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# 饲料钙磷水平对宝石鲈生长和体成分的影响

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**摘要**:以酪蛋白和明胶作为蛋白源,乳酸钙(Ca-lactate)和磷酸二氢钠($NaH_2PO_4 \cdot 2H_2O$)为钙源和磷源,配制成$D_1$(0.0%钙,0.0%磷)、$D_2$(0.5%钙,0.0%磷)、$D_3$(0.0%钙,0.6%磷)、$D_4$(0.5%钙,0.6%磷)、$D_5$(1.0%钙,0.6%磷)和$D_6$(1.5%钙,0.6%磷)六种等氮等能纯化试验饲料。每组饲料饲喂3个重复,每重复饲养20尾宝石鲈幼鱼,经过室内网箱60 d生长试验,探讨在饲料中添加钙磷对宝石鲈幼鱼[初始体重(13.42±0.68) g]生长性能、全鱼和肌肉营养成分以及脊椎骨钙磷含量的影响。试验结果表明:饲料中未添加磷组($D_1$和$D_2$)试验鱼的终末体重、特定生长率和脊椎骨钙磷含量显著低于添加组($P<0.05$),而饲料系数、全体和肌肉脂肪含量显著高于添加组($P<0.05$)。当饲料中未添加磷时,添加0.5%钙对宝石鲈的特定生长率、饲料系数、全鱼和肌肉营养成分、脊椎骨的灰分和钙磷含量没有显著影响($P>0.05$)。当饲料中添加0.6%磷时,钙的添加量(0～1.5%)对宝石鲈的终末体重、特定生长率、饲料系数、全鱼组成、肌肉组成(水分、粗蛋白和灰分)和脊椎骨组成(粗灰分、磷和钙磷比)没有显著影响($P>0.05$)。饲料中钙添加量过大(1.5%)组脊椎骨钙含量显著减少($P<0.05$)。饲料中添加磷显著降低了鱼体中粗脂肪含量($P<0.05$),但提高了脊椎骨钙磷的含量($P<0.05$)。各组脊椎骨钙磷比均处于1.78～1.82范围内,组间差异不显著($P>0.05$)。通过宝石鲈幼鱼生长性能和脊椎骨矿化作用分析表明,当饲料中添加0.6%磷时,钙的适宜添加量为0.5%。

**关键词**:宝石鲈;生长;体成分;钙;磷
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钙磷是维持鱼类正常生长和骨骼发育的重要矿物质元素,它们在骨骼形成和维持体液酸碱平衡中起重要作用,缺钙或缺磷都会引起鱼类生长缓慢、饲料转换率低和死亡率高等现象的发生。钙参与肌肉收缩、血液凝固、渗透压调节、多种酶的激活和细胞膜的完整性和通透性维持等过程,鱼类可直接从水体或饲料中吸收钙来满足身体新陈代谢的需求[1-4]。饲料中钙含量水平影响其它矿物质如磷、锌和镁等的吸收[5-8],但饲料中钙含量过高则会抑制磷的吸收[5]。磷是鱼体内骨骼的重要成分,鱼体三分之一以上的磷储存在磷脂、核酸、细胞膜和其它高能化合物中[9],因此磷在糖类、脂类和蛋白质的新陈代谢、肌肉收缩、神经传导以及体液缓冲调节中发挥重要作用[4,9]。鱼类可直接从水体中吸收磷,但养殖水域中磷含量很低,鱼类必须从饲料中获得磷来满足生长和自身代谢的需要[9],通常鱼类对磷的需求量为0.5%～0.8% [4]。鱼摄食低磷饲料通常产生磷缺陷症状,包括生长缓慢、饲料效率降低和骨骼发育不正常[4,9-10],甚至有时造成身体畸形[10]。

宝石鲈(*Scortum bacoo*)隶属于鲈形目,鯻科,革鯻属,仅分布于澳大利亚的淡水水域。宝石鲈杂食性,具有生长速度快、抗病性强、出肉率高、运输成活率高等优点,近年来受到澳大利亚及周

