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·综述·

利用廉价蛋白源代替鱼饲料中鱼粉的研究进展

Replacement of fish meal with cost-effective protein feedstuffs in feed formulation for fish: review

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饲料费用占鱼类养殖成本的 50% 左右[1-3]。饲料费用取决于饲料的价格和饲料系数，饲料价格往往取决于饲料中蛋白原料的价格，其中鱼粉是最昂贵的蛋白原料之一。利用廉价蛋白原料代替鱼饲料中的鱼粉可降低鱼类养殖的饲料成本，20 世纪 70 年代以来国内外对此进行了大量研究[1,4]。本文综述了针对鱼饲料中常见的几种廉价蛋白原料的利用方面取得的研究进展。

1　利用廉价动物蛋白原料代替鱼饲料中鱼粉

1.1　鸡肉粉

鸡肉粉(poultry by-product meal)的营养组成及消化率与原料来源和加工方法有关[5]。部分研究表明不同厂家生产的鸡肉粉粗蛋白含量变化为 56% ~ 74%，蛋白质表观消化率为 49% ~ 78%[5,6]。这些结果与 NRC 报道值[7]不完全一致。

用 30% 鸡肉粉与 70% 鲑鱼饲料混合配制的饲料投喂斑点叉尾鮰(*Ictalurus punctatus*)导致鱼生长减慢，而用该饲料投喂的鲫鱼(*Carassius auratus*)生长比摄食鲑鱼饲料的鱼快[8]；用鸡肉粉可成功替代大鳞大麻哈鱼(*Oncorhynchus tschawytscha*)饲料中鱼粉的 50%[9]，平鲷(*Rhabdosargus sarba*)饲料中鱼粉的 25%[10]，杂交鲈鱼(*Morone chrysops* × *M. saxatilis*)饲料中鱼粉的 36%[11]，红拟石首鱼(*Sciaenops ocellatus*)饲料中鱼粉的 67%[12]，鲶状黄姑鱼(*Nibea miichthioides*)饲料中鱼粉的 50%[1]。用鸡肉粉和羽毛粉的混合物替代虹鳟(*Oncorhynchus mykiss*)饲料中鱼粉的 44%[13]，用鸡肉粉和豆粕的混合物替代金头鲷(*Pagrus auratus*)饲料中鱼粉的 53%[14]，用鸡肉粉、豆粕和大麻籽粕的混合物完全替代杂交鲈鱼(*Morone chrysops* × *M. saxatilis*)饲料中鱼粉[15]均未发现对鱼生长产生不良影响。

1.2　肉粉和肉骨粉

肉粉(meat meal)与肉骨粉(meat and bone meal)区别在于前者粗蛋白含量较高、灰分和磷含量较低，

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后者粗蛋白含量较低、灰分和磷含量较高[3]。肉骨粉缺乏蛋氨酸[7],脂肪酸不平衡[16,17],营养组成因原料不稳定变化较大。

Kureshy 等[12]认为用肉骨粉替代鱼粉可能降低饲料适口性,Mohsen 和 Lovell[18]指出添加 11%肉骨粉替代豆粕改善了鱼饲料适口性。早期肉骨粉在鱼饲料中的用量很少超过 20%[19]。用肉骨粉替代金头鲷饲料中鱼粉的 40%对鱼增重不会产生显著影响,但饲料中添加 21%肉骨粉导致鱼体脂肪增加,添加 28%肉骨粉导致鱼肝细胞极化和肝坏死[20]。用高脂肉粉替代金头鲷饲料中鱼粉的 42%后显著影响该鱼生长,而用高蛋白肉粉替代饲料中鱼粉的 52%不会对鱼生长产生明显影响,当用高蛋白肉粉替代掉鱼粉的 75%后,鱼生长、饲料效率、蛋白转化效率和表观净蛋白利用率明显降低[2];用肉骨粉可成功替代虹鳟饲料中鱼粉的 27% ~ 32%[21],鲶状黄姑鱼(*Nibea miichthioides*)饲料中鱼粉的 30%(1),用肉粉可成功替代银锯眶鲷(*Bidyanus bidyanus*)饲料中鱼粉的 52%[22]。

1.3 羽毛粉

羽毛粉(feather meal)蛋白质含量高,但可消化率较低,并且不同来源的羽毛粉蛋白质消化率存在明显差异[23,24]。通过改进生产工艺,羽毛粉蛋白质消化率已有显著提高[24]。

