{1,2,3}, Tingting Zhu^{1,2,3}, Peng Sun^{1,2,3}, Qicun Zhou^{1,2,3*}

(1. Laboratory of Fish and Shellfish Nutrition, Ningbo University, Ningbo 315211, PR China; 2. Key Laboratory of Aquacultural Biotechnology Ministry of Education, Ningbo University, Ningbo 315211, PR China; 3. Key Laboratory of Green Mariculture (Co-construction by Ministry and Province), Ministry of Agriculture and Rural, Ningbo 315211, PR China)

Abstract: [Objective] The increasing prevalence of high-fat diets (HFD) has led to widespread fatty deposition and degeneration in fish liver, a common metabolic disease. Fucoidan, a natural sulfated polysaccharide with lipid-lowering properties, was investigated for its molecular mechanisms in alleviating HFD-induced lipid deposition in the liver of marine fish. *In vivo* and *in vitro* fatty liver models of black seabream were established for this study. [Methods] In the *in vivo* experiments, four iso-nitrogen experimental diets were formulated: a control diet, a regular fat diet (12.37% lipid), and two HFDs (18.62% lipid) supplemented with 0.50% and 1.00% fucoidan (designated as HFD + F1 and HFD + F2, respectively). Black seabream were fed these diets for 8 weeks. For the *in vitro* studies, black seabream hepatocytes were treated with oleic acid (OA, 200 μ M) alone and in combination with fucoidan (FUC, 100 μ g). Additional *in vitro* experiments involved treating hepatocytes with OA and a Perk inhibitor (GSK2606414) and examining the effects of transfecting hepatocytes with siRNA targeting Sirt1. Various methodologies, including biochemical assays, qPCR, histology, transmission electron microscopy (TEM), immunofluorescence, Western blotting, and immunoprecipitation, were employed to assess liver lipid deposition, lipid metabolism, and the Sirt1 and Perk-Eif2 α -Atf4 pathways, as well as to analyze protein interactions between Sirt1 and Perk. [Results] Fucoidan significantly reduced HFD-induced lipid accumulation in both serum and liver. The HFD activated the Perk-Atf4-Eif2 α pathway, leading to decreased nuclear translocation of Ppara and increased expression of lipid synthesis genes related to Ppar γ . These effects were reversed with fucoidan-mediated activation of Sirt1. The results of FUC hepatocyte *in vitro* experiments are consistent with those of *in vivo* experiments. The Perk pathway inhibition via GSK2606414 (GSK) enhanced Ppara nuclear translocation while suppressing Ppar γ . Furthermore, fucoidan markedly inhibited the Perk-Atf4-Eif2 α pathway and reduced hepatocyte lipid deposition through the modulation of Ppara and Ppar γ nuclear translocation. Notably, the regulatory effects of fucoidan were abolished following Sirt1 knockout. [Conclusion] In summary, fucoidan alleviates Perk-Eif2 α -Atf4 axis-mediated lipid deposition in the liver of black seabream by activating Sirt1. These findings offer valuable insights into lipid utilization in aquaculture feed and support the application of green polysaccharide additives in aquatic feed.

Key words: Fucoidan; Lipid deposition; Nuclear translocation; Perk-Eif2 α -Atf4 axis; Sirt1

叶酸对草鱼生长性能、肝脏脂质代谢和能量代谢的影响⁴³

王莹¹, 吴培^{1,2,3}, 姜维丹^{1,2,3}, 刘杨^{1,2,3}, 任红梅^{1,2,3}, 金小琬^{1,2,3}, 冯琳^{1,2,3}, 周小秋^{1,2,3*}

(1. 四川农业大学动物营养研究所, 成都, 611130; 2. 鱼类营养与安全生产重点实验室, 成都, 611130; 3. 动物抗病营养农业部、教育部、四川省重点实验室, 成都, 611130)

摘要: 本试验旨在研究饲料中添加不同水平叶酸对草鱼生长性能、肝脏脂质代谢和能量代谢的影响。选取 450 尾体重相近的草鱼 (687.0 ± 1.15) 随机分为 6 组, 每组 3 个重复, 每个重复 30 尾鱼, 对照组饲喂基础饲料 (0.57 mg/Kg), 试验组分别饲喂添加 1.11、1.53、2.08、2.64、3.23 mg/kg 叶酸的试验饲料, 试验期为 8 周。结果表明: 1) 饲料添加 1.11 mg/Kg 的叶酸显著提高了草鱼的终末体重 (FBW)、增重百分比 (PWG)、特异性生长率 (SGR) 和饲料效率 (FE) ($P < 0.05$); 2) 添加 1.11 mg/Kg 叶酸显著降低了草鱼肝脏中脂滴数量、甘油三酯和总胆固醇的含量 ($P < 0.05$); 3) 添加 1.11 mg/Kg 叶酸显著增加了草鱼肝脏中 *LC3*、*LAMP1*、*ATG5*、*ATG12*、*Bclin1* 和 *ULK1* 的基因表达水平, 显著降低了 *P62* 的基因表达, 也显著增加了 *PLIN2* 和 *LC3B* 的荧光强度 ($P < 0.05$); 4) 添加 1.11 mg/Kg 叶酸显著增加了草鱼肝脏中丙酮酸、磷酸烯醇丙酮酸羧激酶、磷酸果糖激酶、糖原磷酸化酶和葡萄糖激酶的含量和基因表达水平 ($P < 0.05$)。综上所述, 饲料添加 1.11 mg/Kg 叶酸可显著提高草鱼生长性能, 并促进其肝脏中自噬和能量代谢, 进而降低肝脏中脂质积累。

关键词: 叶酸; 草鱼; 生长性能; 自噬; 能量代谢

基金项目: 国家现代农业产业技术体系 (CARS-45)、国家重点研发计划“蓝色粮仓科技创新”重点专项 (2019YFD0900200)

通讯作者: 周小秋, 教授, 博士生导师; E-Mail: zhouxq@sicau.edu.cn;

乙醇梭菌蛋白替代鱼粉对青鱼幼鱼生长、血清生化、肌肉质构及品质的影响

付怡帆¹, 魏娇¹, 张金晶¹, 于珈兴¹, 张元元¹, 邵仙萍¹, 杨霞¹, 刘艳¹, 叶金云¹, 吴成龙^{1*}

1.水生动物繁育与营养国家地方联合工程实验室, 湖州师范学院生命科学学院, 浙江 湖州 313000

摘要: 本试验旨在研究饲料中乙醇梭菌蛋白 (*Clostridium autoethanogenum* protein) 替代鱼粉对青鱼 (*Mylopharyngodon piceus*) 幼鱼生长性能、血清生理生化、肌肉质构及品质的影响。选取初始体重为 5.34 ± 0.02 g 的青鱼幼鱼随机分配为 6 个实验组, 每组 3 个重复, 每个重复 25 尾。分别配制 CAP 替代鱼粉量为 0%、20%、40%、60%、80%、100% 的 6 种等氮等能的试验饲料 (分别命名为 CAP0 (对照)、CAP20、CAP40、CAP60、CAP80、CAP100), 养殖周期为 60d。结果表明: CAP 替代鱼粉对鱼的 WG、SGR 无显著性影响 ($P > 0.05$)。血清 HDL、LDL、TC、ALB 随 CAP 替代鱼粉水平的增加呈下降趋势 ($P < 0.05$), 血清 TG 在 CAP40 组显著升高 ($P < 0.05$), 血清 ALT、AST 在 CAP40 组显著降低 ($P < 0.05$), CAP40 和 CAP60 组间无显著差异 ($P > 0.05$)。与对照组相比, 血清 IGF-1 呈先升高后降低的趋势, 在 CAP40 达到最大值 ($P < 0.05$)。与对照组相比, 硬度、韧性、坚实度、弹性随着 CAP 替代鱼粉水平的增加呈现出先升高后降低的趋势, 在替代鱼粉水平为 40% 达到最大值 ($P < 0.05$); 咀嚼性在 CAP 替代鱼粉水平低于 60% 无显著性差异 ($P > 0.05$)。与对照组相比, 试验鱼的胶原蛋白含量在 CAP40 组达到最大值 ($P < 0.05$); LOX、PHD、PYD 含量随着饲料中 CAP 替代鱼粉水平的增加呈现升高后稳定的趋势 ($P < 0.05$)。随着饲料中 CAP 替代鱼粉的比例增加, 肠道绒毛高度、隐窝深度和肌层厚度都呈现出先升高后降低的趋势, 在 CAP40 组达到最大值 ($P < 0.05$)。综上, 饲料中添加 40% 水平 CAP 替代鱼粉能改善青鱼生长性能、肌肉品质。以 WG 评价指标, CAP 替代鱼粉水平为 51.20% 时青鱼幼鱼增重率最高。

关键词: 青鱼; 乙醇梭菌蛋白; 生长; 血清生理生化; 肌肉质构; 肌肉品质。

资助项目: 国家现代农业产业技术体系——青鱼营养与饲料岗位科学家任务(CARS-45-10)

通讯作者: 吴成龙, E-Mail: 01998@zjhu.edu.cn

Effects of fishmeal replacement by *Clostridium autoethanogenum* protein on growth performance, serum biochemistry, Muscle Texture and quality of black carp (*Mylopharyngodon piceus*)

Yifan Fu¹, Jiao Wei¹, Jinjing Zhang¹, Jiaying Yu¹, Yuan yuan Zhang¹, Xianping Shao¹, Xia Yang¹, Yan Liu¹, Jinyun Ye¹, Chenglong Wu^{1*}

¹ National-Local Joint Engineering Laboratory of Aquatic Animal Genetic Breeding and Nutrition (Zhejiang), School of Life Science, Huzhou University, Huzhou 313000

Abstract: This study aimed to investigate the effects of dietary replacement of fishmeal by *Clostridium autoethanogenum* protein (CAP) on growth performance, serum biochemistry, muscle tezture, and muscle quality of black carp (*Mylopharyngodon piceus*). 600 juvenile black carp (initial body weight: 5.34±0.02g) were selected and randomly assigned into six experimental groups with three replicates of 25 fish each. Six isonitrogenous and isoenergetic experimental diets were formulated with different CAP levels (0%, 20%, 40%, 60%, 80%, and 100%), which were named CAP0 (control), CAP20, CAP40, CAP60, CAP80, and CAP100, respectively. After the culture period of 60 days, the results showed that the effects of CAP replacement fishmeal on the fish's WG and SGR were insignificant ($P > 0.05$). Serum HDL, LDL, TC, and ALB showed a decreasing trend with substituting increases of CAP for fishmeal compared with the control group ($P < 0.05$). Serum TG was significantly higher in the CAP40 group ($P < 0.05$), serum ALT and AST were significantly lower in the CAP40 group ($P < 0.05$), and there was no significant difference between the CAP40 and CAP60 groups ($P > 0.05$). Serum hormone IGF-1 showed a tendency to increase and then decrease, and it reached the maximum value at CAP40 ($P < 0.05$). Compared with the control group, hardness, toughness, firmness, and springiness showed a tendency to increase and then decrease with the increase of CAP substituted fishmeal level and reached the maximum value at the substituted fishmeal level of 40% ($P < 0.05$); and chewiness did not show any significant difference at CAP substituted fishmeal levels lower than 60% ($P > 0.05$). The collagen content of the test fish reached its maximum value in the CAP40 group compared to the control group ($P < 0.05$); LOX, PHD, and PYD content increased with increasing levels of CAP replacement fishmeal in the feed ($P < 0.05$). The height of intestinal villi height, crypt depth, and muscular thickness tended to increase and decrease with the proportion of CAP replacement fishmeal in the feed and reached the maximum value in the CAP40 group ($P < 0.05$). In conclusion, the addition of 40% level CAP in feed to replace fishmeal can improve the growth performance and muscle quality of black carp. Based on WG as evaluation indicators, the highest weight gain rate of juvenile black crap was observed at the level of CAP replacement fishmeal of 51.20%.

Key words: *Mylopharyngodon piceus*; *Clostridium autoethanogenum* protein; serum biochemistry; muscle texture; muscle quality

在高糖饲料中添加植物甾醇对大口黑鲈 (*Micropterus salmoides*) 生长、抗氧化能力、组织形态和肠道微生物的影响

石海松^{1#}, 潘忠超^{23#}, 陈雨菲¹, 欧阳徘徊², 孙凤刚², 屈康渊¹, 刘玉成¹, 谭北平¹, 谢诗玮^{1*}

(1. 广东海洋大学水产学院水产动物营养与饲料实验室, 广东 湛江 524088; 2. 广东蔚莱生物科技有限公司, 中国 广州 510000; 3. 中国海洋大学水产学院, 山东 青岛 266003)

摘要:【目的】本研究旨在评估高糖饲料中添加植物甾醇(PS)对大口黑鲈(*Micropterus salmoides*)的生长、抗氧化能力、肌肉和肠道形态以及肠道微生物的影响。【方法】对照组(Control)和高糖饲料组(HC)分别使用淀粉含量为8%和13%的等氮饲料。其他四种饲料在HC的基础上分别添加 0.025%、0.05%、0.075% 和 0.1% 的 PS (HCP1-HCP4)。【结果】随着高糖饲料中PS添加量的增加,大口黑鲈的终末体重和增重率显著增加。此外,PS还能明显提高肠道中超氧化物歧化酶(SOD)和过氧化氢酶(CAT)的活性,降低丙二醛(MDA)浓度、淀粉酶(AMS)和脂肪酶(LPS)的活性($P < 0.05$)。补充PS可改善高糖对肠道皱襞宽度和微绒毛长度的负面影响($P < 0.05$);提高肠道中Bcl-2相关细胞死亡抑制剂(BAD)蛋白的表达($P < 0.05$);提高肌肉中肌细胞增强因子2D (*mef2d*) 基因的相对表达量 ($P < 0.05$) 以及肠道中细胞凋亡调节因子 (*bcl-2*)、紧密连接蛋白-1(*claudin-1*)和紧密连接蛋白-4(*claudin-4*)基因的相对表达量($P < 0.05$);降低肠道BCL-2蛋白和半胱氨酸蛋白酶-3(CASPASE3)蛋白的荧光强度($P < 0.05$);降低肌肉中肌环指蛋白-1(*myf1*)、肌肉萎缩F-box蛋白-1(*atrogin1*)和肌促蛋白(*mstn*)基因的相对表达量($P < 0.05$)。组织形态结果显示,PS能显著增加大口黑鲈单位面积的肌肉纤维数量和肠道褶皱宽度($P < 0.05$)。肠道菌群分析表明,与C组相比,HC组的肠道菌群 α -多样性明显增加,而补充PS则明显降低了 α -多样性($P < 0.05$)。在门水平上,高糖饲料显著提高了放线菌门和拟杆菌门的相对丰度,降低了梭杆菌门的相对丰度。在高糖饲料中添加0.05%的PS后,厚壁菌门的相对丰度增加,而变形菌门的相对丰度减少。在属的水平上,高糖饲料降低了邻单胞菌属的相对丰度,而添加0.05%PS后,黏菌的相对丰度显著增加。【结论】在高糖饲料中添加0.05%的PS可提高大口黑鲈的增重率、改善肌肉品质、增强抗氧化能力、改善肠道完整性并增加有益肠道菌群的丰度。

关键词: 植物甾醇; 碳水化合物; 抗氧化能力; 组织形态; 微生物群落。

Effect of phytosterols added to high carbohydrate diets on growth, antioxidant capacity, tissue morphology and gut microbiota of largemouth bass (*Micropterus salmoides*)

Haisong Shi^{1#}, Zhongchao Pan^{23#}, Yufei Chen¹, Paihuai Ouyang², Fenggang Sun², Kangyuan Qu¹, Yucheng Liu¹, Beiping Tan¹, Shiwei Xie^{1*}

(1. Laboratory of Aquatic Animal Nutrition and Feed, School of Fisheries, Guangdong Ocean University, Zhanjiang China 524088; 2. Guangdong Wei Lai Biotechnology Co., Ltd, Guangzhou China 510000; 3. School of Fisheries, Ocean University of China, Qingdao China 266003)

Abstract: [Objective] This study was to evaluate the effects of phytosterols (PS) added to high carbohydrate diets on growth, antioxidant capacity, muscle and intestinal morphology, and intestinal microbiota of largemouth bass (*Micropterus salmoides*). [Methods] Histomorphological observations, chemical analysis, intestinal flora analysis and real-time fluorescence quantitative PCR (qRT-PCR) were used in this experiment, respectively. [Results] A total of 960 largemouth bass (11.14 ± 0.48 g) were selected and randomly divided into six groups and were fed for 56 d. Isonitrogenous diets with 8% and 13% carbohydrate content were used in the control (Control) and high-carbohydrate (HC) groups, respectively. The other four diets were supplemented with 0.025%, 0.05%, 0.075% and 0.1% PS (HCP1-HCP4) based on the HC diet. The results showed that final body weight and weight gain rate (WGR) of largemouth bass increased significantly with increasing PS additions to high carbohydrate diets. In addition, PS significantly increased the activities of superoxide dismutase (SOD) and catalase (CAT), and reduced the malondialdehyde (MDA) concentration, amylase (AMS), and lipase (LPS) activities in the intestine ($P < 0.05$). The PS supplementation ameliorated the negative effects of high carbohydrate on intestinal fold width and microvillus length ($P < 0.05$). Increased the fluorescence intensity of Bcl-2 associated agonist of cell death (BAD) protein in the intestine ($P < 0.05$). Increased the relative expression of myocyte enhancer factor 2D (*mef2d*) gene in muscle ($P < 0.05$); Increased the relative expression of apoptosis regulator (*bcl-2*), *claudin-1* and *claudin-4* genes in intestine ($P < 0.05$); Decreased the fluorescence intensity of BCL-2 protein and cysteine protease 3 (CASPASE3) protein in the intestine ($P < 0.05$); and decreased the relative expression of *murfl* myocyclic finger protein-1 (*murfl*), *mafbox* (*atrogen1*), and myostatin (*mstn*) genes in muscle ($P < 0.05$). Histomorphometric results showed that PS significantly increased the number of muscle fiber per unit area and the width of intestinal folds in largemouth bass ($P < 0.05$). The analysis of intestinal flora showed a significant increase in the α -diversity of intestinal flora in the HC group compared to the C group, whereas PS supplementation significantly reduced the α -diversity of flora in the high carbohydrate groups ($P < 0.05$). At the phylum level, high carbohydrate diets significantly increased the relative abundance of Actinobacteriota and Bacteroidota and decreased the relative abundance of Fusobacteriota. With

the addition of 0.05% PS to the high carbohydrate diet, the relative abundance of Firmicutes increased and the relative abundance of Proteobacteria decreased. At the genus level, high carbohydrate diet reduced the relative abundance of *Plesiomonas*, whereas the relative abundance of *Mesomycetes* increased significantly when 0.05% PS was added. [Conclusion] In summary, our study demonstrated that dietary supplementation of 0.05% PS to high carbohydrate diet increased WGR, improved muscle quality, ameliorated decreased antioxidant capacity, improved gut integrity, and increased the number of beneficial intestinal flora in largemouth bass.