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边国家和地区人们的青睐。当前,对宝石鲈营养需求方面的研究较少,尚未见有关饲料钙磷含量对宝石鲈生长和体成分影响研究的报道。通过本研究以期为宝石鲈配合饲料的研制提供理论依据,促进宝石鲈养殖业的健康发展。

## 1 材料与方法

### 1.1 材料

宝石鲈幼鱼取自山东省淡水水产研究所良种室,初始体重(13.42 ±0.68) g,初始体长(7.93 ±0.48) cm。酪蛋白、明胶、乳酸钙(Ca-lactate)和磷酸二氢钠($NaH_2PO_4 \cdot 2H_2O$)购自济南一试剂商店,为化学纯。玉米淀粉、鱼油、单项矿物元素和维生素等主要原料由山东天神饲料有限公司提供。

### 1.2 试验设计

饲料原料经粉碎研磨过 40 目筛,混合均匀,制成基础饲料,基础饲料不添加钙和磷(表 1)。在基础饲料中添加钙(0.0%,0.5%,1.0% 和 1.5%)和磷(0.0% 和 0.6%)配制成 6 种等氮等能纯化试验饲料,试验饲料的设计见表 2。钙源为 Ca-lactate,磷源为 $NaH_2PO_4 \cdot 2H_2O$,用纤维素来调节饲料中钙、磷的添加。试验饲料加工成粒径 2.5 mm 的颗粒饲料。各试验组设置三重复。

**表 1 基础饲料配方及营养组成**

**Tab.1 Formulation and proximate composition of the basal diet**

| 成分 ingredient | 干物质(%) in dry weight |
|---|---|
| 酪蛋白 casein | 30 |
| 明胶 gelatin | 7 |
| 鱼油 fish oil | 9 |
| 玉米淀粉 corn starch | 30 |
| 氯化胆碱 choline chloride | 0.5 |
| 复合矿物盐 mineral premix | 2 |
| 复合维生素 vitamin premix | 2 |
| 纤维素 cellulose | 19.5 |
| 营养组成 proximate composition(% in dry weight) | |
| 粗蛋白 crude protein | 36.2 |
| 粗脂肪 crude lipid | 8.5 |
| 粗灰分 ash | 2.5 |

注:1. 复合矿物盐(mg/kg 饲料):$MgSO_4 \cdot 7H_2O$, 5500; Ferric citrate, 150; $CoCl_2 \cdot 6H_2O$, 4; $MnSO_4 \cdot H_2O$, 3; KI, 7; $AlCl_3 \cdot 6H_2O$, 8; $CuSO_4 \cdot 5H_2O$, 8; KCl, 4 000; $ZnSO_4 \cdot 7H_2O$, 140; $Na_2SeO_3$, 0.6。2. 复合维生素(mg 或 IU/kg 饲料):维生素 $B_1$,50;维生素 $B_2$,200;生素 $B_6$,50;维生素 $B_{12}$,0.1;泛酸钙,500;烟酸,750;叶酸,15;肌醇,2000;维生素 $K_3$,40;维生素 A 5000 IU;生物素,5;维生素 C,400;维生素 $D_3$,2 000 IU;维生素 E,400

Notes:1. Mineral premix (mg/kg mixture): $MgSO_4 \cdot 7H_2O$, 5 500; Ferric citrate, 150; $CoCl_2 \cdot 6H_2O$, 4; $MnSO_4 \cdot H_2O$, 3; KI, 7; $AlCl_3 \cdot 6H_2O$, 8; $CuSO_4 \cdot 5H_2O$, 8; KCl, 4 000; $ZnSO_4 \cdot 7H_2O$, 140; $Na_2SeO_3$, 0.6. 2. Vitamin premix (mg or IU/kg diet): thiamin hydrochloride, 50; riboflavin, 200; pyridoxine hydrochloride, 50; vitamin $B_{12}$, 0.1; calcium pantothenate, 500; nicotinic acid, 750; folic acid, 15; inositol, 2 000; menadione, 40; retinol acetate, 5 000 IU; biotin, 5; ascorbic phosphate ester 400; cholecalciferol, 2 000 IU; alphatocopheryl acetate, 400