用羽毛粉可成功替代大鳞大麻哈鱼饲料中鱼粉的 48%[25],南亚野鲮(*Labeo rohita*)饲料中鱼粉的 50%[26],但用羽毛粉替代鲶状黄姑鱼(*Nibea miichthioides*)饲料中鱼粉的 10%导致鱼生长减慢(1)。用羽毛粉与肉粉的混合物可完全替代金头鲷饲料中的鱼粉[2],用羽毛粉、血粉和玉米面筋的混合物可成功替代虹鳟饲料中鱼粉的 40%[21]。

1.4 血粉

血粉(blood meal)粗蛋白含量往往超过 85%,赖氨酸含量 9% ~ 11%,赖氨酸可利用率超过 80%[3],但其氨基酸不平衡,粘性和适口性差。用血粉和肉粉混合物代替斜带石斑鱼(*Epinephelus coioides*)饲料中鱼粉的 80%对鱼的生长、成活率和饲料系数未产生明显影响[27]。

2 利用廉价植物蛋白源代替鱼饲料中鱼粉

2.1 豆粕及其副产物

豆粕(soybean meal)蛋白质含量高、赖氨酸含量丰富,但含硫氨基酸(蛋氨酸、半胱氨酸)较低,并含有胰蛋白抑制剂、植物血凝素和抗维生素等抗营养因子[1]。蛋氨酸含量低和存在抗营养因子限制了豆粕的使用[28,29]。热处理可促进豆粕内营养物质释放,提高其可利用性及适口性,同时也有助于破坏胰蛋白抑制剂等抗营养因子。对豆粕中胰蛋白抑制剂的破坏作用[28-31]和一些必需氨基酸可利用率取决于热处理温度[31-33]。

鱼类对豆粕利用能力与种类有关[34]。分别用商业全脂豆粕、溶剂提取豆粕和溶剂提取加红外线处理的豆粕替代虹鳟饲料中鱼粉的 30%,结果鱼生长、饲料系数和氮利用率均超过摄食对照饲料的鱼;用压榨脱脂豆粕替代饲料中鱼粉的 30%则导致鱼生长显著下降[35]。用脱壳并经溶剂提取的豆粕替代大西洋鲑(*Salmo salar*)饲料中鱼粉的 36%,结果导致鱼生长下降[36]。用溶剂提取豆粕可成功替代尖吻鲈(*Lates calcarifer*)饲料中鱼粉的 38%,但添加压榨提取或蒸汽提取豆粕的饲料适口性较差,浸泡全脂豆粕的饲料效果最差[37]。

用热处理脱脂大豆粉可成功替代银大麻哈鱼(*Oncorhynchus kisutch*)饲料中鱼粉的 15%[38]。用豆粕可成功替代大西洋鲑饲料中鱼粉的 33%[39],四须鲃(*Barbodes altus*)稚鱼饲料中鱼粉的 34%[40],红拟石首鱼饲料中鱼粉的 50%[41],杂交鲈鱼饲料中鱼粉的 50%[42]。

在添加蛋氨酸的情况下,用豆粕可成功替代平鲷饲料中鱼粉的 25%[10],杂交鲈鱼成鱼饲料中鱼粉

(1) Wang Y, Guo J, Bureau D P, *et al*. Replacement of fish meal with rendered animal ingredients in feeds for cuneate drum, *Nibea miichthioides* Aquaculture in press.

的65%[43]。用大豆蛋白浓缩物做虹鳟饲料中唯一蛋白源或用豆粕替代饲料中鱼粉的54%不会对鱼的生长产生负影响[44]；用大豆蛋白混合物替代欧洲鳗饲料中鱼粉的43%对鱼增重、饲料效率及鱼体组成等无显著影响[45]；用大豆蛋白浓缩物替代庸鲽(*Hippoglossus hippoglossus*)饲料中鱼粉的39%对鱼生长无影响[46]。Escaffre等[47]发现在鲤鱼(*Cyprinus carpio*)幼鱼饲料中添加40%的大豆蛋白浓缩物不影响成活率和生长，当大豆蛋白添加量达60%时，即使添加蛋氨酸，鱼生长也降低，认为限制大豆蛋白用量的抗营养因子不仅限于大豆胰蛋白酶抑制剂。因此，尽管添加蛋氨酸可提高豆粕的营养价值，但添加结晶氨基酸并非都表现出好的效果[19,48]。