Keywords: phytosterols; dietary carbohydrate; growth promotion; antioxidant capacity; tissue morphology; microbial community analysis

通讯作者: 谢诗玮, 教授, **E-Mail:** xswzsdx@163.com

基金项目: 国家自然科学基金 (32002402).

外源琥珀酸通过促进肝肠健康提高大口黑鲈对高淀粉饲料的利用

张健敏^{1#}, 曹曼霞^{2,3#}, 王旋³, 刘洋洋¹, 黄峰², 田娟^{1*}

(1. 中国水产科学研究院长江水产研究所, 农业部淡水生物多样性保护重点实验室, 湖北 武汉 430223; 2. 武汉轻工大学, 动物营养与饲料科学湖北省重点实验室, 湖北 武汉 430223; 3. 中国海洋大学海水养殖重点实验室(教育部)、水产动物营养与饲料重点实验室(农业农村部), 山东 青岛 266003)

摘要: 为研究高淀粉饲料中琥珀酸对大口黑鲈 (*Micropterus salmoides*) 生长性能和肝脏及肠道健康的影响, 本研究分别配制 6 组等脂等能饲料, 分别为标准饲料 (含 10%玉米淀粉和 40%鱼粉)、高淀粉饲料 (含 15%玉米淀粉和 36%鱼粉) 以及在高淀粉饲料中分别添加 0.5% (S0.5)、1.0% (S1.0)、1.5% (S1.5) 和 2.0% (S2.0) 的 4 组琥珀酸饲料, 饲喂初始体质量 11.96 ± 0.07 g 大口黑鲈 10 周。本研究揭示了高淀粉饲料的不良影响, 主要包括饲料利用和生长障碍、抗氧化力和免疫力下降以及代谢和肠道菌群紊乱。高淀粉饲料中添加 0.5% 的琥珀酸显著改善了肠道形态, 上调了紧密连接蛋白 (*ZO1* 和 *Claudin4*) 和抗凋亡基因 (*Bcl2*) 的表达, 增加了有益菌群的丰度, 并降低了内质网应激相关基因 (*GRP78*、*PERK*、*IRE1*、*ATF6*、*eIF2 α* 和 *Chop*) 的表达。此外, 外源性琥珀酸上调了肝脏抗炎因子 (*Nrf2*、*TGF β 1* 和 *IL10*)、糖酵解基因 (*PK*、*PFKL2* 和 *GK*)、 β -氧化基因 (*CPT1*)、抗凋亡基因 (*Bag*) 和葡萄糖转运蛋白基因 (*Glut2*) 的表达水平, 显著下调了促炎因子 (*TNF α*)、糖异生关键基因 (*PEPCK* 和 *G6Pase*)、脂肪合成基因 (*ACCI* 和 *FASN*) 和促凋亡基因 (*Bad*) 的表达水平。以生长和饲料利用相关指标为标准, 本实验确定了高淀粉饲料中琥珀酸的适宜添加水平为 0.46%~0.50%。综上所述, 外源性琥珀酸修复了肠道屏障, 调节了肠道菌群, 并减轻了高淀粉饲料引起的肠道和肝脏氧化应激。适宜琥珀酸添加通过影响肠肝健康, 维持糖脂代谢稳态, 提高对饲料淀粉利用, 从而促进大口黑鲈的生长。

关键词: 琥珀酸; 高淀粉饲料; 糖脂代谢; 肝肠健康。

Exogenous succinic acid improved the utilization of high-starch diet in largemouth bass (*Micropterus salmoides*) via enhancing enterohepatic health

Jianmin Zhang^{1#}, Manxia Cao^{2,3#}, Xuan Wang³, Yangyang Liu¹, Feng Huang², Juan Tian^{1*}

(1. Key Laboratory of Freshwater Biodiversity Conservation, Ministry of Agriculture, Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Wuhan 430223, China; 2. Key Laboratory for Animal Nutrition and Feed Science of Hubei Province, Wuhan Polytechnic University, Wuhan 430023, China; 3. Key Laboratory of Mariculture, Ministry of Education, Ocean University of China, Qingdao, 266003, China)

Abstract: A 10-week feeding trial was executed to illustrate the effects of succinic acid (SUA) in high-starch diet (HSD) on growth performance and enterohepatic health of largemouth bass (*Micropterus salmoides*) (11.96 ± 0.7 g). Six diets with equal lipid content and energy level were formulated and presented as the standard diet containing 10% corn starch and 40% fish meal, the HSD containing 15% corn starch and 36% fish meal, and HSDs respectively supplemented with 0.5% (S0.5), 1.0% (S1.0), 1.5% (S1.5) and 2.0% (S2.0) SUA. The study revealed the adverse impacts of HSDs compared to standard diet including the feed utilization and growth hinderance, antioxidant capacity and immunity decline, and the metabolism and gut microbiota disturbance. Significant linear and quadratic trends were observed on feed conversion rate, hepatosomatic index, viscerosomatic index, glycogen content, activities of amylase and protease and liver antioxidant indicators with the increase of SUA supplementation. The addition of 0.5% SUA significantly improved intestinal morphology, tight junction proteins (*ZO1* and *Claudin4*) and anti-apoptotic gene (*Bcl2*) expressions, and abundance of beneficial bacteria. Key genes related to endoplasmic reticulum stress, including *GRP78*, *PERK*, *IRE1*, *ATF6*, *eIF2a* and *Chopa*, were also down-regulated. Besides, exogenous SUA up-regulated the expressions of liver anti-inflammatory factors (*Nrf2*, *TGFβ1* and *IL10*), glycolytic genes (*PK*, *PFKL2* and *GK*), β-oxidation gene (*CPT1*), anti-apoptotic gene (*Bag*) and glucose transporter (*Glut2*). The mRNA expression levels of pro-inflammatory factors (*TNFα*), gluconeogenesis key genes (*PEPCK* and *G6Pase*), fat synthesis genes (*ACCI* and *FASN*) and pro-apoptotic gene (*Bad*) were down-regulated. The optimal supplemental level of SUA was considered to be 0.46%-0.50% in the present study according to the comprehensive evaluation on growth and feed utilization. Overall, SUA repaired intestinal barriers, regulated gut microbiota, and alleviated oxidative stress in intestine and liver induced by HSDs. By influencing the enterohepatic health and maintaining glucose-lipid metabolism homeostasis, appropriate SUA enhanced the utilization of starch and promoted the growth.

Key words: Succinic acid, high-starch diet, glucolipid metabolism, enterohepatic health

转录组与微生物组分析：探究黄粉虫作为凡纳滨对虾饲料主要蛋白源的影响

郑煜东¹, 侯翠红¹, 陈俭¹, 王红明¹, 袁航¹, Asare Derrick¹, 史黎黎^{1,4}, 章双^{1,2,3*}

(1. 广东海洋大学, 水产学院, 水产动物营养与饲料实验室, 广东 湛江 524088; 2. 农业部华南水产与畜禽饲料重点实验室, 广东 湛江 524088; 3. 广东省水产动物精准营养与高效饲料工程技术研究中心, 广东 湛江 524088; 4. 广东海洋大学深圳研究院, 广东 深圳 518100)

摘要:【目的】本研究旨在探究不同蛋白质水平下, 以黄粉虫粉 (*Tenebrio molitor* meal) 替代鱼粉 (Fishmeal) 作为饲料中主要蛋白质来源对凡纳滨对虾 (*Litopenaeus vannamei*) 生长、酶活性、抗病力、肠道菌群和血淋巴转录组的影响。【方法】将 32%、36%、40%、44% 和 48% 的蛋白质水平 (分别记为 TM32、TM36、TM40、TM44、TM48) 的饲料喂养初始体重为 $0.40\text{g}\pm 0.01\text{g}$ 的凡纳滨对虾。【结果】适宜的蛋白质水平促进了凡纳滨对虾的生长, TM36-TM44 组的最终体重、增重率和特定生长率显著高于 TM32 和 TM48 组 ($P < 0.05$)。通过增重率拟合曲线确定, 凡纳滨对虾的最佳生长蛋白质水平为 39.80%。肝胰腺酶活性分析显示, 随着饲料蛋白质水平的升高, 免疫酶 ACP、AKP、CAT、SOD、PO 和 LZM 活性增加, 而 AST、ALT 和 MDA 酶活性先降后升。肠道消化酶活性分析显示, 随着饲料蛋白质水平的增加, 淀粉酶、胰蛋白酶和脂肪酶活性增加。在挑战性感染副溶血性弧菌 (1.3×10^7 CFU/mL) 后, TM44 组的存活率显著高于 TM32 组 ($P < 0.05$)。RNA 测序分析显示, 差异表达基因主要集中在“核糖体途径”、“真核生物核糖体生物合成途径”、“氧化磷酸化”和“AMPK 信号通路”。 α 多样性分析显示, TM48 组的 Sobs 和 ACE 值最高。 β 多样性分析表明五组间存在显著差异 ($P < 0.05$)。基于 Indval 指示物种分析, 可以区分三个科和两个属, 结果与转录组相关, 表明 *Tenacibaculum* 和 *Pseudoalteromonas* 与 mTOR 通路负相关, 与凋亡正相关。【结论】本研究揭示了以 TM 为主要蛋白质来源的饲料蛋白质水平对凡纳滨对虾在转录组和菌群响应机制的影响, 发现 39.80% 的蛋白质水平是最佳生长点, 并暗示高蛋白摄入可能导致凡纳滨对虾内质网应激和 mTOR 通路抑制。

关键词: 凡纳滨对虾; 黄粉虫; 蛋白水平; 转录组; 肠道菌群; 内质网应激。

Integrating transcriptome and microbiome analyses to understand the effects of using *Tenebrio molitor* as a primary protein source in *Litopenaeus vannamei* diets

Yudong Zheng¹, Cuihong Hou¹, Jian Chen¹, Hongming Wang¹, Hang Yuan¹, Asare Derrick¹, Lili Shi^{1,4}, Shuang Zhang^{1,2,3*}

(1. College of Fisheries, Guangdong Ocean University, Zhanjiang, China 524088; 2. Key Laboratory of Aquatic, Livestock and Poultry Feed Science and Technology in South China, Ministry of Agriculture, Zhanjiang, China 524088; 3. Aquatic Animals Precision Nutrition and High Efficiency Feed Engineering Research Center of Guangdong Province, Zhanjiang, China 524088; 4. Shenzhen Research Institute of Guangdong Ocean University, Shenzhen, Guangdong)

Abstract: [Objective] As the price and demand for fishmeal (FM) in aquaculture feeds continue to rise, research on the use of *Tenebrio molitor* meal (TM) in the diet of *Litopenaeus vannamei* has been extensive. This study aimed to investigate the effects of varying protein levels in the diet, with TM as the sole protein source other than FM, on the growth, enzyme activity, resistance to *Vibrio parahaemolyticus*, intestine microbiota, and hemolymph transcriptome of *L. vannamei*. [Methods] Diets with protein levels set at 32%, 36%, 40%, 44%, and 48% (TM32, TM36, TM40, TM44, TM48, respectively) were fed to *L. vannamei* (initial weight: 0.40 g ± 0.01 g). [Result] Results indicated that an appropriate dietary protein level led to better growth performance in *L. vannamei*, with TM36-TM44 groups showing significantly higher final weight (FW), weight gain rate (WR), and specific growth rate (SGR) compared to TM32 and TM48 groups ($P < 0.05$). The optimal growth performance for *L. vannamei* was achieved at a dietary protein level of 39.80% as determined by the fitted curve using WGR. In terms of hepatopancreas enzyme activity, immune enzymes ACP, AKP, CAT, SOD, PO, and LZM increased with rising feed protein levels, while AST, ALT, and MDA enzyme activities first decreased and then increased. In the intestine digestive enzyme activity, amylase, trypsin, and lipase increased with increasing feed protein levels. Under challenge with *Vibrio parahaemolyticus* (1.3×10^7 CFU/mL), the survival rate of the TM44 group was significantly higher than that of the TM32 group ($P < 0.05$). RNA-seq analysis revealed that the DEGs mainly concentrated in the pathways of "Ribosome pathway" (ko03010), "Eukaryotic ribosome biogenesis pathway" (ko03008), "Oxidative phosphorylation" (ko00190), and "AMPK signalling pathway" (ko04152) for TM32 and TM48 groups. Alpha diversity analysis showed that the highest values for Sobs and ACE were in the TM48 group. Beta diversity analysis indicated significant differences among five groups ($P < 0.05$). Based on the Indval indicator species, three families and two genera could be distinguished, and the results related to the transcriptome showed that *Tenacibaculum* and *Pseudoalteromonas* were negatively correlated with the mTOR pathway and positively correlated with apoptosis. [Conclusion] This study provides insights into the molecular and microbiota

response mechanisms underlying the effects of dietary protein levels, with TM as the primary protein, revealing optimal growth at 39.80% protein and suggests that intake higher-protein would cause ER stress and mTOR pathway inhibition in *L.vannamei*.

Key words: *Litopenaeus vannamei*, *Tenebrio molitor*, protein level, transcriptome, microbiome, ER stress

左旋肉碱对高脂饲喂鲤肌肉营养代谢、肠道健康和肠道微生物的影响⁴⁵

贺思洁¹, 袁荣杰², 卢荣华¹, 张玉茹¹, 徐歆歆¹, 曹香林^{1*}

(1.河南师范大学水产学院, 新乡 453007; 2. 河南师范大学生命科学学院, 新乡 453007)

摘要: 【目的】本试验旨在研究左旋肉碱对高脂饲喂鲤肌肉营养代谢, 肠道健康及肠道微生态的潜在影响。【方法】取鲤幼鱼 360 尾, 分为四组: 分别饲喂 Control (对照组), HFD (高脂组)、LLC (500mg/kg 左旋肉碱组+高脂组)、和 HLC(1000mg/kg 左旋肉碱组+高脂组)日粮。饲喂 8 周后, 测定其生长性能并采集血液、肝脏、肠道和肌肉组织测定生化指标、进行组织切片观察, 并对肠道内容物进行代谢组和 16SrRNA 分析。【结果】结果表明: 1) 添加左旋肉碱可以显著改善高脂饲喂引起的血脂异常和肝胰脏脂质蓄积, 降低血清和肝胰脏中总甘油三酯 (TG)、总胆固醇 (T-CHO)。2)左旋肉碱能改善 HFD 鲤肌肉组织形态, 使鱼的肌纤维直径增加, 改善 HFD 鲤肌肉脂肪酸组成, 提高肌肉中 EPA 和 DHA 含量; 此外, 左旋肉碱还可以上调肝胰脏中脂质分解相关基因 (*abca1*、*ppara*、*cpt1a*、*lcad* 和 *acox1*) 和蛋白质合成代谢基因 (*igf-1*、*pi3k*、*akt2*、*mtor* 和 *p70s6k*), 下调脂质合成 (*fas*、*srebp-1c* 和 *hmgcr*) 和蛋白质分解相关基因 (*4ebp-1*、*foxo3a* 和 *murf-1*) 的表达。3) 左旋肉碱能够显著改善高脂饲喂引起的肠道组织形态异常和粘液含量减少, 降低肠道炎症相关基因 (*tlr4*、*myd88*、*il-1 β* 、*tnf- α* 和 *il-8*)、细胞凋亡相关基因 (*caspase-3* 和 *caspase-9*) 以及增强肠道紧密连接蛋白相关基因 (*claudin-2*、*occludin* 和 *zo-1*) 的表达, 上调抗氧化相关基因 (*nrf-2* 和 *ho-1*) 和氨基酸转运相关基因的表达; 左旋肉碱可有效调节肠道菌群失衡, 增加梭杆菌门和鲸杆菌属的丰度, 显著调整肠道代谢物的组成和含量, 为高脂饲喂鲤的肠道健康提供保护作用。【结论】综上所述, 本文研究了左旋肉碱对高脂饲喂鲤肌肉营养代谢、肠道健康和肠道微生物的影响, 为左旋肉碱在水产养殖中的应用提供了科学依据, 而且对于缓解和改善高脂饲喂可能引发的负面健康影响提出了有效的策略。

关键词: 左旋肉碱; 高脂饲料; 营养代谢; 肠道健康; 肠道微生物。

资助项目: 河南省科技开发联合基金重点项目 (235200810023)

通讯作者: 曹香林, E-Mail: 041114@htu.edu.cn

专题五

水产微生物生态营养

贝莱斯芽孢杆菌 H16 抗菌物质的纯化鉴定和特性研究⁴⁶

胡婷^{1,2}, 班赛男², 汪攀², 叶继丹^{1*}, 易敢峰²

(1. 集美大学, 水产学院, 福建 厦门 361021; 2. 福建省水产功能性饲料与环境调控重点实验室, 福建 大北农华有水产科技集团有限公司, 福建 漳州 363500)