**表 2 试验各组钙、磷的添加和含量分析**

**Tab.2 Calcium and phosphorus supplements and their analyzed content in experimental diets**

| 组别 group | 添加量(g/100 g) supplement | | 分析含量(g/100 g) analyzed | |
|---|---|---|---|---|
| | 钙 calcium | 磷 phosphorus | 钙 calcium | 磷 phosphorus |
| $D_1$ | 0.0 | 0.0 | 0.25 | 0.31 |
| $D_2$ | 0.5 | 0.0 | 0.76 | 0.30 |
| $D_3$ | 0.0 | 0.6 | 0.24 | 0.93 |
| $D_4$ | 0.5 | 0.6 | 0.77 | 0.92 |
| $D_5$ | 1.0 | 0.6 | 1.23 | 0.92 |
| $D_6$ | 1.5 | 0.6 | 1.79 | 0.91 |

注:1. 钙源为 Ca-lactate;2. 磷源为 $NaH_2PO_4 \cdot 2H_2O$

Notes: 1. Ca as Ca-lactate; 2. P as $NaH_2PO_4 \cdot 2H_2O$

### 1.3 试验鱼的饲养及日常管理

试验在山东省淡水水产研究所国家级水产良种场温室内同一个圆形水泥池(规格 $r = h = 150$ cm)中进行。试验幼鱼先在温室内水泥池内驯养 7 d,每天投喂未添加钙、磷组($D_1$)饲料 3 次,投喂时间为 8:30、13:30 和 17:00。水泥池四周挂有 18 个聚乙烯网箱,网箱规格为 60 cm ×60 cm ×120 cm,每箱放 20 尾鱼,随机分为 6 组,每组 3 个重复。池中水位高 150 cm,网箱有效水位 100 cm。试验水源为玉景矿泉水厂 700 m 深井水(水温 25 ℃),试验期间水温(25 ±1) ℃;水泥池中间有增氧气头,24 h 充气;$NH_3$-N <0.4 mg/L。每 5 天换水一次,换水量为 1/3,每天投喂 3 次,时间分别为 8:30,13:30,17:00,投饵量为 8% 左右。每 5 天清理网箱的残饵和粪便一次,饲养时间为 2007 年 8 月 3 号 –10 月 3 号,共 60 d。

### 1.4 样品分析测定方法

试验开始时随机选取 20 尾幼鱼,进行初始体长和体重的测定,试验结束时对各个网箱所有试验幼鱼测定终末体长和体重。试验开始和结束时,试验鱼饥饿 24 h 后准确称重,并根据以下公式计算成活率、相对增长率、相对增重率、饲料系数和蛋白质效率。

相对增重率(%)=(终末体重 - 初始体重)/初始体重 ×100;

特定生长率(%/d)=(Ln 试验结束体重 - Ln 试验初始体重)/试验天数 ×100

饲料系数=饲料总消耗量/总增重;

成活率(%)=终末尾数/初始尾数 ×100

生长试验结束后,从各饲料组随机取宝石鲈 5 尾,吸干鱼体外表的水分后,将全鱼剪成块,捣碎,混合均匀进行全鱼营养成分的测定;另取 5 尾吸干鱼体外表水分后,去皮去骨,将全鱼的肌肉剪成块,捣碎,混合均匀进行肌肉营养成分的测定;从每个养殖组取 5 尾鱼,吸干鱼体外表的水分后用微波炉加热至鱼体熟化后,分离脊柱,用去离子水冲洗干净,干燥,粉碎后去脂制备脱脂干骨[11]测定脊椎骨灰分和钙磷含量。水分测定用常压干燥法;采用凯氏定氮法测定粗蛋白的含量;采用索氏抽提法(乙醚为溶剂)测定粗脂肪含量;灰分是在马福炉中焚烧(550 ℃)测得;钙用乙二胺四乙酸二钠法测定;用钒钼酸铵法测得磷含量。

### 1.5 数据统计

采用 Statistics 分析软件进行单因子方差分析和 Duncan 氏多重检验,显著水平采用 $P<0.05$。

## 2 结果

### 2.1 饲料中添加钙磷对宝石鲈生长和饲料利用的影响

饲料中不同含量的钙磷喂养宝石鲈幼鱼 60 d(表 3),对宝石鲈生长和饲料利用有显著影响($P<0.05$)。饲料中未添加磷组($D_1$ 和 $D_2$)试验鱼终末体重和特定生长率显著低于添加组($P<0.05$),而饲料系数显著高于添加组($P<0.05$)。当饲料添加 0.6% 磷时($D_3$ ~ $D_6$),饲料中添加不同含量的钙(0.0% ~1.5%)对宝石鲈幼鱼的终末体重(33.40 ~34.61 g)、特定生长率(1.51% ~1.57%)和饲料系数(1.15 ~1.20)没有显著影响($P>0.05$)。整个试验期间未发生宝石鲈死亡现象,成活率均为 100%。

**表 3 饲料中添加钙磷对宝石鲈生长和饲料利用的影响**

**Tab. 3 Effect of dietary Ca and P contents on growth and feed utilization of *Scortum bacoo***

mean ± SD, $n=3$

| 组别<br>group | 终末体重(g)<br>final weight | 特定生长率(%/d)<br>special growth rate | 饲料系数<br>feed conversion rate | 成活率(%)<br>survival rate |
|---|---|---|---|---|
| $D_1$ | $30.23 \pm 1.47^b$ | $1.36 \pm 0.06^b$ | $1.55 \pm 0.12^a$ | 100 |
| $D_2$ | $29.37 \pm 1.25^b$ | $1.30 \pm 0.07^b$ | $1.51 \pm 0.05^a$ | 100 |
| $D_3$ | $33.40 \pm 0.80^a$ | $1.51 \pm 0.04^a$ | $1.18 \pm 0.09^b$ | 100 |
| $D_4$ | $34.61 \pm 1.02^a$ | $1.57 \pm 0.05^a$ | $1.15 \pm 0.07^b$ | 100 |
| $D_5$ | $34.38 \pm 0.81^a$ | $1.56 \pm 0.04^a$ | $1.17 \pm 0.08^b$ | 100 |
| $D_6$ | $33.52 \pm 1.13^a$ | $1.52 \pm 0.05^a$ | $1.20 \pm 0.06^b$ | 100 |

注:表中同列不同字母表示差异显著($P<0.05$)

Notes: Means in the same row with different superscripts indicate significant difference ($P<0.05$)

### 2.2 饲料中添加钙磷对宝石鲈全鱼组成的影响

饲料中添加钙磷对全鱼营养成分的影响见表 4。饲料中钙磷水平对宝石鲈全鱼水分(62.53% ~63.42%)、粗蛋白(42.84% ~44.08%)和灰分(7.85% ~8.24%)含量没有显著影响($P>0.05$),但影响鱼体中粗脂肪的含量,添加钙磷组 $D_4$、$D_5$ 和 $D_6$ 的全鱼脂肪含量(48.01%,48.40% 和 48.53%)显著低于未添加钙磷组 $D_1$(51.61%)含量($P<0.05$)。当饲料中磷含量相同时,饲料中添加钙对全鱼脂肪含量(48.01% ~50.28%)没有显著影响($P>0.05$)。