摘要:【目的】副溶血弧菌 (*Vibrio parahaemolyticus*) 是我国海水养殖鱼类疾病爆发的主要病原菌之一, 利用拮抗菌及其代谢产物为病原菌防治提供新方向。【方法】本研究从海水鱼类生存环境样品中筛选到 1 株针对副溶血弧菌的高效拮抗菌株 H16; 通过硫酸铵沉淀、离子交换层析、凝胶过滤层析和液相色谱等纯化方法获得目标蛋白; 结合 LC-MS/MS 检测和生物信息学分析确定该物质的氨基酸序列和分子量; 并对其耐热性、酸碱耐受性、蛋白酶敏感性以及可见光与紫外线的稳定性进行了研究。【结果】结果表明, 菌株 H16 鉴定为贝莱斯芽孢杆菌 (*Bacillus velezensis*); 通过纯化方案获得分子量为 7435.28 Da 的抗菌肽, 含 69 个氨基酸, 其中正电荷氨基酸和负电荷氨基酸各有 6 个; 该抗菌肽在 100°C 下处理 60 min, 活性仍保有 56.6%; 当 pH 为 2-10 时, 抑菌活性 >83.6%; 经蛋白酶 K、胃蛋白酶及胰蛋白酶处理 6h, 抑菌活性分别为 38.9%、14.4% 和 19.3%; 经可见光和紫外线照射 4 h 后, 活性均保持不变。【结论】综上所述, 菌株 H16 为贝莱斯芽孢杆菌, 其可产生具有高效抑制致病性弧菌的抗菌肽, 其具有良好的耐热性和酸碱耐受性, 对可见光和紫外线不敏感, 具备开发绿色安全抗菌剂的潜力。

关键词: 副溶血弧菌; 贝莱斯芽孢杆菌; 纯化; 抗菌肽;

Purification and Characteristics of Antimicrobial Peptide produced by *Bacillus velezensis* strain H16

Ting Hu^{1,2}, Sainan Ban², Pan Wang², Jidan Ye^{1*}, Ganfeng Yi²

(1. Fisheries College, Jimei University, Xiamen, Fujian 361021, China; 2. Key Laboratory of Aquatic Functional Feed and Environmental Regulation of Fujian Province, Fujian Dabeinong Huayou Aquatic Sci. & Tech. Co., Ltd, Zhangzhou, Fujian 363500, China)

Abstract: [Objective] *Vibrio parahaemolyticus* is one of the main pathogen causing disease outbreaks in marine fish in China, the use of antagonistic bacteria and their metabolites provides a new direction for prevention and control of pathogen control. [Methods] In this study, a highly efficient antagonistic strain H16 against *Vibrio parahaemolyticus* derived from marine fish living environment samples. The target antibacterial pure substance was obtained by ammonium sulphate precipitation, ion exchange chromatography, gel filtration chromatography and liquid chromatography. The amino acid sequence and molecular weight of the substance were analyzed through LC-MS/MS and bioinformatics analysis. And the heat resistance, acid-base tolerance, protease sensitivity, stability under visible and ultraviolet light of obtained substance were investigated. [Results] The results showed that the strain H16 could be identified as *Bacillus velezensis*. A 7435.28 Da antibacterial peptide was obtained through purification scheme. which contained 69 amino acids, 6 positively charged amino acids and 6 negatively charged amino acids. The antibacterial peptide could keep an antibacterial activity of 56.6% after treatment of 100 °C for 60 minutes. When the pH was 2-10, its antibacterial activity was greater than 83.6%. After treatment with proteinase K, pepsin, and trypsin for 6 hours, the antibacterial activities were 38.9%, 14.4%, and 19.3%, respectively. With exposure to visible light and ultraviolet radiation for 4 hours, the activity remained unchanged. [Conclusion] In summary, strain H16 was *Bacillus velezensis*, which can produce antimicrobial peptide with high efficiency in inhibiting pathogenic *Vibrio*. The antimicrobial peptide has good thermo stability, acid-base tolerance, and was not sensitive to visible light and ultraviolet rays. It has potential to be an effective antimicrobial antagonistic agent.

Key words: *Vibrio parahaemolyticus*; *Bacillus velezensis*; purification; antibacterial peptide

不同益生元在中华绒螯蟹肠道菌群体外发酵中的益生效果比较

47

李炜¹, 刘树彬², 王晓丹¹, 陈立侨¹, 李二超^{1*}

(1.华东师范大学生命科学学院, 上海 200241; 2.上海市水产研究所, 上海, 200433)

摘要:【目的】益生元的生理功能基础在于它们通过调节肠道微生物群来改善肠道健康和整体健康。然而, 益生元类型和肠道微生物群及肠道微生物群代谢之间的关系仍不清楚。【方法】本论文以中华绒螯蟹 (Chinese Mitten Crab) 为材料, 研究了低聚果糖 (FOS)、低聚半乳糖 (GOS)、甘露寡糖 (MOS)、菊粉 (Inulin)、 β -葡聚糖、低聚异麦芽糖 (IMO) 和低聚木糖 (XOS) 对肠道菌群的影响。对发酵液的 pH 值、消化酶活性进行了测定, 再从中选取了低聚半乳糖 (GOS)、低聚甘露糖 (MOS)、 β -葡聚糖、低聚异麦芽糖 (IMO) 和低聚木糖 (XOS) 这五种效果较显著且不同种类的益生元进行了短链脂肪酸产量和肠道菌群的测定。【结果】结果表明, 在体外发酵 12 小时后, 添加甘露寡糖的组别 pH 值最低, 且胰蛋白酶活力和脂肪酶活力也最高。另外, 在短链脂肪酸产量和肠道菌群方面。甘露寡糖比其他类型的益生元具有更高的产生短链脂肪酸 (SCFA) 的能力, 尤其是丁酸。其次, 相对于其他组别, 甘露寡糖对梭菌属及乳球菌属的生长有更明显的促进作用。【结论】这些结果都表明, 对于中华绒螯蟹肠道健康, 甘露寡糖是优于其他类型益生元的, 是最适合的益生元类型。**关键词:** 益生元; 体外发酵; 中华绒螯蟹; 肠道菌群。

资助项目: 国家重点研发计划 (2023YFD2402000)、国家自然科学基金项目(32072986)、财政部和农业农村部国家现代农业产业技术体系、上海市中华绒螯蟹产业技术体系 (202404)
通讯作者: 李二超, E-mail: ecl@bio.ecnu.edu.cn

Comparison of Probiotic Effects of Different Prebiotics on In Vitro Fermentation of Gut Microbiota in Chinese Mitten Crab

Wei Li¹, Shubin Liu², Xiaodan Wang¹, Liqiao Chen¹, Erchao Li^{1*}

(1. School of Life Sciences, East China Normal University, 500 Dongchuan Road, Shanghai 200241, China; 2. Shanghai Fisheries Research Institute, Shanghai Fisheries Technical Extension Station, Shanghai 200433, China)

Abstract: [Objective] The physiological function of prebiotics is based on their ability to improve gut health and overall health by modulating the gut microbiota. However, the relationship between different types of prebiotics, the gut microbiota, and the metabolism of the gut microbiota remains unclear. [Methods] This study uses the Chinese Mitten Crab as the subject to investigate the effects of various prebiotics, including Fructo-Oligosaccharides (FOS), Galacto-Oligosaccharides (GOS), Mannan-Oligosaccharides (MOS), Inulin, β -Glucan, Iso-Maltodextrin (IMO), and Xylo-Oligosaccharides (XOS) on the gut microbiota. The pH values and digestive enzyme activities of the fermentation liquids were measured. Subsequently, GOS, MOS, β -Glucan, IMO, and XOS—five prebiotics that showed significant effects—were selected for further analysis of short-chain fatty acid (SCFA) production and gut microbiota composition. [Results] The results indicated that after 12 hours of in vitro fermentation, the group supplemented with Mannan-Oligosaccharides had the lowest pH and the highest protease and lipase activities. Additionally, regarding SCFA production and gut microbiota, Mannan-Oligosaccharides exhibited a superior ability to produce short-chain fatty acids compared to other types of prebiotics, especially butyric acid. Furthermore, Mannan-Oligosaccharides significantly promoted the growth of *Clostridium* and *Lactobacillus* compared to the other groups. [Conclusion] These results suggest that Mannan-Oligosaccharides are a more effective prebiotic type than others for gut health in the Chinese Mitten Crab and are therefore the most suitable option.

Key words: Prebiotics; In vitro fermentation; Chinese Mitten Crab; Gut microbiota

豆粕提质处理重塑微生物代谢功能以缓解高豆粕诱导的克氏原螯虾肠道氧化损伤⁴⁸

蔡明浪¹, 张华军², 胡毅^{1*}

(1.湖南农业大学水产学院, 湖南 长沙 410128; 2.广东粤海饲料集团, 广东 湛江 524017)

摘要: 本研究旨在探讨使用两种大豆蛋白(发酵豆粕和大豆浓缩蛋白)替代豆粕(SBM)对克氏原螯虾肠道组织形态学、抗氧化能力和非特异性免疫的影响,以及潜在的微生物代谢调控机制。将600只克氏原螯虾(均重4.00克)随机分为四组(FM、SBM、FSM和SPC),分别饲喂含有鱼粉和三种不同大豆蛋白的饲料,养殖实验共持续六周。结果表明,饲料中添加FSM和SPC可减轻摄食SBM饲料对肠道的损伤,具体表现为绒毛、上皮组织和致密结缔组织发育良好,血淋巴MDA和LD含量的显著降低($P < 0.05$)。与SBM组相比,添加FSM和SPC饲料的克氏原螯虾免疫力增强,血淋巴LZM和ACP活性提高($P < 0.05$),*nfkb*和*alf*mRNA表达水平下调($P < 0.05$)。同时,摄入FSM和SPC饲料的克氏原螯虾肠道GSH含量、抗氧化相关酶活性增加,*nrf2*和抗氧化相关基因表达水平上调($P < 0.05$)。此外,饲料中添加FSM和SPC可增加微生物的richness指数,从而缓解SBM引起的微生物失调和功能障碍,具体表现为*Citrobacter*和*Anaerorhabdus*的减少以及*RsaHf231*的增加。多组学关联分析表明,SBM组与FM组和SBM提质组之间共有88种不同的微生物和66种不同的代谢物,其中*Candidatus Bacilloplasma*、*Cyanobium PCC-6307*和*Vogesella*以及磷脂酰胆碱是影响克氏原螯虾健康的主要贡献者。此外,豆粕提质处理有助于形成更强大、更复杂的微生物共现网络,并激活氨基酸相关的代谢途径。总之,饲料中补充FSM和SPC可通过重塑微生物代谢功能,并缓解豆粕诱导的克氏原螯虾肠道炎症反应和氧化应激,进而改善肠道组织形态结构。

关键词: 克氏原螯虾; 大豆蛋白; 肠道微生物; 免疫; 氧化损伤。

Soybean meal-refined treatment mitigated high soybean meal diet-induced oxidative damage in the gut of crayfish via microbial metabolic function remodeling

Minglang Cai¹, Huajun Zhang², Yi Hu^{1,*}

(1. Fisheries College, Hunan Agricultural University, Changsha China 410128; 2. Guangdong Yuehai Feed Group Co., Ltd., Zhanjiang China 524000)

Abstract: The high cost and unreliable supply of fish meal has stimulated concern over low fish meal feed, making soy-derived protein receive more attention recently. Dietary high soybean meal (SBM) supplementation negatively affects host growth and health, encouraging the search for novel soy-derived protein sources to replace SBM. Besides, there is a general negligence concerning the interface between host physiological status and microbial metabolic function. As such, the aim of this study was to investigate the effects of replacing SBM with two soy-derived proteins (fermented soybean meal and soybean protein concentrate) on the gut histomorphology, antioxidant capacities, and non-specific immunity of crayfish, together with the underlying metabolic mechanisms of microbial regulation. 600 crayfish (4.00 g) were randomly divided into four groups (FM, SBM, FSM, and SPC) and fed diets with fishmeal and three different soy-derived proteins for six weeks. The present findings revealed that dietary FSM and SPC inclusion mitigated intestine injury caused by the SBM diet, as evidenced by the well-developed villus, epithelium, and dense connective tissue, as well as lower hemolymph MDA and LD contents ($P < 0.05$). Moreover, crayfish supplemented with FSM and SPC diets experienced an enhanced immunity compared to the SBM group, together with the increased hemolymph LZM and ACP activities ($P < 0.05$), and the down-regulated *nfkB* and *alm* mRNA expression levels ($P < 0.05$). Also, crayfish subjected to FSM and SPC diets exhibited increases in the intestine GSH contents, antioxidant-related enzyme activities, and up-regulated *nrf2*, antioxidant-related gene expression levels ($P < 0.05$). Furthermore, dietary FSM and SPC supplementation eliminated SBM-induced microbial dysbiosis and dysfunction by increasing richness, as characterized by the decreased *Citrobacter* and *Anaerorhabdus* and increased *RsaHf231*. Further findings revealed that the identified 88 differential microbes and 66 differential metabolites were shared between the SBM group and the FM and SBM-refined groups, with *Candidatus* Bacilloplasma, *Cyanobium* PCC-6307 and *Vogesella*, and PC (18:4(6Z,9Z,12Z,15Z)/17:1(9Z)) and PC (18:3(6Z,9Z,12Z)/22:1(11Z)) being the main contributors to crayfish health. Moreover, dietary SBM-refined treatment contributed to more robust and complicated microbial co-occurrence networks and activated amino acid-related metabolism pathways. To conclude, dietary FSM and SPC supplementation reversed the weakened immunity and antioxidant capacities of crayfish given a soybean meal diet by reshaping microbial metabolic functions, which in turn improved intestinal histomorphological structure.

Key words: *Procambarus clarkii*; Soy-derived protein; Gut microbiota; Immunity; oxidative damage

短小芽孢杆菌 SE5 调控斜带石斑鱼 (*Epinephelus coioides*) 肠道上皮细胞 β 防御素表达机制的初探⁴⁹

徐健铭¹, 杨红玲^{1,2}, 蔡国鹤^{1,2}, 孙云章^{1,2*}

(1. 集美大学水产学院, 厦门市饲料检测与安全评价重点实验室, 福建 厦门 361021;

2. 集美大学水产学院, 农业农村部东海海水健康养殖重点实验室, 福建 厦门 361021)

摘要:【目的】课题组前期研究发现短小芽孢杆菌 (*Bacillus pumilus*) SE5 可促进斜带石斑鱼肠道组织中抗菌肽— β 防御素 mRNA 基因的相对表达, 进而调节肠道菌群平衡并改善肠道免疫功能。基于此, 本研究通过建立稳定的斜带石斑鱼肠道上皮细胞 (IECs) 培养体系, 旨在深入探究 SE5 调控 IECs 内 β 防御素表达的具体机制。【方法】为构建稳定的细胞培养体系, 本研究对细胞的分离条件及培养基与血清成分进行了筛选优化。在此基础上, 向培养基中加入梯度浓度 (10^{11} 、 10^{10} 、 10^9 、 10^8 、 10^7 和 10^6 CFU/mL) 的灭活菌 SE5, 并与细胞共孵育不同时长 (0、1、3 和 6h) 以确定灭活菌诱导 β 防御素表达的最优条件。基于此最优条件进一步地实施了转录组学测序。针对差异基因富集的通路, 分别使用 NOD2 抑制剂 (GSK717), TLR2 抑制剂 (C29), JNK1 抑制剂 (SP600125), STAT1 抑制剂 (Fludarabine), P38MAPK 通路抑制剂 (SB202190), NF- κ B 通路抑制剂 (PDTC) 处理细胞后, 对灭活菌诱导 β 防御素表达的可能信号传导机制进行初步研究。【结果】研究结果如下: IECs 的分离培养和鉴定结果表明, 酶消化法 (0.25mg/ml 胰蛋白酶+0.91mMEDTA, 15min) 优于组织块法, 其最佳培养条件为含 20%胎牛血清的 L15 培养基。透射电镜观察、碱性磷酸酶染色和标志性基因表达检测进一步证实所培养的细胞为肠道上皮细胞, 基因序列比对证明细胞来源于斜带石斑鱼。因此, 0.25mg/ml 胰蛋白酶 (含 0.91mMEDTA) 消化 15min, 培养 48h 可得到初始条件一致、生长旺盛的斜带石斑鱼原代 IECs。将 IECs 与不同浓度 (10^{11} 、 10^{10} 、 10^9 、 10^8 、 10^7 和 10^6 CFU/mL) 的灭活短小芽孢杆菌 SE5 分别孵育 0、1、3 和 6h 后, 发现 1×10^8 CFU/mL 灭活菌孵育 IECs 3 h 时 β 防御素的 mRNA 相对表达量和蛋白含量均达峰值且明显高于对照组 ($P < 0.05$), 因此, 该条件被确定为灭活菌诱导斜带石斑鱼 IECs 表达 β 防御素的最优条件。此条件下, 转录组学测序结果揭示, 灭活 SE5 主要影响了 IECs NLRs、TLRs、JAK-STAT、MAPK、NF- κ B 通路。进一步的抑制剂试验表明, IECs 内 β 防御素受灭活 SE5 诱导的表达过程, 是由 NOD2、TLR2、JNK1、STAT1、P38MAPK、NF- κ B 共同介导的。【结论】以上研究结果为深入研究短小芽孢杆菌 SE5 调控石斑鱼肠道上皮细胞 β 防御素表达的关键靶点和信号通路奠定了基础, 为水产益生元件的开发和应用提供了理论支撑。

关键词: 斜带石斑鱼; 肠道上皮细胞; 短小芽孢杆菌 SE5; β 防御素。

资助项目: 国家自然科学基金面上项目 (32072990)

通讯作者: 孙云章, E-mail: jmusunyunzhang@163.com

The preliminary exploration of mechanisms underlying the regulation of β -defensin expression in intestinal epithelial cells of *Epinephelus coioides* by inactivated *Bacillus pumilus*

Jianming Xu¹, Hongling Yang^{1,2}, Guohe Cai^{1,2}, Yunzhang Sun^{1,2*}

(1. College of Fisheries, Jimei University; Key Laboratory of Feed Detection and Safety Evaluation in Xiamen City, Xiamen, Fujian 361021, China; 2. College of Fisheries, Jimei University; Key Laboratory of East China Sea Healthy Marine Aquaculture, Ministry of Agriculture and Rural Affairs, Xiamen, Fujian 361021, China)

Abstract: [Objective] Previous research by our research group revealed that inactivated *Bacillus pumilus* SE5 enhances the relative expression of the antibacterial peptide β -defensin mRNA gene in the intestinal tissue of *Epinephelus coioides*, thereby modulating intestinal microbiota balance and improving intestinal immune function. Based on these findings, the present study aims to establish a stable culture system for intestinal epithelial cells (IECs) of grouper to further investigate the mechanism underlying the regulation of β -defensin expression in IECs by *Bacillus pumilus* SE5. [Methods] To establish a stable cell culture protocol, we screened cell isolation conditions, media, and serum in the culture system. Gradient concentrations of inactivated SE5 were added to the media and co-incubated with cells for various durations to determine the optimal conditions for inducing β -defensin expression. Subsequently, transcriptome sequencing was conducted. Based on the enriched pathways of differential genes, cells were pretreated with inhibitors targeting NOD2 (GSK717), TLR2 (C29), JNK1 (SP600125), STAT1 (Fludarabine), P38MAPK (SB202190), and NF- κ B (PDTC) to preliminarily investigate the potential signaling mechanisms underlying β -defensin expression induced by inactivated SE5. [Results] The research findings are as follows: The isolation, cultivation, and identification of IECs revealed that enzymatic digestion with 0.25 mg/ml trypsin + 0.91 mM EDTA for 15 minutes outperformed the tissue explant method. Optimal culture conditions were achieved using L15 medium supplemented with 20% fetal bovine serum, resulting in cells exhibiting well morphology and epithelial characteristics. Further confirmation of IEC identity was provided by transmission electron microscopy, alkaline phosphatase staining, and detection of marker gene expression, with genetic sequencing confirming their origin from *Epinephelus coioides*. Therefore, primary IECs from orange-spotted grouper with consistent initial conditions and vigorous growth were obtained after digestion with 0.25 mg/ml trypsin (containing 0.91 mM EDTA) for 15 minutes and culturing for 48 hours. Incubation of IECs with inactivated *Bacillus pumilus* SE5 at various concentrations (10^{11} , 10^{10} , 10^9 , 10^8 , 10^7 , and 10^6 CFU/mL) for different durations (0, 1, 3, and 6 h) revealed that the optimal condition for inducing β -defensin expression was incubation with 1×10^8 CFU/mL inactivated SE5 for 3 h, resulting in a significant increase in both mRNA relative expression and protein content of β -defensin compared to the control group ($P < 0.05$). Transcriptome sequencing indicated that inactivated SE5 induced changes

in genes involved in NLRs, TLRs, JAK-STAT, MAPK and NF- κ B pathways in IECs. Inhibitor experiments demonstrated that the induction of β -defensin expression by inactivated SE5 was jointly regulated by NOD2, TLR2, JNK1, STAT1, P38MAPK and NF- κ B. [Conclusion] The aforementioned research findings lay a foundation for further exploring the key targets and signaling pathways through which inactivated *Bacillus pumilus* SE5 regulates the expression of antimicrobial peptides in intestinal epithelial cells of grouper, thereby providing theoretical support for the development and application of aquatic probiotic components.

Key words: *Epinephelus coioides*; Intestinal epithelial cells; Inactivated *Bacillus pumilus* SE5; β defensin

复方植物精油对益生菌及致病菌的影响

李方希¹, 曹宏伟², 于海霞², 董小敬^{1*}

(1. 扬州大学动物科学与技术学院; 2. 青岛普维动物保健有限公司)

摘要: 【目的】检测不同浓度复方植物精油(肉桂油、百里香油、肉桂醛、百里香酚等)对发酵饲料中的芽孢杆菌、乳酸菌和酵母菌的影响, 以及对致病菌维氏气单胞菌、副溶血弧菌、琥珀葡萄球菌和哈维弧菌的最小抑菌浓度。【方法】使用平板划线法和涂布法研究不同浓度复方植物精油处理后的芽孢杆菌和乳酸菌数量变化; 使用分光光度计法测定处理后酵母菌培养液的变化; 使用平板涂布法观察不同致病菌在添加不同浓度复方植物精油琼脂平板上的生长情况。【结果】处理12h后, 2 mg/g和4 mg/g复方植物精油添加组和对照组中的芽孢杆菌和乳酸菌数量无差异, 并且酵母菌浓度也无差异。处理24h后, 两个浓度复方植物精油组与对照组相比, 芽孢数量下降较快, 乳酸菌和酵母菌生长则无明显影响; 当复方植物精油添加量为2 mg/g时, 能完全抑制维氏气单胞菌、副溶血弧菌和哈维弧菌的生长; 当添加量为3 mg/g时, 能完全抑制琥珀葡萄球菌的生长。【结论】复方植物精油添加对益生菌芽孢杆菌、乳酸菌和酵母菌的生长无明显影响, 对致病菌维氏气单胞菌、副溶血弧菌、琥珀葡萄球菌和哈维弧菌均具有较强的抑菌能力。

关键词: 植物精油; 益生菌; 致病菌

Effects of compound plant essential oil on probiotics and pathogenic bacterias

Fangxi Li¹, Hongwei Cao², Hongxia Yu², Xiaojing Dong¹

(1. Yangzhou University College of Animal Science and Technology; 2. PlusVet Qingdao Animal Health Co., LTD)

Abstract: [Objective] To test the effects of different concentrations of compound plant essential oil (include Cinnamon oil, Thyme Oil, Thymol, Cinnamaldehyde et al) on *Bacillus*, *Lactic Acid Bacteria* and *Yeast* in fermented feed, as well as the minimum inhibitory concentrations against pathogenic bacteria *Aeromonas vickers*, *Vibrio parahaemolyticus*, *Staphylococcus succinus* and *Vibrio harvey*. [Methods] Using spread plate method and streak plate method record the changes in the number of *Bacillus* and *Lactic acid bacteria* after treatment with different concentrations of compound plant essential oil. Changes in yeast culture after treatment are determined by spectrophotometry. The spread plate method was also used to observe the growth of different pathogens on agar plates with different concentrations of compound plant essential oil. [Results]. After 12 hours of treatment, there was no significant difference observed in the number of *Bacillus* and *Lactic acid bacteria*, as well as the concentration of *Saccharomyces*, between 2 mg/g and 4 mg/g compound plant essential oil supplementation group and the control group. However, after 24 hours of treatment, it was found that the number of *Bacillus* in the two concentrations of compound plant essential oil decreased at a faster rate compared to the control group. Nevertheless, there was no noticeable impact on the growth of lactic acid bacteria and *saccharomyces*. Furthermore, it was discovered that when compound plant essential oil dosage reached 2 mg/g, complete inhibition of *Aeromonas vickerii*, *Vibrio parahaemolyticus* and *Vibrio Harveyi* growth could be achieved. Similarly, when an addition amount of 3 mg/g was used, complete inhibition of *Staphylococcus succinis* growth could be observed. [Conclusion] The addition of 2 mg/g and 4 mg/g compound plant essential oil did not demonstrate a significant impact on the growth of probiotics *Bacillus*, *Lactic acid bacteria*, and *Saccharomyces*. Furthermore, compound plant essential oil exhibited potent antibacterial activity against *Aeromonas vickeri*, *Vibrio parahemolyticus*, *Staphylococcus succinis*, and *Vibrio Harvey*.

Key words: Compound plant essential oil; Probiotics; Pathogenic bacterias

姜黄素对慢性热胁迫后西伯利亚鲟肠道与肝脏的抗氧化功能及肠道微生物组成的影响⁵⁰

荆兆鑫¹, 谭超伦¹, 冯浪坤¹, 张朝阳², 李云坤², 杜小刚², 杨世勇^{1*}

(1.四川农业大学动物科技学院, 四川 成都 611130; 2. 四川农业大学生命科学学院, 四川 雅安 625014)

摘要: 西伯利亚鲟 (*Acipenser baerii*) 作为冷水性鱼类, 常受到外界环境水体的影响, 从而影响其生存和繁殖。近年来, 全球气候变暖带来的夏季高温会使水体环境温度升高, 由此引发的热胁迫对水生变温动物生长速率、生理生化水平、新陈代谢和生命活动均存在一定威胁。姜黄素 (Curcumin) 是一种提取自姜黄根茎多酚类化合物, 具有提高动物生产性能、抗炎、抗氧化等主要生物学功能, 其作为饲料添加剂广泛应用于动物的养殖生产。本研究旨在探究姜黄素对慢性热胁迫后西伯利亚鲟肠道与肝脏的抗氧化功能及肠道微生物组成的影响。结果表明:

(1) 长期预防性投喂姜黄素 (200 mg/kg) 能显著提升西伯利亚鲟生长性能, 末体重、总增重、增重率、平均日增重和特定生长率相较于对照组显著增加。日粮中添加姜黄素 (200 mg/kg) 可改善西伯利亚鲟幼鱼肝脏组织结构, 主要表现为血清中总胆固醇含量显著减少以及肝脏中肝细胞空泡化降低; 姜黄素还能有效改善西伯利亚鲟的肠道内部形态, 提高肠道消化能力, 主要表现为瓣肠肠绒毛高度和宽度增加、肠道消化酶活性的升高等。

(2) 姜黄素可在一定程度上提升西伯利亚鲟幼鱼肝脏与肠道的抗氧化能力, 主要表现为姜黄素显著提高了西伯利亚鲟幼鱼肝脏与肠道中抗氧化酶基因表达量以及抗氧化酶活力; 饲料中添加姜黄素可明显改变西伯利亚鲟瓣肠微生物菌群的种类与丰度, 其中益生菌占比显著提升。

(3) 慢性热胁迫会造成西伯利亚鲟幼鱼肝脏和肠道损伤, 血清中的 AST 以及 ALT 活性显著升高; 肝脏组织切片显示肝细胞空泡化增加、出现炎性细胞浸润以及炎灶等; 并且其肝脏中 MDA 含量极显著上升, 抗氧化酶活力降低; 并且肝脏中 NO 的含量以及 *il-1 β* 和 *il-6* 的基因表达量显著上升; *il-10* 的基因表达量显著降低。慢性热胁迫会导致西伯利亚鲟瓣肠肠绒毛表皮细胞损伤脱落、瓣肠环肌肌肉细胞死亡和肠绒毛肿大; 瓣肠微生物菌群紊乱, 致病菌种类和数量显著增多。

(4) 姜黄素对慢性热胁迫下西伯利亚鲟幼鱼肝脏与肠道具有一定的保护作用。主要表现为慢性热胁迫下, 预饲喂姜黄素的西伯利亚鲟幼鱼血清中 AST 和 ALT 活力有下降趋势; 肝细胞空泡化现象有所改善; 肝脏中 MDA 含量显著降低, SOD、CAT 以及 GSH-Px 活力和基因表达均呈上升趋势; *nrf2* 基因表达量显著上升, *keap1* 基因表达量呈下降趋势; 肝脏中炎症标志物 NO 含量以及促炎因子 *tnf- α* 基因表达量显著降低; 抗炎因子 *il-11* 基因表达量显著升高。预防性饲喂姜黄素可通过优化西伯利亚鲟肠道结构、增强消化酶活性、增强抗氧化能力、维持肠道菌群组成等方式缓解或抵消慢性热胁迫的不利影响。

(5) 此外, 转录组分析表明: 慢性热胁迫下鲟鱼肠道内可能出现了由复合体蛋白 I 和 V 介

资助项目: 四川省重点研发计划 (2021YFYZ0015)、四川省自然科学基金 (2022NSFSC0070)、国家现代农业产业体系·四川淡水鱼创新团队岗位计划项目 (SCCXTD-15)、四川省自然科学基金 (2022NSFSC1723)

通讯作者: 杨世勇, E-Mail: yangshiyong@sicau.edu.cn

导的过度氧化磷酸化解反应，导致线粒体内能量代谢增强，引起肠上皮细胞 ROS 含量上升进而导致细胞凋亡。而姜黄素添加有助于可改善西伯利亚鲟的代谢频率，从而对慢性热胁迫导致的瓣肠损伤起到修复作用。

综上所述，本研究表明姜黄素可以改善慢性热胁迫下西伯利亚鲟幼鱼生长性能、肝脏与肠道的组织结构和抗氧化能力；还可以通过调节瓣肠肠道菌群与线粒体能量代谢、改善肠道免疫调节功能来维持西伯利亚鲟肠道健康。

关键词：姜黄素；西伯利亚鲟；慢性热胁迫；肝脏；抗氧化能力；肠道菌群；基因表达。

The effect of curcumin on the antioxidant function and gut microbial composition of Siberian sturgeon intestine and liver after chronic heat stress

Shiyong Yang¹, Langkun Feng¹, Chaolun Tan¹, Yunkun Li^{2*}

(1. Department of Aquaculture, College of Animal Science & Technology, Sichuan Agricultural University, Chengdu China 611130; 2. Department of Engineering and Applied Biology, College of Life Science, Sichuan Agricultural University, Ya'an China 625014)

Abstract : The Siberian sturgeon (*Acipenser baerii*), as a cold water fish, is often affected by environmental water bodies, thereby affecting its survival and reproduction. In recent years, the high summer temperatures caused by global climate change have led to an increase in water environmental temperature. The resulting heat stress poses a certain threat to the growth rate, physiological and biochemical levels, metabolism, and life activities of aquatic ectothermic animals. Curcumin is a polyphenolic compound extracted from the rhizome of turmeric, which has main biological functions such as improving animal production performance, anti-inflammatory, and antioxidant effects. It is widely used as a feed additive in animal farming production. The aim of this study is to investigate the effects of curcumin on the antioxidant function and gut microbiota composition of Siberian sturgeon intestine and liver after chronic heat stress. The results indicate that:

(1) Long term prophylactic feeding of curcumin (200 mg/kg) can significantly improve the growth performance of Siberian sturgeons, with significant increases in final body weight, total weight gain, weight gain rate, average daily weight gain, and specific growth rate compared to the control group. Adding curcumin (200 mg/kg) to the diet can improve the liver tissue structure of Siberian sturgeon juveniles, mainly manifested as a significant reduction in total cholesterol content in serum and a decrease in hepatocyte vacuolization in the liver; Curcumin can effectively improve the internal morphology of the Siberian sturgeon's intestine and enhance its digestive capacity, mainly manifested as an increase in the height and width of the villi in the valve intestine, as well as an increase in intestinal digestive enzyme activity.

(2) Curcumin can enhance the antioxidant capacity of the liver and intestines of Siberian sturgeon juveniles to a certain extent, mainly manifested in the significant increase of antioxidant enzyme gene expression and antioxidant enzyme activity in the liver and intestines of Siberian sturgeon juveniles; Adding curcumin to the feed can significantly alter the types and abundance of gut microbiota in Siberian sturgeons, with a significant increase in the proportion of probiotics.

(3) Chronic heat stress can cause liver and intestinal damage in Siberian sturgeon juveniles, with significantly increased levels of AST and ALT activity in serum; Liver tissue slices show increased vacuolization of liver cells, inflammatory cell infiltration, and inflammatory lesions; And the MDA content in its liver significantly increased, while the antioxidant enzyme activity decreased; And the

content of NO and the gene expression levels of *il-1 β* and *il-6* in the liver significantly increased; The gene expression level of *il-10* was significantly reduced. Chronic heat stress can lead to damage and shedding of epidermal cells in the intestinal villi of Siberian sturgeons, death of muscle cells in the gastroesophageal sphincter, and enlargement of intestinal villi; The gut microbiota is disrupted, with a significant increase in the types and quantities of pathogenic bacteria.

(4) Curcumin has a certain protective effect on the liver and intestines of Siberian sturgeon juveniles under chronic heat stress. The main manifestation is that under chronic heat stress, the serum AST and ALT activities of Siberian sturgeon juveniles pre fed with curcumin show a decreasing trend; The phenomenon of hepatocyte vacuolization has been improved; The MDA content in the liver significantly decreased, while the activities and gene expression of SOD, CAT, and GSH Px showed an upward trend; The expression level of *nrf2* gene significantly increased, while the expression level of *keap1* gene showed a decreasing trend; The levels of inflammatory marker NO and pro-inflammatory cytokine *tnf- α* gene expression in the liver were significantly reduced; The expression level of anti-inflammatory factor *il-11* gene significantly increased. Prophylactic feeding of curcumin can alleviate or counteract the adverse effects of chronic heat stress by optimizing the intestinal structure of Siberian sturgeons, enhancing digestive enzyme activity, enhancing antioxidant capacity, and maintaining gut microbiota composition.

(5) In addition, transcriptome analysis showed that under chronic heat stress, there may be an excessive oxidative phosphorylation reaction mediated by complex proteins I and V in the intestine of sturgeon, leading to enhanced energy metabolism in mitochondria and an increase in ROS content in intestinal epithelial cells, resulting in cell apoptosis. The addition of curcumin can help improve the metabolic frequency of Siberian sturgeons, thereby playing a repairing role in the intestinal injury caused by chronic heat stress.

In conclusion, this study shows that curcumin can improve the growth performance, liver and intestinal tissue structure and antioxidant capacity of juvenile Siberian sturgeon under chronic heat stress; It is also possible to maintain the intestinal health of Siberian sturgeons by regulating the gut microbiota and mitochondrial energy metabolism, and improving intestinal immune regulation function.