**表 4 饲料中添加钙磷对宝石鲈全鱼组成的影响**

**Tab. 4 Effect of dietary Ca and P contents on whole body compositions of *Scortum bacoo***

**mean ± SD, *n* = 3**

| 组别 group | $D_1$ | $D_2$ | $D_3$ | $D_4$ | $D_5$ | $D_6$ |
|---|---|---|---|---|---|---|
| 水分 moisture | 62.55 ± 0.99 | 62.53 ± 1.32 | 63.36 ± 0.95 | 63.42 ± 0.65 | 62.69 ± 1.01 | 62.84 ± 0.90 |
| 粗蛋白 crude protein | 43.43 ± 1.21 | 42.84 ± 1.14 | 43.83 ± 1.01 | 43.30 ± 0.89 | 43.09 ± 1.37 | 44.08 ± 0.53 |
| 粗脂肪 crude lipid | $51.62 \pm 1.24^{a}$ | $50.22 \pm 0.32^{ab}$ | $50.28 \pm 1.29^{ab}$ | $48.01 \pm 0.39^{b}$ | $48.40 \pm 3.56^{b}$ | $48.53 \pm 0.58^{b}$ |
| 粗灰分 ash | 8.16 ± 0.30 | 7.97 ± 0.05 | 8.22 ± 0.22 | 8.24 ± 0.41 | 8.00 ± 0.50 | 7.85 ± 0.31 |

注:表中同列不同字母表示差异显著($P<0.05$)

Notes: Means in the same row with different superscripts indicate significant difference ($P<0.05$)

### 2.3 饲料中添加钙磷对宝石鲈肌肉组成的影响

试验后各试验组宝石鲈幼鱼肌肉水分、粗蛋白、粗脂肪和灰分含量见表 5。饲料中添加钙磷对宝石鲈肌肉水分(69.81% ~ 71.58%)、粗蛋白(63.05% ~ 65.39%)和灰分(4.63% ~ 5.23%)含量没有显著影响($P>0.05$),但随着钙磷添加量的增加,肌肉灰分含量具有升高趋势。饲料钙磷水平影响肌肉中粗脂肪的含量($P<0.05$)。$D_5$ 和 $D_6$ 组的肌肉脂肪含量(34.15% 和 33.39%)显著低于未添加钙磷组 $D_1$(36.14%)含量($P<0.05$)。当饲料添加 0.6% 磷时,饲料中添加钙对肌肉脂肪含量有显著影响,随着饲料中钙添加量的增加,肌肉脂肪含量显著降低,1.5% 钙组($D_6$)肌肉脂肪含量(33.39%)显著低于 0.0% 钙组和 0.5% 钙组(35.00% 和 35.02%)含量($P<0.05$)。

**表 5 饲料中添加钙磷对宝石鲈肌肉组成的影响**

**Tab. 5 Effect of dietary Ca and P contents on muscle compositions of *Scortum bacoo***

**mean ± SD, *n* = 3**

| 组别 group | $D_1$ | $D_2$ | $D_3$ | $D_4$ | $D_5$ | $D_6$ |
|---|---|---|---|---|---|---|
| 水分 moisture | 69.81 ± 1.68 | 69.97 ± 1.19 | 70.96 ± 1.30 | 71.58 ± 0.82 | 70.35 ± 0.99 | 70.49 ± 1.24 |
| 粗蛋白 crude protein | 63.55 ± 1.09 | 64.15 ± 1.95 | 63.93 ± 1.32 | 65.39 ± 0.65 | 64.92 ± 3.25 | 63.05 ± 1.35 |
| 粗脂肪 crude lipid | $36.14 \pm 1.26^{a}$ | $35.17 \pm 0.43^{ab}$ | $35.00 \pm 1.04^{ab}$ | $35.02 \pm 0.98^{ab}$ | $34.15 \pm 0.29^{bc}$ | 33.39 ± 0.87 |
| 粗灰分 ash | 4.81 ± 0.32 | 4.63 ± 0.22 | 4.85 ± 0.10 | 4.84 ± 0.28 | 5.00 ± 0.10 | 5.23 ± 0.40 |

注:表中同列不同字母表示差异显著($P<0.05$)

Notes: Means in the same row with different superscripts indicate significant difference ($P<0.05$)

### 2.4 饲料中添加钙磷对宝石鲈脊椎骨组成的影响

摄食不同钙磷水平饲料 60 d 后宝石鲈脊椎骨的灰分、钙磷含量及钙磷比见表 6。试验各组脊椎骨的粗灰分含量(49.04% ~ 52.75%)没有显著差异,但饲料中添加钙磷使脊椎骨的灰分含量具有升高趋势($P>0.05$)。未添加磷组($D_1$ 和 $D_2$)试验鱼脊椎骨钙磷含量显著低于 $D_4$ 和 $D_5$ 组($P<0.05$),与 $D_3$ 和 $D_6$ 组差异不显著($P>0.05$)。饲料中添加磷后,钙的添加量对脊椎骨钙含量有显著影响,1.5% 钙组钙含量(13.64%)显著低于 1.0% 钙组(14.44%)含量($P>0.05$),但对脊椎骨磷含量(7.72% ~ 8.00%)没有显著影响($P>0.05$)。各组脊椎骨钙磷比均处于 1.78 ~ 1.82 范围内,组间差异不显著($P>0.05$)。

**表 6 饲料中添加钙磷对宝石鲈脊椎骨组成的影响**

**Tab. 6 Effect of dietary Ca and P content on vertebrae compositions of *Scortum bacoo***

**mean ± SD, *n* = 3**

| 组别 group | $D_1$ | $D_2$ | $D_3$ | $D_4$ | $D_5$ | $D_6$ |
|---|---|---|---|---|---|---|
| 粗灰分 ash | 49.04 ± 1.18 | 50.45 ± 1.39 | 52.82 ± 1.59 | 52.34 ± 1.61 | 52.52 ± 1.72 | 52.75 ± 1.02 |
| 钙 Ca | $13.31 \pm 0.07^{c}$ | $13.62 \pm 0.42^{c}$ | $13.84 \pm 0.54^{abc}$ | $14.31 \pm 0.62^{ab}$ | $14.44 \pm 0.07^{a}$ | $13.64 \pm 0.13^{bc}$ |
| 磷 P | $7.40 \pm 0.07^{b}$ | $7.46 \pm 0.22^{b}$ | $7.72 \pm 0.22^{ab}$ | $7.94 \pm 0.37^{a}$ | $8.00 \pm 0.11^{a}$ | $7.74 \pm 0.23^{ab}$ |
| 钙磷比 Ca/P | 1.81 ± 0.02 | 1.82 ± 0.03 | 1.79 ± 0.03 | 1.80 ± 0.03 | 1.81 ± 0.02 | 1.78 ± 0.03 |

注:表中同列不同字母表示差异显著($P<0.05$)

Notes: Means in the same row with different superscripts indicate significant difference ($P<0.05$)

## 3 讨论

饲料中添加0.6%磷显著提高了宝石鲈的生长性能和饲料利用率(表3),饲料中磷不足导致特定生长率较低和饲料系数较高。饲喂低磷饲料在其它鱼类也发现生长缓慢和饲料利用率低的现象,如欧洲鲈(*Dicentrarchus labrax* L.)[12]、鳕(*Melanogrammus aeglefinus* L.)[13-14]、虹鳟(*Oncorhynchus mykiss*)[15]、阳光鲈(*Morone chrysops* × *M. saxatilis*)[16]、斑点叉尾鮰(*Ictalurus punctauts*)[17-19]、真鲷(*Chrysophrys major*)[20],罗非鱼(*Orechromis aureus*)[21]、条纹鲈(*Morone saxatilis*)[22] 和遮目鱼[*Chanos chanos* (Forsskål)][23]。Baeverfjord 等[24]推测由于饲料磷不足引起鱼生长缓慢现象的发生很可能是磷缺乏导致自身代谢功能受损引起的。鱼类可直接从水体中吸收磷,但养殖水域中磷含量和吸收利用率很低,鱼类必须从饲料中获得磷来满足生长和自身代谢的需要[9]。如饲料中磷含量低,鲤(*Cyprinus carpio* L.)体内的脂肪便不能作能源有效利用,积蓄于体内,使鲤肥满度增高;又因蛋白质较多地作为能源而消耗,导致增重率降低;而摄取适宜磷量饲料的鲤,促进了脂肪在体内的氧化,蛋白质可少转变为能源,有助于节约蛋白和体重增加[25]。摄食低磷饲料鲤的肝脏糖异生酶活性升高[26]、体脂肪含量高[27]、血磷水平低[28]。磷摄入不足也会导致真鲷血浆碱性磷酸酶活性升高和肝糖原含量降低[29]。研究者发现饲喂低磷饲料未导致虹鳟[30]和大西洋鲑(*Salmon salar*)[31-32]生长减慢和饲料效率低。大量研究表明,大多数鱼类可从养殖水体中吸收钙来满足生理需求,饲料中不需添加钙[3,33-35]。淡水中的鱼类如鲤、虹鳟、大马哈鱼[*Oncorhynchus keta*(Walbaum)]、斑点叉尾鮰和孔雀鱼(*Poecilia reticulate*)饲料中不需额外添加钙[36-39]。本试验发现,饲料中添加钙对宝石鲈的生长性能和饲料利用没有显著影响,表明宝石鲈从水体和基础饲料中吸收的钙可以满足自身代谢的需要。