Key words : Curcumin; Siberian sturgeon; Chronic heat stress; Liver; Antioxidant capacity; Intestinal microbiota ; Gene expression

酵母培养物和复合益生菌对黄鳝生长性能、血清生化指标、肝肠健康和肌肉质构特性的影响

徐嘉玲¹, 李加敏¹, 彭墨^{1*}

(1.江西农业大学动物科学技术学院, 江西 南昌 330045)

摘要:【目的】试验旨在研究商用后生元产品(酵母培养物和复合益生菌)对黄鳝生长性能、血清生化指标、肝肠健康和肌肉质构特性的影响。【方法】选用 1200 尾初始体重为(23.04±0.04) g 的健康黄鳝, 随机分为 5 组, 每组 4 个重复, 每个重复 60 尾, 分别投喂基础饲料(CON 组)和添加了 0.3%酵母培养物(LYC 组)、0.3%复合益生菌(LCP 组)、0.6%酵母培养物(HYC 组)、0.6%复合益生菌(HCP 组)配置成的等氮等脂饲料。【结果】为期 56 天的养殖试验结果显示, 在基础饲料中添加两种后生元产品均可显著提高黄鳝的末均重、增重率和特定生长率($P < 0.05$), 并降低饲料转化率。与对照组相比, HYC 组、HCP 组全鱼粗蛋白含量显著提高($P < 0.05$), 但后生元组肌肉粗蛋白含量均显著升高($P < 0.05$), LYC 组、LCP 组和 HYC 组肝脏粗脂肪含量显著降低($P < 0.05$), LYC 组肌肉粗脂肪含量显著降低($P < 0.05$)。其次, 就血清指标而言, 后生元组 ALT 活性较对照组有所降低, 但 HYC 组 AST 活性、TG 和 TC 含量显著升高($P < 0.05$), HCP 组 HDL-C 含量显著升高($P < 0.05$), LYC 组、LCP 组和 HYC 组 LDL-C 含量显著降低($P < 0.05$)。后生元组血清 DAO 活性和 D-LA 含量均显著降低($P < 0.05$)。再次, 就免疫和抗氧化能力指标而言, 后生元组血清 AKP 活力均显著升高($P < 0.05$), LYC 组、LCP 组、HYC 组血清 ACP 活力显著升高($P < 0.05$), LCP 组、HYC 组、HCP 组肝脏 LZM 活力显著升高($P < 0.05$)。后生元组均显著提高了肝脏 T-SOD 活力和 GSH 含量($P < 0.05$), 并显著提高 LYC 组、LCP 组 CAT 活力($P < 0.05$), 显著降低 LYC 组、LCP 组和 HCP 组 MDA 含量($P < 0.05$)。后生元组均显著提高了肠道 T-SOD 活力($P < 0.05$), LYC 组、LCP 组 GSH 含量显著降低($P < 0.05$), 但仅 LCP 组和 HCP 组显著提高了 GSH-Px 活力($P < 0.05$), 并显著降低 MDA 含量($P < 0.05$)。同时, HYC 组、HCP 组可显著提高肠道 α -淀粉酶和胰蛋白酶活力($P < 0.05$)。肝脏油红染色结果表明, LYC、LCP 及 HCP 组肝细胞脂滴沉积少于 CON 组。肠道 HE 染色结果表明, 饲料中添加后生元产品对黄鳝的肠上皮细胞高度、皱褶高度, 以及杯状细胞的产生有显著的促进作用。后生元组黄鳝肌肉的硬度、胶着性和咀嚼性显著提高($P < 0.05$), 且后生元组单个肌纤维横截面积和单个肌纤维直径均小于 CON 组($P < 0.05$)。【结论】本研究表明, 添加适量的酵母培养物和复合益生菌可提高黄鳝的生长性能, 可降低肝脂沉积, 增强肝脏和肠道的抗氧化能力, 并提高免疫能力, 缓解肝脏损伤, 促进肝肠健康, 同时可增加肌肉蛋白含量, 并改善黄鳝的肌肉质构特性。本研究可为黄鳝的健康养殖提供参考依据。

关键词: 黄鳝; 后生元; 生长性能; 免疫; 抗氧化能力; 肝肠健康; 质构。

Effects of yeast culture and complex probiotics on growth performance, serum biochemical indices, liver and intestinal health and muscle texture characteristics of *Monopterus albus*

Jialing Xu¹, Jiamin Li¹, Mo Peng^{1*}

(2. College of Animal Science and Technology, Jiangxi Agricultural University, Nanchang China 330045)

Abstract: [Objective] The aim of this experiment was to study the effects of commercial probiotics products (yeast culture and complex probiotics) on growth performance, serum biochemical indices, liver and intestinal health and muscle texture characteristics of *Monopterus albus*. [Methods] 1200 healthy *M. albus* with an initial body weight of (23.04±0.04) g were randomly divided into 5 groups with 4 replicates per group and 60 *M. albus* per replicate. The basic diet (CON group) and the isonitrogenous and isolipid diets diet supplemented with 0.3% yeast culture (LYC group), 0.3% complex probiotics (LCP group), 0.6% yeast culture (HYC group) and 0.6% complex probiotics (HCP group) were fed, respectively. [Results] The results of the 56-d experiment showed that the two probiotics products significantly increased the average final weight, weight gain rate and specific growth rate ($P < 0.05$), and reduced feed conversion rate. Compared with CON group, the crude protein content of whole fish in HYC and HCP groups was significantly increased ($P < 0.05$), but the crude protein content of muscle in all probiotics groups was significantly increased ($P < 0.05$), the liver crude lipid content in LYC, LCP and HYC groups was significantly decreased ($P < 0.05$), the content of crude lipid in muscle of LYC group was significantly decreased ($P < 0.05$). Additionally, in terms of serum indexes, ALT activity in other four groups was decreased compared with CON group, but AST activity, TG and TC contents in HYC group were significantly increased ($P < 0.05$), HDL-C content in HCP group was significantly increased ($P < 0.05$), LDL-C content in LYC group, LCP group and HYC group was significantly decreased ($P < 0.05$). Serum DAO activity and D-LA content were significantly decreased ($P < 0.05$). Besides, in terms of immune and antioxidant capacity indexes, serum AKP activity was significantly increased in all probiotics group ($P < 0.05$), serum ACP activity was significantly increased in LYC group, LCP group and HYC group ($P < 0.05$), liver LZM activity in LCP, HYC and HCP groups was significantly increased ($P < 0.05$). The activity of T-SOD and the content of GSH in liver were significantly increased ($P < 0.05$), the activity of CAT in LYC and LCP groups was significantly increased ($P < 0.05$), and the content of MDA in LYC, LCP and HCP groups was significantly decreased ($P < 0.05$). The intestinal T-SOD activity was significantly increased in all probiotics groups ($P < 0.05$), the GSH content in LYC and LCP groups was significantly decreased ($P < 0.05$), but only the GSH-Px activity in LCP and HCP groups was significantly increased ($P < 0.05$), and the MDA content was significantly decreased ($P < 0.05$). Meanwhile, the activities of intestinal α -amylase and trypsin in HYC and HCP groups were significantly increased ($P < 0.05$). The liver oil red staining showed that lipid droplets deposition in LYC, LCP and HCP groups was smaller than CON group. The intestinal HE staining showed that probiotics products could promote the

intestinal epithelial cell height, fold height and goblet cell production. The muscle hardness, gumminess and chewiness in probiotics groups were significantly increased ($P < 0.05$), and the cross-sectional area and diameter of individual muscle fibers in probiotics group were smaller than CON group ($P < 0.05$).**[Conclusion]**Appropriate yeast culture and complex probiotics can increase growth performance of *M. albus*, enhance the antioxidant capacity of liver and intestine, improve the immune capacity, reduce liver lipid deposition, promote liver and intestinal health, and positively affect the texture characteristics of muscle. This study can provide a reference for healthy culture of *M. albus*.

Key words: *Monopterus albus*; Probiotics; Growth performance; Immunity; Antioxidant capacity; Intestinal health; Texture

乳酸乳球菌对高温条件下美洲鲈生长、代谢及肠道微生物群落结构的影响⁵¹

邱楚雯^{1,2}, 施永海^{1,*}, 黄旭雄^{2,*}, 陈再忠²

(1.上海市水产研究所(上海市水产技术推广站), 上海 200433; 2. 上海海洋大学农业农村部淡水水产种质资源重点实验室, 上海 201306)

摘要:【目的】美洲鲈(*Alosa sapidissima*)是一种温度敏感型淡水鱼类, 温度是阻碍其生存的重要因素。益生菌在缓解温度应激对鱼类的影响方面有着巨大的潜力, 为探究高温条件下益生菌在缓解温度应激对美洲鲈影响的作用。【方法】本研究以美国鲈鱼为对象, 设置基础饲料与基础饲料中添加乳酸乳球菌 2 组饲料(CK、LL), 高温条件下在室内循环水系统中养殖 8 周。饲养实验结束后, 测定美洲鲈生长性能及不同组织的消化酶、抗氧化酶及非特异性免疫酶活性, 采用高通量测序方法分析肠道菌群结构变化, 并利用转录组测序技术对肝脏样本进行测序, 筛选差异表达基因。【结果】与对照组相比, 饲料中添加乳酸乳球菌提高美洲鲈的生长性能, 其中特定增长率及肥满度达显著提高, 饲料系数有所降低; 肠道脂肪酶(LPS)、肝脏、幽门盲囊总超氧化物歧化酶(T-SOD)、肠道和胃谷胱甘肽过氧化物酶(GSH-PX)、肝脏碱性磷酸酶(AKP)、酸性磷酸酶(ACP)活性显著提高, 胃中 MDA 含量显著降低。乳酸乳球菌组肠道菌落多样性及肠道中常见有益菌的相对丰度有所提高。肝脏转录组学分析筛选到 268 个上调基因, 318 个下调基因。KEGG 富集分析显示差异基因主要富集在昼夜节律、脂肪酸降解等代谢通路。【结论】在美洲鲈高温养殖条件下, 乳酸乳球菌提高美洲鲈肠道细菌多样性, 并通过调节昼夜节律、免疫和脂质代谢以缓解应激反应, 促进其生长。本研究为益生菌在美洲鲈高温条件下的应用提供参考。

关键词: 乳酸乳球菌; 美洲鲈; 生长; 代谢; 肠道菌群结构; 转录组

资助项目: 上海市科技兴农项目课题(2022-02-08-00-12-F01180); 上海长江口主要经济水生动物人工繁育工程技术研究中心(13DZ2251800); 上海市农业领军人才项目(G201860)

通讯作者: 施永海, E-Mail: yonghais@163.com; 黄旭雄, E-Mail: xxhuang@shou.edu.cn

Effects of dietary *Lactococcus lactis* on growth, metabolism and intestinal microbial community structure of American shad (*Alosa sapidissima*) under high temperature

Chuwen Qiu^{1,2}, Yonghai Shi^{*1}, Xuxiong Huang^{*2}, Zaizhong Chen,^{*2}

(1. Shanghai Fisheries Research Institute, Shanghai Fisheries Technical Extension Station, Shanghai China 200433; 2. Key Laboratory of Freshwater Aquatic Genetic Resources, Ministry of Agriculture and Rural Affairs, Shanghai Ocean University, Shanghai China 201306)

Abstract: [Objective] *Alosa sapidissima* is a temperature-sensitive freshwater fish, and temperature is an important obstacle to its survival. Probiotics have great potential in alleviating the effects of temperature stress on fish. In order to explore the effect of probiotics in alleviating temperature stress on *A. sapidissima* at high temperature. [Methods] In this study, *A. sapidissima* was cultured in indoor circulating water system for 8 weeks under high temperature by setting two groups including the basic diet and the basic diet added *Lactococcus lactis* groups (CK, LL). After the feeding experiment, *A. sapidissima* growth performance and the activities of digestive enzymes, antioxidant enzymes, and non-specific immune enzymes in different organs were determined. High-throughput sequencing method was used to analyze the changes of the intestine microbial community structure. Transcriptome sequencing technology was used to sequence liver samples and screen differentially expressed genes. [Results] Compared with control group, dietary *L. lactis* improved the growth performance of *A. sapidissima*, with significant increases in the specific growth rate and condition factor, and decreased feed conversion ratio. The activities of intestinal lipase (LPS), total superoxide dismutase (T-SOD), intestinal and gastric glutathione peroxidase (GSH-PX), hepatic alkaline phosphatase (AKP) and acid phosphatase (ACP) were significantly increased, while the content of MDA in stomach was significantly decreased. The diversity of intestinal microbial diversity and the relative abundance of common beneficial bacteria in dietary *L. lactis* group were increased. Liver transcriptomic analysis identified 268 up-regulated genes and 318 down-regulated genes. KEGG enrichment analysis showed that differential genes were mainly enriched in metabolic pathways such as circadian rhythm and fatty acid degradation. [Conclusion] In high temperature breeding conditions, *L. lactis* increased intestine bacterial diversity, alleviated stress response and promoted growth by regulating circadian rhythm, immunity and lipid metabolism. This study provided reference for the application of probiotics in *A. sapidissima* at high temperature.

Key words: *Lactococcus lactis*; *Alosa sapidissima*; growth; metabolism; intestinal microbial structure; transcriptome

三种益生菌对卵形鲳鲅生长及肠道菌群的影响⁵²

兰鲲鹏¹, 吴光德¹, 黄林峰¹, 王芸¹, 周传朋¹, 黄忠¹, 林黑着^{1,2}, 马振华^{1,3,4}, 王珺^{1,2,3*}

(1. 中国水产科学研究院南海水产研究所/农业农村部水产品加工重点实验室, 广东 广州 510300; 2. 南方海洋科学与工程广东省实验室(珠海), 广东 珠海 519082; 3. 三亚热带研究院, 海南 三亚 572018; 4. 海南省深远海渔业资源高效利用与加工重点实验室, 海南 三亚 572018)

摘要: 本论文探究了高碳水化合物水平饲料中添加罗伊氏乳杆菌 (*Lactobacillus reuteri*) 制剂、解淀粉芽孢杆菌 (*Bacillus amyloliquefaciens*) 制剂、凝结芽孢杆菌 (*Bacillus coagulans*) 制剂对卵形鲳鲅 (*Trachinotus ovatus*) 生长及肠道菌群的影响, 以此来评估益生菌的作用效果, 为优化海水鱼类饲料配方提供参考。依据益生菌在鱼体内的有效活菌数, 我们制作了对照组 L1 (17.74%碳水化合物)、22.14%高碳水化合物模型组 L2、添加 0.1 g·kg⁻¹ 罗伊氏乳杆菌实验组 L3、0.1 g·kg⁻¹ 解淀粉芽孢杆菌实验组 L4、0.5 g·kg⁻¹ 凝结芽孢杆菌实验组 L5 和三种菌的等比例混合实验组 L6 共 6 种等氮等脂饲料, 每种饲料 3 个重复, 每个重复 30 尾鱼, 投喂卵形鲳鲅幼鱼 (初始体重 13.46±0.02 g) 8 周。结果表明, L3 (0.1 g·kg⁻¹ 罗伊氏乳杆菌)、L4 (0.1 g·kg⁻¹ 解淀粉芽孢杆菌) 组卵形鲳鲅的末重 (FBW)、增重率 (WG) 和特定生长率 (SGR) 相比于对照组 L1 和高糖模型组 L2 显著提升 ($P < 0.05$)。L3 (0.1 g·kg⁻¹ 罗伊氏乳杆菌) 和 L5 (0.5 g·kg⁻¹ 凝结芽孢杆菌) 组的肠道淀粉酶活性显著低于 L2 高糖模型组和 L6 等比例混合菌种组, 而 L3 (0.1 g·kg⁻¹ 罗伊氏乳杆菌)、L4 (0.1 g·kg⁻¹ 解淀粉芽孢杆菌) 和 L5 (0.5 g·kg⁻¹ 凝结芽孢杆菌) 组的肠道糜蛋白酶活性显著高于 L1 对照组和 L6 等比例混合菌种组 ($P < 0.05$)。L4, L5, L6 组的胆固醇 CHO, 甘油三酯 TG 和低密度脂蛋白 LDL 水平显著高于高糖组 L2 ($P < 0.05$)。在肠道菌群的门水平上 L3 (0.1 g·kg⁻¹ 罗伊氏乳杆菌) 组的变形菌门丰度低于对照组 L1 与高碳水化合物模型组 L2, 而厚壁菌门和拟杆菌门则呈现相反的趋势 ($P < 0.05$)。L4 (0.1 g·kg⁻¹ 解淀粉芽孢杆菌) 组的变形菌门 (Proteobacteria) 丰度显著低于高碳水化合物组 L2, 而厚壁菌门 (Firmicutes) 和拟杆菌门 (Bacteroidetes) 呈现相反的趋势 ($P < 0.05$)。在属水平上 L3 (0.1 g·kg⁻¹ 罗伊氏乳杆菌)、L4 (0.1 g·kg⁻¹ 解淀粉芽孢杆菌) 和 L5 (0.5 g·kg⁻¹ 凝结芽孢杆菌) 组的无色杆菌属 (*Achromobacter*) 和戴尔福特菌属 (*Delftia*) 的种群丰度显著低于高碳水化合物模型组 L2, 而且在 L3 (0.1 g·kg⁻¹ 罗伊氏乳杆菌) 组值最小 ($P < 0.05$)。但 L3 (0.1 g·kg⁻¹ 罗伊氏乳杆菌) 组普雷沃菌属 (*Prevotella*) 的种群丰度显著高于其他组 ($P < 0.05$)。综合以上结果, 我们发现三种益生菌都能提高卵形鲳鲅的生长性能和肠道健康, 其中罗伊氏乳杆菌添加剂组对卵形鲳鲅的影响最优。

关键词: 卵形鲳鲅; 益生菌; 碳水化合物; 肠道菌群。

资助项目: 国家自然科学基金面上项目 (32172984)、广东省自然科学基金面上项目(2024A1515010084)、南方海洋科学与工程广东实验室(海珠)(SML2023SP236)

通讯作者: 王珺, E-Mail: jwang@scsfri.ac.cn

Effects of Probiotics on Growth Performance and Intestinal Microflora of Golden Pompano (*Trachinotus ovatus*)