饲料中添加钙磷对宝石鲈全鱼和肌肉的水分、粗蛋白和灰分没有显著影响,但降低了全鱼和肌肉脂肪含量。饲料中磷不足易导致过多的脂肪储存在鱼体的不同组织中,如肝脏、内脏、肌肉、胴体和全鱼[14,20]。磷是三磷酸腺苷、核酸、磷脂、细胞膜和多种辅酶的重要组成成分,与能量转化、细胞膜通透性和生长有密切关系[25]。磷参与机体的许多生理过程,饲料磷不足可引起鱼体新陈代谢过程紊乱,造成脂肪沉积[4,9]。摄食低磷饲料鲤鱼的肝脏糖异生酶活性升高[26]、体脂肪含量高[27]。磷摄入不足也会导致真鲷血浆碱性磷酸酶活性升高和肝糖原含量降低[29]。Vielma 等[40]认为饲料中无机磷缺乏可抑制线粒体外游离脂肪酸和乙酰 CoA 发生酯化作用,阻止产生酯酰 CoA,导致脂肪作为能量的利用率降低。饲料钙的添加降低了全鱼和肌肉脂肪含量,表明钙和磷对降低体脂肪有相似的作用,但钙对鱼体脂肪新陈代谢的作用机理有待进一步探讨。

饲料中添加钙对脊椎骨灰分、钙和磷含量的影响与磷不同。当饲料中未添加磷时,单独添加钙对脊椎骨灰分和钙磷含量没有影响,表明在饲料磷缺乏的情况下,单独钙的添加不能促进脊椎骨的矿化以及钙磷的沉积。当饲料添加0.6%磷时,添加0.0%,0.5%和1.0%钙对脊椎骨灰分、钙和磷含量没有显著影响,说明当饲料磷充足的情况下,鱼体从水环境和基础饲料中吸收的钙能够满足脊椎骨的矿化以及钙和磷的沉积,此与在真鲷[41]和大西洋鲑[42]上的研究结果一致。钙与磷之间的关系很特别,当两者比例适宜时,既有利于钙磷的吸收,又有利于钙磷在体内的利用,表现明显的协同作用;当两者比例不当时则产生拮抗作用,钙含量过高,降低磷的吸收,磷含量过高则降低钙的吸收[25]。本试验也发现,1.5%钙组脊椎骨钙含量显著低于1.0%钙组,表明饲料中1.5%钙添加量过大,导致钙磷比例不当,影响钙的吸收和矿化。

鱼摄食低磷饲料容易引起骨骼变形是能观察到的主要外部特征[4,43-44]。未添加磷组宝石鲈脊椎骨灰分具有降低趋势,钙和磷含量低于添加组,表明磷是骨质矿化的一种必需元素。骨骼与血液中的钙磷持续地进行交换作用,在骨的不同部位也进行着交换,骨中的钙磷处于一种动态平衡,骨骼不但是沉积之处,而且也是钙磷的贮藏库,当饲料中钙磷不足时,骨组织中的钙磷会转移至血液中[25]。饲料磷不足使大西洋鲑全体、骨、皮肤和鳞片的钙、磷和镁含量显著减少,随着饲养时间的延长,骨骼逐渐变软并产生身体畸形[45]。另一方面,饲料中添加过多的磷会影响钙、铁、镁、

锰和锌在肠道的吸收[25],造成饲料成本增加和过多磷排出对水环境产生污染。本试验进行 60 d 未发现骨骼变形导致的身体畸形,以前的一些研究也发现鱼摄食磷不足饲料未导致骨骼变形[12,16,23],饲料中磷缺乏导致身体畸形程度与试验时间、饲料因素、养殖种类、水中矿物盐含量、水温和养殖条件有关[14]。本试验中,宝石鲈摄食未添加磷饲料表现为食欲不高、体色暗淡和活力下降,与 Hardy 等[46] 在虹鳟上的研究结果一致。Roy 等[14]研究发现饲喂未加磷组的鳕拥有显著低的脊椎骨灰分、钙和磷含量。低磷饲料组[24]和未添加磷试验组[34]大西洋鲑脊椎骨均表现低的灰分、钙和磷含量,在斑点叉尾鮰[17-19],大西洋鲑[47],虹鳟[28],真鲷[20],大马哈鱼[48],孔雀鱼[39],阳光鲈[16]和虹鳟[30]也发现相似的研究结果。

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# Effects of dietary calcium and phosphorus on growth and body composition of juvenile *Scortum bacoo*

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**Abstract**: A study was conducted to investigate the effects of dietary calcium (Ca) and phosphorus (P) on juvenile jade perch, *Scortum bacoo*, and to characterize P deficiency signs. Six isoenergetic and isonitrogenous purified diets ($D_1$: 0.0% Ca, 0.0% P; $D_2$: 0.5% Ca, 0.0% P; $D_3$: 0.0% Ca, 0.6% P; $D_4$: 0.5% Ca, 0.6% P; $D_5$: 1.0% Ca, 0.61% P; $D_6$: 1.5% Ca, 0.6% P) were prepared using casein and gelatin as the main protein sources, Ca-lactate and $NaH_2PO_4 \cdot 2H_2O$ as the Ca, P source , respectively. A design of six treatments with three replicates per treatment was used. Each group contained 20 juveniles placed randomly in net cages. Jade perch with an initial weight of 13.42 ±0.68 g were fed to satiation with one of the six diets for 60 days. At the end of the experiment, growth permance, whole body and muscle composition, and mineral (Ca, and P) deposition in vertebrae were measured. Fish fed diets without P supplement($D_1$ and $D_2$) showed reduced final weight, special growth rate and mineral (Ca and P) deposition in vertebrae, and an increase in feed conversion rate , whole body and muscle lipid content than fish fed diets with P supplement ($P < 0.05$). When P was not supplemented, 0.5% Ca supplement had no significant effect on final weight, special growth rate , feed conversion rate , whole body and muscle composition, ash content and mineral (Ca, and P) deposition in vertebrae ($P > 0.05$). When diets were supplemented with 0.6% P, Ca supplement from 0.0% to 1.5% had no significant effect on final weight, special growth rate , whole body composition, muscle composition (moisture, crude protein and ash), vertebrae composition (ash, P and Ca-P ratio ) ($P > 0.05$) . Excess Ca supplement (1.5% ) had a negative effect on vertebrae Ca deposition ($P < 0.05$). Fish fed diets with P supplement($D_3 - D_6$) showed an decrease in whole body and muscle lipid content, an increase in ash content and mineral (Ca, and P) deposition in vertebrae ($P < 0.05$) . Ca and P supplement had no significant effect on Ca-P ratio ranged froml.78 to 1.82 in vertebrae ($P > 0.05$). If growth performance and vertebrae mineralization are taken into account, 0.5% Ca supplement might be optimum when diet was supplemented with 0.6% P.

**Key words**: *Scortum bacoo*; growth; body composition; calcium; phosphorus