Kunpeng Lan¹, Guangde Wu¹, Linfeng Huang¹, Yun Wang¹, Chuanpeng Zhou¹, Huang Zhong¹,
Heizhao Lin^{1,2}, Zhenhua Ma^{1,3,4}, Jun Wang^{1,2,3*}

(1. Key Laboratory of Aquatic Product Processing, Ministry of Agriculture and Rural Affairs, South China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Guangzhou, P.R. China, 510300; 2. Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), Zhuhai 519082, China; 3. Sanya Tropical Fisheries Research Institute, Sanya, P.R. China, 572018; 4. Hainan Provincial Key Laboratory of Efficient Utilization and Processing of Marine Fishery Resources, Sanya, P.R. China, 572018)

Abstract: This study evaluated the effects of dietary supplementation with *Lactobacillus reuteri*, *Bacillus amyloliquefaciens* and *Bacillus coagulans* on the growth performance and intestinal microflora of golden pompano. In terms of probiotics, we produced six isonitrogenous and isolipid diets, including L1 for the control group with 17.74% carbohydrate level, L2 for the 22.14% carbohydrate level group, L3 with 0.1 g·kg⁻¹ *L. reuteri*, L4 with 0.1 g·kg⁻¹ *B. amyloliquefaciens*, L5 with 0.5 g·kg⁻¹ *B. coagulans*, and L6 for the experimental group with equal proportions of the three probiotics. Three replicates of 30 fish per replicate were fed to golden pompano (initial weight 13.46 ± 0.02 g) with their diet for 8 weeks. Results showed that the final body weight (FBW), weight gain rate (WG) and specific growth rate (SGR) of golden pompano in L3 (0.1 g·kg⁻¹ *L. reuteri*) and L4 (0.1 g·kg⁻¹ *B. amyloliquefaciens*) groups were significantly increased compared with the control group L1 and high carbohydrate level group L2 ($P < 0.05$). The intestinal enzymes activities in the L3 (0.1 g·kg⁻¹ *L. reuteri*) and L5 (0.5 g·kg⁻¹ *B. amyloliquefaciens*) groups were significantly lower than those in the high carbohydrate level group L2 and L6 group, whereas the intestinal chymotrypsin activities in the L3 (0.1 g·kg⁻¹ *L. reuteri*), L4 (0.1 g·kg⁻¹ *B. amyloliquefaciens*) and L5 (0.5 g·kg⁻¹ *B. coagulans*) groups were significantly higher than those in the L1 control group and L6 group ($P < 0.05$). The cholesterol (CHO), triglyceride (TG) and high-density lipoprotein (LDL) levels in the L4, L5 and L6 groups were significantly higher than those in the high carbohydrate level group L2 ($P < 0.05$). At the phylum level of the intestinal microflora, the abundance of Proteobacteria in the L3 (0.1 g·kg⁻¹ *L. reuteri*) group was lower than the control L1 and the high carbohydrate level group L2, while the opposite trend was observed for the Firmicutes and Bacteroidetes. At the genus level, the abundance of *Achromobacter*, *Delftia* and *Brevundimonas* in the L3 (0.1 g·kg⁻¹ *L. reuteri*), L4 (0.1 g·kg⁻¹ *B. amyloliquefaciens*) and L5 (0.5 g·kg⁻¹ *B. coagulans*) groups were lower than those in the high carbohydrate level group L2, and the minimum value was obtained in the L3 (0.1 g·kg⁻¹ *L. reuteri*) group ($P > 0.05$). However, the abundance of *Prevotella* 9 in the L3 (0.1 g·kg⁻¹ *L. reuteri*) group was significantly higher than that in the other groups ($P < 0.05$). In conclusion, the present study demonstrated that all three probiotics could improve the growth of golden pompano. Further more L3 (0.1 g·kg⁻¹ *L. reuteri*) group showed the best results.

Key words: *Trachinotus ovatus*; intestinal microflora; carbohydrate, probiotics

饲料中补充索氏鲸杆菌 WT-1 (*Cetobacterium somerae* WT-1) 后生元可促进大菱鲂 (*Scophthalmus maximus* L.) 的生长性能、肠道健康及免疫功能⁵³

王文韬¹, 周学琪¹, 陈梦麒¹, 梁书菲¹, 李泽恒¹, 师文凯¹, 艾庆辉^{1,2}, 麦康森^{1,2}, 万敏^{1,2*}
(1.中国海洋大学海水养殖重点实验室(教育部)、水产动物营养与饲料重点实验室(农业农村部), 山东 青岛 266003; 2. 青岛海洋科学与技术国家实验室, 海洋渔业科学与食物产出过程功能实验室, 山东 青岛 266237)

摘要: 后生元作为一种新型饲料添加剂, 在水产养殖领域正引起广泛关注。本研究评估了来源于热处理的索氏鲸杆菌 WT-1 (*Cetobacterium somerae* WT-1) 发酵液的后生元对大菱鲂 (*Scophthalmus maximus* L.) 生长性能、肠道健康及免疫功能的影响。实验配制了六种等氮和等脂的饲料, 后生元添加浓度分别为 0%、0.2%、0.4%、0.6%、1% 和 2%, 对应命名为 Ctrl、F-2、F-4、F-6、F-10 和 F-20。实验鱼初始体重为 10.48 ± 0.02 g, 并进行了为期 8 周的饲喂试验。结果表明, 相较于对照组, F-4 和 F-6 组的大菱鲂表现出显著更高的增重率、蛋白质效率比以及肠道脂肪酶和胰蛋白酶的活性, 同时饲料转化率显著降低。此外, F-4 和 F-6 组大菱鲂的肠道健康明显改善, 表现为肠道炎症标志物水平的下降以及紧密连接蛋白基因表达的上调。适量的后生元补充还优化了肠道微生物群的组成, 降低了变形菌门 (*Proteobacteria*) 的丰度, 增加了厚壁菌门 (*Firmicutes*), 特别是乳杆菌 (*Lactobacillus*) 的比例。在感染实验中, 后生元显著提高了鱼的存活率, 并在亚致死感染条件下上调了肾脏中的免疫基因表达。进一步, 通过对 WT-1 后生元液体的代谢组学分析发现, 其中羧酸及其衍生物占总成分的 35%, 苯及其衍生物占 11%。与发酵前的培养基相比, 检测到 310 种正离子和 255 种负离子物质发生了显著变化。其中, 乙酸含量增加了 27.5 倍, 丁酸提高了 32.5 倍。此外, 鸟氨酸、精氨酸和脯氨酸等氨基酸水平也显著上升。综上所述, 饲料中补充由索氏鲸杆菌 WT-1 衍生的后生元能有效提升大菱鲂的生长性能、肠道健康及抗感染能力, 突显其作为水产养殖有益饲料添加剂的潜力。

关键词: 索氏鲸杆菌; 后生元; 饲料添加剂; 肠道健康; 免疫功能

资助项目: 国家自然科学基金重点项目 (31972802)、国家重点研发计划 (2018YFD0900405)
通讯作者: 万敏, E-Mail: wanmin@ouc.edu.cn

Dietary supplementation with postbiotics from *Cetobacterium somerae* WT-1 promotes growth performance, intestinal health, and immune function in turbot (*Scophthalmus maximus* L.)

Wentao Wang¹, Xueqi Zhou¹, Mengqi Chen¹, Shufei Liang¹, Zeheng Li¹, Wenkai Shi¹, Qinghui Ai^{1,2}, Kangsen Mai^{1,2}, Min Wan^{1,2,*}

(1. Key Laboratory of Mariculture (Ministry of Education and), and Key Laboratory of Aquaculture Nutrition and Feed (Ministry of Agriculture and Rural Affairs), Ocean University of China, Qingdao China 266003; 2. Laboratory for Marine Fisheries Science and Food Production Processes, Qingdao National Laboratory for Marine Science and Technology, Qingdao China 266237)

Abstract: Postbiotics, a novel type of feed additive, are gaining significant attention in aquaculture. In this study, the effects of postbiotics derived from the heat-treated fermentation broth of *Cetobacterium somerae* WT-1 on the growth performance, gut health, and immune function of turbot (*Scophthalmus maximus* L.) were evaluated. Six isonitrogenous and isolipidic diets were formulated with varying concentrations of postbiotics (0%, 0.2%, 0.4%, 0.6%, 1%, and 2%), referred to as Ctrl, F-2, F-4, F-6, F-10, and F-20, respectively. The experimental diets were administered to turbot (initial body weight: 10.48 ± 0.02 g) during an 8-week feeding trial. The results showed that turbot in the F-4 and F-6 groups exhibited significantly higher weight gain rates, protein efficiency ratios, and activities of intestinal lipase and trypsin, while their feed conversion ratios were significantly lower compared to the control group. Moreover, the intestinal health of turbot in these two groups showed notable improvements, evidenced by reduced levels of intestinal inflammatory markers and enhanced expression of tight junction protein genes. Additionally, appropriate supplementation with postbiotics optimized the composition of the intestinal microbiota, decreasing the abundance of *Proteobacteria* and increasing the prevalence of *Firmicutes*, particularly *Lactobacillus*. Postbiotics also significantly improved the survival rate of turbot following infection and upregulated immune gene expression in the kidneys under sub-lethal infection conditions. Furthermore, metabolomic profiling of the *Cetobacterium somerae* WT-1 postbiotic solution revealed that carboxylic acids and their derivatives constituted 35% of the total metabolites, while aromatic compounds accounted for 11%. In comparison to the pre-fermentation medium, 310 cationic and 255 anionic metabolites exhibited significant alterations. Notably, the concentration of acetic acid increased by 27.5-fold, while butyric acid rose by 32.5-fold. Moreover, the levels of amino acids such as ornithine, arginine, and proline were markedly elevated.

In conclusion, dietary supplementation with postbiotics derived from *Cetobacterium somerae* WT-1 effectively enhanced growth performance, gut health, and infection resistance in turbot, highlighting its potential as a beneficial feed additive in aquaculture.

Key words: *Cetobacterium somerae*; Postbiotics; Feed Additives; Gut Health; Immune Function

饲料中添加丁酸梭菌代谢产物通过改善肝肠健康提高凡纳滨对虾生长性能

郑兴龙¹, 郜卫华², 姚海行¹, 张健敏¹, 刘洋洋, 田娟^{1,2*}

(1. 中国水产科学研究院长江水产研究所, 湖北 武汉 430223;

2. 长江大学, 涝渍灾害与湿地农业湖北省重点实验室, 湖北 荆州 434024;)

摘要: 为研究饲料中添加丁酸梭菌代谢产物 (CBM) 对凡纳滨对虾生长性能、肝脏及肠道健康的影响, 本试验配制了 6 组等氮等能饲料, 分别为高鱼粉饲料 (含 20% 鱼粉和 22% 豆粕, 简称为 PC 组)、低鱼粉饲料 (含 14% 鱼粉和 30% 豆粕, NC 组)、4 个丁酸梭菌代谢产物添加组 (CBM, 添加量分别为 0.05%、0.1%、0.2%、0.4%), 饲喂初始体质量 (2.05 ± 0.03) g 凡纳滨对虾 (*Litopenaeus vannamei*) 6 周, 结果显示, 较 PC 组, NC 组凡纳滨对虾出现了明显的肝脏损伤, 主要体现在 NC 组显著提升了凡纳滨对虾血清谷丙转氨酶 (ALT) 的活性, 在肝脏组织形态的显微结构观察中 NC 组中出现大量液泡且大部分肝细胞坏死并出现在管腔内、肝细胞结构模糊、肝小管结构消失、大量血细胞渗入肝胰腺的所有部位。且生长性能、肠道和肝胰腺消化酶及抗氧化酶活性显著降低。在 NC 组饲料中添加 0.2% CBM 显著增加了凡纳滨对虾的增重率、蛋白质效率、消化酶活性及有益菌群丰度, 显著降低了血清 AST 和 ALT 活性。此外, CBM 添加组显著上调了抗氧化基因 (*Nrf2* 和 *CAT*)、肠道屏障相关基因 (*Zo1* 和 *Mucin-1*) 和抗炎因子 (*TNF- α*) 的 mRNA 相对表达水平。综上所述, 本试验条件下, 添加 0.2% CBM 可提高凡纳滨对虾对低鱼粉饲料的利用率, 且通过改善肠道和肝脏健康提高了其生长性能。

关键词: 凡纳滨对虾; 丁酸梭菌代谢产物; 生长性能; 肠道健康

Dietary supplementation with *Clostridium butyricum* metabolites improves growth performance of *Litopenaeus vannamei* by improving liver and intestinal health

Xinglong Zheng¹, Weihua Gao², Haihang Yao¹, Jianmin Zhang¹, Yangyang Liu¹, Juan Tian^{1, 2*}

(1. Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Wuhan, 430223, China; 2. Yangtze University, Hubei Key Laboratory of Waterlogging Disaster and Agricultural Use of Wetland, Jingzhou 434024, China)

Abstract: To investigate the effects of feed additions of *Clostridium butyricum* metabolites (CBM) on the growth performance, liver and intestinal health of shrimp *Litopenaeus vannamei*, six groups of isonitrogenous and isoenergetic feeds were formulated in this experiment, namely, a high fishmeal feed (containing 20% fishmeal and 22% soya bean meal, referred to as the PC group), a low fishmeal feed (containing 14% fishmeal and 30% soya bean meal, the NC group), and four *Clostridium butyricum* metabolites additions groups (CBM additions of 0.05%, 0.1%, 0.2%, and 0.4%, respectively), fed to initial body mass [(2.05 ± 0.03) g] of *Litopenaeus vannamei* for 6 weeks, and the results showed that compared with the PC group, shrimp from the NC group showed significant liver damage, which was mainly manifested as the activity of serum alanine aminotransferase (ALT) was significantly increased in the NC group. In the NC group, there were a large number of vacuoles and most of the hepatocytes were necrotic and appeared in the lumen, the structure of hepatocytes was blurred, the structure of hepatic tubules disappeared, and a large number of blood cells infiltrated into all parts of hepatopancreas, and growth performance, intestinal and hepatopancreatic digestive enzymes and antioxidant enzymes activities were significantly reduced. Addition of 0.2% CBM to the NC feed significantly increased the weight gain rate, protein efficiency, digestive enzyme activities and abundance of beneficial bacterial flora of intestine, and significantly reduced serum AST and ALT activities. In addition, the CBM-added groups significantly up-regulated the relative mRNA expression levels of antioxidant genes (*Nrf2* and *CAT*), gut barrier-related genes (*Zo1* and *Mucin-1*) and anti-inflammatory factors (*TNF-α*). In conclusion, the addition of 0.2% CBM increased the utilisation of low-fishmeal diets by *Litopenaeus vannamei* under the conditions of this experiment, and enhanced its growth performance by improving intestinal and liver health.

Key words: *Litopenaeus vannamei*; Metabolites of *Clostridium butyricum*; Growth Performance; Intestinal health.

⁵⁴ 资助项目：国家重点研发计划 (2023YFD2402000 [Supported by National Key R&D Program of China (2023YFD2402000)])

通讯作者：田娟，副研究员，主要从事水产动物营养与饲料学研究，E-mail: tianjuan@yfi.ac.cn

微生物组视角：有机铜在促进凡纳滨对虾健康养殖中的作用⁵⁵

杨金柱¹，张忠浩¹，林刚²，李明珠³，张彦娇^{1,4*}，麦康森^{1,4}

(1. 中国海洋大学海水养殖重点实验室(教育部)、水产动物营养与饲料重点实验室(农业农村部)，山东 青岛 266003；2. 中国农业科学院质量标准研究所，北京，100600；3. 鲁东大学，农学院，山东 烟台 264025；4. 青岛海洋科学与技术国家实验室，海洋渔业科学与食物产出过程功能实验室，山东 青岛 266237)

摘要：【目的】微生物组测序为水产动物营养研究提供了有效的手段。目前还未有研究全面探究宿主微生物组(肠道、鳃和水体)对微量元素的响应。本实验从微生物组角度分析有机铜在凡纳滨对虾健康水产养殖的应用潜力，并挖掘其对宿主微生物组生态功能的调节作用。【方法】在8周的养殖实验中，对虾分别被饲喂无铜源添加、30 mg/kg 无机铜添加(CuSO₄·5H₂O)或有机铜添加(Cu-proteinate)的饲料。之后对生理指标进行评估，对肠道、鳃、水体样本进行16S rRNA 基因V3-4区测序。【结果】饲喂有机铜饲料组对虾健康状态和营养代谢效率更佳。有机铜组对虾微生物组 alpha 和 beta 多样性更为独特，其微生物共生网络结构更复杂，网络鲁棒性和抗毁性更高。各组的核微生物组成相似，但有机铜组核微生物对维持宿主微生态群落稳定性的贡献更大，如 *Vibrio*、*Candidatus_Bacilloplasma*、*Photobacterium*。在有机铜组具有促进宿主营养代谢的微生物明显富集，并且其丰度与对虾生理指标具有协同性，如 *Alloprevotella*、*Butyricoccus*、*f_Prevotellaceae*、*Lactobacillus*。有机铜组宿主微生物具有更高的生态功能(如碳氮循环)丰度(FAPROTAX 数据库)以及营养和能量代谢功能丰度(Tax4Fun2 数据库)。【结论】有机铜不仅有利于凡纳滨对虾的机体健康，还能增强宿主微生物群落的稳定性，并且具有促进宿主营养代谢功能和生态循环功能。本研究从微生物组视角表明有机铜应用于水产饲料，有助于推动健康水产养殖和水产饲料配方创新发展。

关键词：健康水产养殖；宿主微生物；微生物群落稳定性；微生物功能；有机铜；凡纳滨对虾。

资助项目：国家自然科学基金(31872577)

通讯作者：张彦娇，E-Mail: yanjiaozhang@ouc.edu.cn

Microbiome insights: the role of organic copper in enhancing healthy shrimp (*Penaeus vannamei* Boone, 1931) culture

Jinzhu Yang¹, Zhonghao Zhang¹, Gang Lin², Mingzhu Li³, Yanjiao Zhang^{1,4*}, Kangsen Mai^{1,4}

(1. Key Laboratory of Mariculture (Ministry of Education and), and Key Laboratory of Aquaculture Nutrition and Feed (Ministry of Agriculture and Rural Affairs), Ocean University of China, Qingdao China 266003; 2. Institute of Quality Standards and Testing Technology for Agricultural Products, Chinese Academy of Agricultural Sciences, Beijing 100081, China; 3. College of Agriculture, Ludong University, Yantai 264025, China; 4. Laboratory for Marine Fisheries Science and Food Production Processes, Qingdao National Laboratory for Marine Science and Technology, Qingdao China 266237)

Abstract: [Objective] Microbiome sequencing represents an effective tool for the advancement of aquatic nutrition research. To our knowledge, limit studies have conducted comprehensive investigations into the response of the host microbiome to trace minerals. In this study, we aim to investigate the potential applications of organic copper in the healthy aquaculture of white shrimp (*Penaeus vannamei* Boone, 1931) from the perspective of host microbiome (intestine, gill, and water microbiota), and explores its effects on the host microbiome's potential ecological functions. [Methods] In an 8-week feeding trial experiment, shrimp were fed diets with no copper, 30 mg/kg inorganic copper (CuSO₄·5H₂O) or organic copper (Cu-proteinate) supplementation. Physiological indicators were assessed, and the V3-V4 region of the 16S rRNA gene was sequenced on intestine, gill, and water samples. [Results] Shrimp fed the organic copper diet showed better health status and nutritional metabolic efficiency. The organic copper group exhibited unique alpha and beta diversities of shrimp microbiome, and demonstrated a more complex microbial co-occurrence network structure with promoted network natural connectivity and robustness. The core features at genus level were similar across all groups. However, the core features in the organic copper group contributed more to maintaining the stability of host microbial co-occurrence network, such as *Vibrio*, *Candidatus_Bacilloplasma*, and *Photobacterium*. Microbes with the capacity to enhance host nutrient metabolism were significantly enriched in the organic copper group, such as *Alloprevotella*, *Butyricoccus*, *f_Prevotellaceae*, and *Lactobacillus*. Moreover, this enrichment was synergistic with shrimp physiological indicators. The functional annotation indicated that the host microbiome in the organic copper group had higher nutritional and energy metabolic function abundance (Tax4Fun2 database) and ecological function abundance, such as carbon and nitrogen cycling (FAPROTAX database). [Conclusion] The use of organic copper in aquafeed shows a beneficial impact on the health of white shrimp. It has also been demonstrated to enhance the stability of the host microbiome community and to promote the functions of host nutrient metabolism and ecological cycling. This study confirmed the application of organic copper in aquafeed, from a microbiome insight, is beneficial for the advancement of healthy aquaculture and the innovation of aquafeed development.

Key words: Healthy aquaculture; Host microbiome; Microbiome community stability; Microbiota functions; Organic copper; *Penaeus vannamei* Boone, 1931

放养密度对大口黑鲈鱼养殖水质及鱼体营养品质的影响

张波^{1,2}, 沈奇健^{1,2}, 谢晓晖³, 温小波^{1,2}, 宁丽军^{1,2*}

(1. 华南农业大学, 海洋学院, 岭南现代农业科学与技术广东省实验室, 海洋生物资源保护与利用粤港联合实验室, 广东 广州 510642; 2. 广州南沙华农渔业研究院, 广东 广州 511457; 3. 广州市科沐生物科技有限公司, 广东 广州 510670)

摘要: 养殖密度是水产养殖的最重要的变量之一。为了探究放养密度对养殖水质以及鱼体营养品质的影响, 本研究以大口黑鲈为研究对象, 在高低密度养殖塘各采集 5 份水样, 并随机采集 4 尾大口黑鲈进行实验分析。低密度组放养密度分别为 3.26kg/m²(1 号塘)、3.24kg/m²(2 号塘)和 3.23kg/m²(3 号塘), 高密度组分别为 4.52kg/m²(4 号塘)、4.51kg/m²(5 号塘)和 4.55kg/m²(6 号塘)。结果显示, 高密度池塘水体溶氧、总磷和叶绿素 a 指标显著低于低密度池塘($P<0.05$), 总氮、亚硝酸盐和COD显著高于低密度塘($P<0.05$)。硅藻门、绿藻门、蓝藻门丰度低密度组均显著大于高密度组($P<0.05$)。此外, 高密度塘水体菌群Chao、Ace指数显著低于低密度塘($P<0.05$); 在门水平上, 经统计分析, 高低密度组放线菌门、变形菌门丰度均相对较高, 但高低密度组之间没有显著差异($P>0.05$)。在营养品质方面, 大口黑鲈肌肉的硬度、剪切力、咀嚼性、胶着性参数高密度小于低密度塘($P<0.05$); 肌肉粗蛋白和粗脂肪低密度组显著高于高密度组($P<0.05$), 粗灰分低密度组高于高密度组但没有显著性($P>0.05$)。研究表明, 高密度与低密度塘相比, 水质指标、藻类组成、菌群多样性及鱼体质构、营养成分等指标中大部分参数呈现一致性负面影响, 共同构成大口黑鲈水质与养殖环境的敏感参数。此外, 低密度组也呈现富营养化及轻度水质污染, 推测为本实验池塘未翻耕背景对水质产生负面影响, 提示底质改良对实际水产养殖生产的重要性。本研究结果可为优化高密度养殖提供理论参考。

关键词: 放养密度; 营养品质; 富营养化; 水质变化; 大口黑鲈

Effects of stocking density on water quality and fish nutrient quality in American Black Bass culture

Bo Zhang^{1,2}, Qijian Shen^{1,2}, Xiaohui Xie³, Xiaobo Wen^{1,2}, Lijun Ning^{1,2*}

(1. Joint Laboratory of Guangdong Province and Hong Kong Region on Marine Bioresource Conservation and Exploitation, College of Marine Sciences of South China Agricultural University & Guangdong Laboratory for Lingnan Modern Agriculture, Guangzhou, Guangdong 510642; 2. Guangzhou Nansha Huanong Fisheries Research Institute, Guangzhou, Guangdong 511457; 3. Guangzhou Kemu Biotechnology Co., Ltd, Guangzhou, Guangdong 510000)

Abstract: Stocking density is one of the most important variables in aquaculture. In order to investigate the effect of stocking density on the quality of cultured water as well as the nutritional quality of fish, this study took American Black Bass as the object of study, and five water samples were collected from each of the high and low density culture ponds, and four American Black Bass were randomly collected for experimental analysis. The stocking densities were 3.26 kg/m² (Pond 1), 3.24 kg/m² (Pond 2) and 3.23 kg/m² (Pond 3) for the low density group and 4.52 kg/m² (Pond 4), 4.51 kg/m² (Pond 5) and 4.55 kg/m² (Pond 6) for the high density group. The results showed that the indicators of dissolved oxygen, total phosphorus and chlorophyll *a* were significantly lower ($P < 0.05$) and total nitrogen, nitrite and COD were significantly higher ($P < 0.05$) in the water column of high-density ponds than in low-density ponds. The abundance of diatom phylum, green algal phylum and cyanobacterial phylum were significantly greater in the low density group than in the high density group ($P < 0.05$). In addition, the water column flora Chao and Ace indices of high-density ponds were significantly lower than those of low-density ponds ($P < 0.05$); at the phylum level, statistically analyzed, the abundance of Actinobacteria phylum and Ascomycetes phylum in both high- and low-density groups were relatively high, but there was no significant difference between high- and low-density groups ($P > 0.05$). In terms of nutritional quality, the hardness, shear force, chewiness, and adhesion parameters of American Black Bass muscle were less in high density than in low density ponds ($P < 0.05$); muscle crude

protein and crude fat were significantly higher in low density than in high density group ($P < 0.05$), and crude ash was higher in low density than in high density group but not significantly ($P > 0.05$). The study showed that most of the parameters in water quality indicators, algal composition, bacterial diversity and fish body composition, nutrient content and other indicators showed consistent negative impacts when compared with low-density ponds, which together constituted the sensitive parameters of American Black Bass water quality and aquaculture environment. In addition, the low-density group also showed eutrophication and mild water pollution, which was hypothesized to be the negative impact of the untilled background of the ponds in this experiment on water quality, suggesting the importance of substrate improvement for actual aquaculture production. The results of this study can provide theoretical reference for optimizing high-density culture.

Keywords: stocking density; nutrient quality; eutrophication; water quality change; American Black Bass

蓝桉精油对高温胁迫鳊鱼肠道的结构功能改善

陈雨霜¹, 王文洁¹, 于俊琦¹, 翟旭亮², 薛洋², 乔伟³, 汪福保⁴, 陈拥军¹,

刘海平¹, 罗莉^{1*}

(1. 西南大学水产学院, 西部(重庆)科学城种质创制大科学中心, 淡水鱼类资源与生殖发育教育部重点实验室, 重庆 400715; 2. 重庆市水产技术推广总站, 重庆 400400; 3. 云南绿宝香精香料股份有限公司, 云南 昆明 650000; 4. 广东杰大饲料有限公司, 广东 佛山 528211)

摘要: 本试验旨在研究日粮中蓝桉精油水平对高温胁迫下鳊鱼肠道结构和功能的改善作用。选取体质量为(16.74±0.22) g的300尾鳊鱼饲养2周, 随机分为5组, 每组3个重复, 每个重复20尾, 室温以1℃/d的速度分别升温到(32±1)℃。在基础饲料中依次添加蓝桉精油0、0.5、1、2、4g/kg, 分别命名为I0、I0.5、I1、I2、I4。结果显示: 鳊的终末体重(FBW)和增重率(WGR)随蓝桉精油添加量上升逐渐升高, 并在I1组达到最高, 分别升高了10.56%和19.74%, 饲料系数(FCR)显著降低后回升, 在I1组达到最低。与I0组相比, I1组和I4组肠道二胺氧化酶(ADO)活性与内毒素(ET)含量显著降低, I1组比I4组分别低了30.13%和9.79%; 总抗氧化能力(T-AOC)与谷胱甘肽过氧化物酶(GSH-Px)活性显著升高, 丙二醛(MDA)含量显著降低, I1组比I4组低了28.62%。I1组相较于I0组T-SOD、Na⁺-K⁺-ATP酶活性与免疫球蛋白M(IgM)含量显著升高($P<0.05$)。I0组肠黏膜皱襞排列疏松, 皱襞长度较短, 皱襞间质变宽; 肠微绒毛排列紊乱, 并且伴有微绒毛脱落; 细胞间紧密连接破坏严重; 线粒体数量明显减少、破碎, 线粒体嵴消失。与I0组相比, I1组肠道绒毛高度较高, 排列紧密, 所形成的皱襞面积较大, 肠道结构相对完整、绒毛完整、清晰; 肠微绒毛排列相对紧密有序, 细胞间紧密连接蛋白呈连续条带状, 线粒体结构完整; I4组肠微绒毛脱落程度有所改善, 但仍出现线粒体肿胀。高温胁迫下, 鳊鱼生长受到抑制、肠道屏障受损、抗氧化与免疫能力显著降低, 肠组织结构遭到破坏; 饲料中添加1~2 g/kg蓝桉精油可以有效改善高温对鳊肠道结构造成的应激损伤。

关键词: 鳊; 蓝桉精油; 氧化应激; 肠

Blue Eucalyptus Essential Oil Improves the Structural and Functional Integrity of the Intestine in Mandarin Fish Exposed to High Temperature Stress

Yushuang Chen¹, Wenjie Wang¹, Junqi Yu¹, Xuliang Zhai², Yang Xue², Wei Qiao³, Fubao Wang⁴, Yongjun Chen¹, Haiping Liu¹, Li Luo^{1*}

(1. Key Laboratory of Freshwater Fish Resources and Reproductive Development of Ministry of Education, College of Fisheries, Southwest University, Chongqing China 400716; 2. Chongqing Fisheries Technology Extension Station, Chongqing China 400400; 3. Yunnan Green Treasure Flavor & Fragrance Co., Ltd., Kunming China 650000; 4. Guangdong Jieda Feed Co., Ltd., Foshan China 528211)

Abstract: This experiment aimed to investigate the effects of dietary levels of eucalyptus oil on the improvement of intestinal structure and function in mandarin fish (*Siniperca chuatsi*) under high-temperature stress. A total of 300 mandarin fish with an initial body weight of (16.74±0.22) g were selected and raised for 2 weeks. The fish were randomly divided into 5 groups with 3 replicates per group and 20 fish per replicate. The room temperature was increased by 1°C/day to reach (32±1)°C. Eucalyptus oil was added to the basal diet at levels of 0, 0.5, 1, 2, and 4 g/kg, designated as I0, I0.5, I1, I2, and I4, respectively. The results showed that the final body weight (FBW) and weight gain rate (WGR) of the mandarin fish increased gradually with the addition of eucalyptus oil, reaching the highest levels in group I1, which increased by 10.56% and 19.74%, respectively. The feed conversion ratio (FCR) significantly decreased and then rebounded, reaching the lowest level in group I1. Compared to group I0, the activities of diamine oxidase (ADO) and endotoxin (ET) content in the intestine were significantly reduced in groups I1 and I4, with group I1 showing a 30.13% and 9.79% lower reduction compared to group I4, respectively. The total antioxidant capacity (T-AOC) and glutathione peroxidase (GSH-Px) activity significantly increased, while the malondialdehyde (MDA) content significantly decreased, with group I1 showing a 26.62% lower MDA content compared to group I4. Group I1 also showed significantly higher activities of total superoxide dismutase (T-SOD), Na⁺-K⁺-ATPase, and immunoglobulin M (IgM) content compared to group I0 (P<0.05). The intestinal mucosal folds in Group I0 are loosely arranged, with shorter fold lengths and widened interfold spaces. The intestinal microvilli are disorganized and accompanied by microvillus shedding. The tight junctions between cells are severely damaged. The number of mitochondria is significantly

reduced, and they are fragmented with loss of cristae. In contrast, Group I1 exhibits higher intestinal villi, tightly arranged, forming larger fold areas, with relatively intact and clear intestinal structures. The microvilli are relatively tightly and orderly arranged, and the tight junction proteins between cells form continuous belt-like structures. The mitochondrial structure remains intact. In Group I4, the degree of microvillus shedding is improved, but mitochondrial swelling is still observed. Under high temperature stress, the growth of mandarin fish is inhibited, the intestinal barrier is damaged, and antioxidant and immune capacities are significantly reduced. The intestinal tissue structure is compromised. The addition of 1-2 g/kg of eucalyptus oil to the diet can effectively alleviate the stress-induced damage to the intestinal structure of mandarin fish under high temperature conditions.

Key words: Mandarin fish; Eucalyptus oil; Oxidative stress; Intestine

适宜蛋白水平对稻田养殖克氏原螯虾 (*Procambarus clarkii*) 亲虾生长、繁殖性能及健康状况的促进作用¹

秦凤¹, 金鸿浩¹, 李雨¹, 吕光俊¹, 叶华¹, 罗辉^{1,*}

(1.西南大学水产学院, 淡水鱼类资源与生殖发育教育部重点实验室, 重庆 402460)

摘要:【目的】本研究旨在评估在稻田养殖条件下克氏原螯虾 (*Procambarus clarkii*) 的最适蛋白质需求。【方法】实验分别准备了六种等能和等脂的饲料, 其蛋白质含量分别为 28%、31%、34%、37%、40%和 43% (分别记为 P1-P6 组)。每个处理组设有 3 个重复, 每个重复包含 20 只初始平均体重为(20.30 ± 0.24)g 的克氏原螯虾, 并对其进行为期 56 天的饲养。

【结果】结果显示, P3 组的末均重、增重率和特定生长率均达到最大值, 且显著高于 P1 组和 P4-6 组 ($P < 0.05$)。当饲料蛋白质含量从 28%增加到 37%时, 繁殖指数、繁殖力、卵径和产卵量均有显著提高 ($P < 0.05$), 但当蛋白质含量进一步增加到 43%时, 则未观察到显著增长 ($P > 0.05$)。肌肉蛋白质含量随饲料蛋白质水平的增加而显著增加, 且在 P4 组中达到最高 ($P < 0.05$)。各组间的肌肉水分、粗脂肪和粗灰分含量无显著差异 ($P > 0.05$)。P3 组的天冬氨酸转氨酶和乳酸脱氢酶活性最高, 与 P1 组和 P4-6 组相比存在显著差异 ($P < 0.05$)。饲料蛋白质含量与总胆红素浓度呈正相关。饲料蛋白质含量对胰蛋白酶活性有显著影响, P6 组的胰蛋白酶活性显著高于 P1-4 组 ($P < 0.05$)。总超氧化物歧化酶、过氧化氢酶、谷胱甘肽过氧化物酶和溶菌酶的活性在 P2 组中达到峰值, 且显著高于 P6 组 ($P < 0.05$)。P4 组的一氧化氮浓度显著高于其他所有组 ($P < 0.05$)。丙二醛含量随饲料蛋白质水平的增加而显著增加, 且在 P6 组中达到最高 ($P < 0.05$)。【结论】综上, 在稻田养殖条件下, 饲料蛋白含量为 34%时, 克氏原螯虾展现出卓越的生长性能, 这一比例显著提高了鱼苗的抗氧化能力和免

资助项目: 广西创新驱动发展专项 (桂科 AA20302019-6); 重庆市水产科技创新联盟项目 (CQFTIU2024-11); 重庆市生态渔产业技术体系

通讯作者: 罗辉, E-Mail: Luohui2629@126.com

疫机能。进一步基于产卵量的综合考量，克氏原螯虾的最适饲料蛋白质含量为 38.62%，以此实现繁殖性能的优化。

关键词：克氏原螯虾；蛋白需求；生长性能；繁殖性能；健康；稻虾综合种养

Positive effects of optimal dietary protein level on the growth, reproductive performance, and health of red swamp crayfish (*Procambarus clarkii*) broodstock farming in rice field

Feng Qin¹, Honghao Jin¹, Yu Li¹, Guangjun Lv¹, Hua Ye¹, Hui Luo^{1,*}

(1. 1. Key Laboratory of Freshwater Fish Reproduction and Development (Ministry of Education), Key Laboratory of Aquatic Science of Chongqing, College of Fisheries, Southwest University, Chongqing 402460, China)

Abstract : [Objective] This study was conducted to evaluate the optimal protein requirement of *Procambarus clarkii* cultured in paddy field. [Methods] six types of isoenergetic and isolipidic diets with different protein content were prepared (28%, 31%, 34%, 37%, 40% and 43%), respectively. There were 3 replicates in each treatment and 20 crayfish in each replicate with an initial average body weight of (20.30 ± 0.24) g were fed for 56 days. [Results] Our results showed that final body weight, weight gain rate and specific growth rate were maximized in the P3 group, which was significantly higher than the P1 group and the P4-6 groups ($P < 0.05$). Significant improvements in reproductive index, fecundity, egg diameter and egg production were found by increasing the dietary protein level from 28% to 37% ($P < 0.05$), while no significant increase was observed when the protein level was further increased to 43% ($P > 0.05$). Muscle protein content significantly increased as dietary protein level increasing and was highest in P4 group ($P < 0.05$). There was no significant difference in muscle moisture, crude lipid and crude ash content of among all groups ($P > 0.05$). P3

group showed the maximum levels of aspartate transaminase and lactate dehydrogenase activity, with a significant difference ($P < 0.05$) compared to P1 and P4-6 groups. A positive correlation was observed between the dietary protein level and total bilirubin concentration. Dietary protein level had a significant impact on trypsin activity, with the P6 group showing significantly increased trypsin activity compared to the P1-4 groups ($P < 0.05$). The activity of total superoxide dismutase, catalase, glutathione peroxidase, and lysozyme peaked in the P2 group and was significantly higher than in the P6 group ($P < 0.05$). The nitric oxide concentration was significantly higher in the P4 group compared to all other groups ($P < 0.05$). The malondialdehyde content significantly increased as dietary protein level increasing, which was highest in the P6 group ($P < 0.05$). [Conclusion] The present study suggested that a dietary protein level of 34% provided superior growth performance of the *P. clarkii*, optimization of dietary protein content was found to be beneficial in enhancing both antioxidant capacity and immune function of the broodstock. The optimal dietary protein content for *P. clarkii* was 38.62% based on EP under the rice field rearing conditions.

Key words : *Procambarus clarkii*; dietary protein; growth; reproductive performance; health; rice-shrimp culture

转录组学和代谢组学联合分析揭示低磷饲料引起花鲈生长差异的机制

吴世杰, 金楠, 李学山*, 宋凯, 鲁康乐, 王玲, 张春晓*

(集美大学, 水产学院, 厦门市饲料检测与安全评价重点实验室, 福建 厦门 361021)

摘要: 为分析低磷饲料引起花鲈生长差异的机制, 试验选用初始体重为 4.49 ± 0.01 g 的花鲈 150 尾(50 尾/缸), 饲喂低磷饲料 8 周。试验结束时, 在每桶中分别选取体重最大和体重最小的五尾花鲈分别作为生长快速的花鲈(FG)和生长缓慢的花鲈(SG), 对其肝脏进行代谢组学与转录组学分析。FG 组花鲈肝脏抗氧化能力显著高于 SG 组。在两组中共检测到 431 个差异表达基因, 其中大部分差异表达基因参与如类固醇生物合成、糖酵解或糖异生、蛋白质消化吸收等的代谢相关途径, 其中与物质运输相关的调节因子和转运蛋白相关的通路显著上调。此外, FG 组花鲈肝脏中大量代谢物显著上调, 特别是氨基酸、左旋肉碱和脱氢表雄酮。差异代谢物与基因的分析进一步表明, 与 SG 组相比, FG 组花鲈肝脏中蛋白质消化吸收和苯丙氨酸新陈代谢途径的相互作用显著增加。综上所述, 低磷饲料可上调 FG 组花鲈肝脏的免疫反应、物质转运和氨基酸新陈代谢。本研究为花鲈生长速率差异的遗传机制和调控途径提供参考, 并为花鲈有效利用低磷饲料和人工育种提供了依据。

关键词: 花鲈; 转录组测序技术; 代谢组学; 生长。

Combination of Transcriptomics and Metabolomics Analyses Provides Insights into the Mechanisms of Growth Differences in Spotted Seabass (*Lateolabrax maculatus*) Fed a Low-Phosphorus Diet

Shijie Wu, Nan Jin, Xueshan Li*, Kai Song, Kangle Lu, Ling Wang, Chunxiao Zhang*

(Xiamen Key Laboratory for Feed Quality Testing and Safety Evaluation, Fisheries College, Jimei University, Xiamen 361021, P. R. China)

Abstract To analyze the potential mechanisms of growth differences in spotted seabass (*Lateolabrax maculatus*) fed a low-phosphorus diet, a total of 150 spotted seabass with an initial body weight of 4.49 ± 0.01 g were used (50 fish per tank) and fed a low-phosphorus diet for eight weeks. At the end of the experiment, five of the heaviest and five of the lightest fish were selected from each tank as fast-growing spotted seabass (FG) and slow-growing spotted seabass (SG), respectively, and their livers were analyzed by metabolomics and transcriptomics. The hepatic antioxidant capacity of the FG fed a low-phosphorus diet was significantly higher than that of the SG. A total of 431 differentially expressed genes (DEGs) were determined in the two groups, and most of the DEGs were involved in metabolism-related pathways such as steroid biosynthesis, glycolysis/gluconeogenesis, and protein digestion and absorption. Substance transport-related regulators and transporters were predominantly up-regulated. Furthermore, a large number of metabolites in the liver of FG were significantly up-regulated, especially amino acids, decanoyl-L-carnitine and dehydroepiandrosterone. The integration analysis of differential metabolites and genes further revealed that the interaction between protein digestion and absorption, as well as phenylalanine metabolism pathways were significantly increased in the liver of FG compared to those of the SG. In general, FG fed a low-phosphorus diet induced an enhancement in hepatic immune response, substance transport, and amino acid metabolism. This study provides new information on genetic mechanisms and regulatory pathways underlying differential growth rate and provides a basis for the foundation of efficient utilization of low-phosphorus diets and selective breeding programs for spotted seabass.

Key words *Lateolabrax maculatus*; RNA-seq; metabolomics; growth

通讯作者: 张春晓, E-Mail: cxzhang@jmu.edu.cn; 李学山, E-Mail: xsli@jmu.edu.cn

资助项目: 国家自然科学基金(32202955); 福建省自然科学基金(2023J05155; 20119J01688)

饲料磷脂水平对拟穴青蟹生长，卵巢发育和脂质代谢影响

郑佳^{1,2}，刘耕^{1,2*}

(1. 华南农业大学海洋学院，广东省岭南现代农业实验室，广东广州 510642)

摘要:拟穴青蟹 (*Scylla paramamosain*) 作为我国重要养殖蟹类，因其营养丰富、肉质鲜美，深受消费者喜爱，而卵巢发育成熟的雌性青蟹不仅营养价值更高，经济价值也比普通肉蟹高出很多。磷脂作为一类重要的复合脂，是水产动物饲料中重要的营养物质之一。虽然甲壳动物对磷脂的需求量一般较低，但其对甲壳动物生长、发育和生殖等方面都扮演重要角色。国内外专家学者已经在许多水产动物中开展了磷脂的营养研究，但是对拟穴青蟹的研究颇少。本论文以拟穴青蟹雌蟹为研究对象，设计四组不同磷脂水平（0%对照组、2%、4%、6%）的等氮等脂饲料开展 10 周养殖实验，分析不同饲料对青蟹生长性能、脂质代谢和卵巢发育的影响。具体研究内容和主要结果如下：1、饲料中不同磷脂水平对拟穴青蟹雌蟹生长性能、生理生化组成的影响 对生长性能而言，与对照组相比，4%组能显著提高拟穴青蟹的增重率、特定生长率和成活率 ($P < 0.05$)。对营养及生化组成而言，4%组肝胰腺粗脂肪和肌肉水分含量显著高于其他组 ($P < 0.05$)，但该组肌肉粗脂肪含量显著低于其他组 ($P < 0.05$)。各组间肝胰腺和卵巢中甘油三酯含量随着磷脂水平升高而显著升高 ($P < 0.05$)，最高值均在 6%组；另外 4%组肝胰腺中碱性磷酸酶和酸性磷酸酶活性显著高于对照组 ($P < 0.05$)。磷脂添加 4%组血清中甘油三酯、低密度脂蛋白、卵黄蛋白原、孕酮、 17β -雌二醇含量显著高于其他组 ($P < 0.05$)，而该组谷丙转氨酶和谷草转氨酶活性显著降低 ($P < 0.05$)；血清中胆固醇和高密度脂蛋白含量分别出现在 2%组和 6%组，均显著升高 ($P < 0.05$)。4%组眼柄中性腺抑制激素含量显著高于对照组 ($P < 0.05$)，但该组蜕皮抑制激素含量与对照组无显著差异 ($P > 0.05$)。2、饲料中不同磷脂水平对拟穴青蟹雌蟹抗氧化能力、消化能力、脂肪酸组成及组织结构的影响 对抗氧化能力和消化能力而言，4%组肝胰腺中超氧化物歧化酶、淀粉酶活性显著高于其他组 ($P < 0.05$)，同时该组丙二醛含量显著降低 ($P < 0.05$)；肝胰腺中总抗氧化能力最高值出现在 2%组，脂肪酶活性最高值出现在 6%组，均显著高于对照组 ($P < 0.05$)。对脂肪酸组成而言，肝胰腺中 ARA、EPA、DHA、n-3 HUFA 含量随着饲料中磷脂水平逐渐升高呈现出先升高后下降趋势，且 4%组 DHA/EPA 比例显著高于其他组 ($P < 0.05$)；肌肉 ARA、EPA、DHA 含量随着磷脂水平升高而显著升高，2%和 4%组 n-3 HUFA 含量 III 均显著高于对照组 ($P < 0.05$)，说明磷脂添加能为卵巢发育提供更多能量和必需脂肪酸。与对照组相比，磷脂添加组肠道肌层厚度和绒毛长度均显著升高 ($P < 0.05$)，肝胰腺中 B 细胞、R 细胞及脂滴数量也明显增加。3、饲料中不同磷脂水平对拟穴青蟹雌蟹脂质代谢和卵巢发育相关基因表达量的影响 对肝胰腺而言，4%组能显著上调组织中脂质吸收、转运和氧化相关基因 (*Fabp 1*、*Fatp 4*、*Cpt-1*、*Cpt-2*、*Aco 1*、*Aco 3*、*Mttp*) 的表达水平 ($P < 0.05$)；同时磷脂添加 6%时也能显著上调脂质合成基因 (*Srebp 1*、*Fas*、*Dgat 1*) 和磷脂代谢相关基因 (*PLALpcat*) 的表达水平 ($P < 0.05$)，但磷脂添加对 *Agpat 9* 的 mRNA 表达量无显著差异 ($P > 0.05$)。对卵巢而言，各组间 *Fatp 4*、*Aco 1*、*Elovl 6* 和 *17β-HSD* 的表达水平无显著差异 ($P > 0.05$)。相对于对照组，4%组能显著上调 $\Delta 9$ *Fad*、*Fas*、*Dgat 1*、*Fabp 1* 和卵巢发育 (*Vtg*、*Vgr*) 相关基因的表达水平 ($P < 0.05$)；同时磷脂添加 6%时，*Acs1 1* 和 *Cpt-1* 的 mRNA 表达量也显著升高 ($P < 0.05$)。综上所述，磷脂添加 4%时可以提高拟穴青蟹的生长性能、抗氧化能力和消化能力，也可以维护肠道和肝胰腺的正常组织形态，保证其基本功能。同时磷脂添加可以促进蟹体脂质运输和卵巢发育。本研究结果一方面可为拟穴青蟹雌蟹饲料中磷脂的添加提供现实指导，另一方面能为甲壳动物脂代谢和卵巢发育研究提供理论基础和参考。

关键词:拟穴青蟹；磷脂；脂代谢；卵巢发育

Effects of dietary phospholipid levels on growth, ovarian development and lipid metabolism of female *Scylla paramamosain*

Abstract: *Scylla paramamosain*, as an important cultured crab in china, is very popular among consumers because of its rich nutrition and delicious meat, while female crabs with mature ovaries not only have higher nutritional value, but also economic value than ordinary meat crabs. As an important complex lipid, phospholipids are one of the important nutrients in aquatic animal feed. Although crustaceans generally have a low demand for phospholipids, but they play an important role in growth, development and reproduction of crustaceans. Experts and scholars at domestic and foreign have carried out nutritional research on phospholipids in many aquatic animals, but there is little research on burrowing *Scylla paramamosain*. In this thesis, four groups of isonitrogen and other fat feeds with different phospholipid levels (0% control group, 2%, 4%, 6%) were designed to carry out 10-week breeding experiments to analyze the effects of different feeds on growth performance, lipid metabolism and ovarian development of *Scylla paramamosain*. The specific research content and main results are as follows: 1. Effects of different dietary phospholipid levels on growth performance, physiological and biochemical composition of female crabs of *Scylla paramamosain* In terms of growth performance, compared with the control group, the 4% group could significantly improve the weight gain rate, specific growth rate and survival rate of crabs ($P < 0.05$), while nutrition and biochemical composition, hepatopancreas crude fat and muscle water content in 4% group was significantly higher than that in other groups ($P < 0.05$), but muscle crude fat content in this group was significantly lower ($P < 0.05$). The content of triglycerides in the hepatopancreas and ovaries increased significantly with the increase of phospholipid levels between the groups ($P < 0.05$), and the highest values were in the 6% group. In addition, the activity of alkaline phosphatase and acid phosphatase in the III hepatopancreas was significantly higher in the 4% group than in the control group ($P < 0.05$). Serum triglycerides contents, low-density lipoprotein, vitelin, progesterone, and 17β -estradiol in the 4% group were significantly higher than those in other groups ($P < 0.05$), the activities of alanine aminotransferase and aspartate aminotransferase in this group were significantly reduced ($P < 0.05$), serum cholesterol and high-density lipoprotein contents were significantly increased in the 2% and 6% groups, respectively ($P < 0.05$). The content of gonadal suppressor hormone in the ocular stalk of the 4% group was significantly higher than that in the control group ($P < 0.05$), but the ecdysin-suppressing hormone content was not change from that in the control group ($P > 0.05$). 2. Effects of different dietary phospholipids levels on antioxidant capacity, digestion, fatty acid composition and tissue structure of female crabs of *Scylla paramamosain* In terms of antioxidant capacity and digestive capacity, the activities of superoxide dismutase and amylase in the 4% group were significantly higher than those in other groups ($P < 0.05$), and malondialdehyde presents the opposite manifestation ($P < 0.05$), whereas the total antioxidant capacity in the hepatopancreas in the 2% group and lipase activity in the 6% group were significantly higher than those in the control group ($P < 0.05$). For fatty acid composition, the contents of ARA, EPA, DHA and n-3 HUFA in the hepatopancreas showed a trend of increasing first and then decreasing with the gradual increase of phospholipid levels in feed, and the DHA/EPA ratio in the 4% group was significantly higher than that in other groups ($P < 0.05$). The contents of muscle ARA, EPA and DHA increased significantly with the increase of phospholipid levels, and the contents of n-3 HUFA in the 2% and 4% groups were significantly higher than those in the control group ($P < 0.05$), indicating that phospholipid addition could provide more energy and essential fatty acids for ovarian development. Compared with the control group, the thickness of the intestinal muscles and villi length were significantly increased in the phospholipid addition group ($P < 0.05$), and the number of B cells, R cells and lipid droplets in the hepatopancreas was also significantly increased. 3. Effects of dietary phospholipids on lipid metabolism and gene expression related to ovarian development in female crabs of *Scylla paramamosain* IVV For the hepatopancreas, the 4% group could significantly upregulate the expression levels of lipid uptake, transport and oxidation-related genes (*Fabp 1*, *Fatp 4*, *Cpt-I*, *Cpt-II*, *Aco 1*, *Aco 3*, *Mtp*) in tissues ($P < 0.05$), at the same time, the lipid synthesis genes (*Srebp 1*, *Fas*, *Dgat 1*) and phospholipid metabolism-related genes (*PLA2*, *Lpcat*) ($P < 0.05$) could be significantly upregulated when phospholipids were added at 6%, but there was no significant difference of *Agpat9* ($P > 0.05$). For ovaries, there were no significant differences in the expression levels of *Fatp 4*, *Aco 1*, *Elovl 6* and 17β -HSD between groups ($P > 0.05$). Compared with the control group, the expression levels of genes related to $\Delta 9$ *Fad*, *Fas*, *Dgat 1*, *Fabp 1* and ovarian development (*Vtg*, *Vgr*) could be significantly upregulated in the 4% group ($P < 0.05$). At the same time, when phospholipids were added by 6%, the mRNA expression of *Acs1 1* and *Cpt-I* was also significantly increased ($P < 0.05$). In summary, adding 4% phospholipids can improve the growth performance, antioxidant ability and digestive ability, and can also maintain the normal tissue morphology of the intestine and hepatopancreas to ensure their basic functions. Moreover, phospholipids supplementation can promote lipid transport and ovarian development of crabs. On the one hand, the results of this study can provide practical guidance for the addition of phospholipids in feed of female crabs, and on the other hand, it can provide a theoretical basis and reference for the study of lipid metabolism and ovarian development in crustaceans.

Key words: *Scylla paramamosain*; Phospholipids; Lipid metabolism; Ovarian development