添加豆粕会降低鱼饲料适口性。用热处理脱脂大豆粉替代银大麻哈鱼饲料中15%以上的鱼粉后饲料适口性降低[38]，红拟石首鱼饲料中豆粕与鱼粉的比例超过1:1时饲料适口性下降[41]。用含全脂豆粕的饲料投喂大鳞大麻哈鱼稚鱼导致鱼摄食和生长率下降，死亡率升高[49]；添加磷虾粉和鱿鱼粉等可改善豆粕蛋白饲料的适口性[38,50]。

2.2　棉籽粕

棉籽粕(cottonseed meal)缺乏赖氨酸，蛋氨酸和半胱氨酸含量较低，棉酚含量高。棉酚可降低赖氨酸的生物有效性[51]。不同种类的鱼对饲料中棉酚敏感程度不同。当饲料中棉酚含量达到0.03%时虹鳟(*Salmo gairdneri*)生长下降，死亡率增加[52]；达到0.09%时斑点叉尾鮰生长开始下降[53]；达到0.2%时罗非鱼(*Tilapia aurea*)生长、饲料系数和成活率不受影响[54]。

在饲料中添加17.4%溶剂提取棉籽粕对斑点叉尾鮰没有毒性[53]。用溶剂提取棉籽粕可成功替代大鳞大麻哈鱼饲料中鱼粉的47%，在银大麻哈鱼饲料中棉籽粕添加量可达22%[49]。用压榨加溶剂提取处理的棉籽粕可成功替代罗非鱼(*Sarotherodon mossambicus*)饲料中鱼粉的50%，但用棉籽粕完全替代饲料中的鱼粉后鱼表现出生长率和增重下降，饲料系数升高的趋势[55]。用去皮、压榨且溶剂提取的棉籽粕完全替代尼罗罗非鱼(*Oreochromis niloticus*)饲料中的鱼粉导致鱼生长显著下降[56]。摄食含16%～19%棉籽饼饲料的尼罗罗非鱼生长明显低于摄食含43%鱼粉的饲料的鱼[57]。

2.3　菜籽粕

菜籽粕(rapeseed meal)蛋白质消化率较豆粕和棉籽粕低，赖氨酸和蛋氨酸含量及利用率较低，并含有蛋白酶抑制剂、植酸、丹宁酸、芥子酸、芥子油苷(一种抗甲状腺因子)和异硫氰酸盐[58]等抗营养因子。菜籽粕中的酚化合物如芥子酸胆碱和丹宁酸等可降低饲料的适口性[59]。

莫桑比克罗非鱼(*Oreochromis mossambicus*)饲料中菜籽粕添加量超过15%会导致鱼生长和饲料效率下降[60]。用压榨和溶剂提取的菜籽粕替代罗非鱼饲料中鱼粉的75%鱼显现出生长率降低、饲料系数升高的趋势，但影响不明显[55]；用菜籽粕和野豌豆的混合物替代虹鳟饲料中鱼粉的16%对鱼生长、能量利用和肌肉脂肪酸组成无负影响[61]；用经过热处理的菜籽粕替代瘤棘鲆(*Psetta maxima*)饲料中鱼粉的22%对鱼生长和鱼体组成无影响，当饲料中热处理菜籽粕添加量达到46%，或未经热处理菜籽粕添加量达到30%后会明显抑制鱼的生长[62]。

3　结论与问题

3.1　利用廉价蛋白原料替代饲料中鱼粉的潜力

现有研究表明：用鸡肉粉、肉骨粉、羽毛粉、豆粕、棉籽粕、菜籽粕等廉价蛋白源分别能够替代掉鱼饲料中鱼粉的15%～67%、5%～52%、15%～50%、15%～65%、47%～50%和16%～75%，并且将多种廉价蛋白原料合理搭配能够取得更好的替代效果。添加晶体氨基酸可改善廉价蛋白原料的营养价值。

3.2　利用廉价蛋白原料替代饲料中鱼粉研究中存在的问题

(1)鱼种类[34]、个体大小或生长阶段[43]、水温[14]、投饲方法[50]、廉价蛋白源的生产工艺[56]、饲料中其它原料的营养组成[15]等都会对替代实验结果产生影响。已发表的实验中对上述因素往往未严格控

制,因此不同实验的结果可比性不强。

(2)当饲料中鱼粉含量达到60%一般能够满足温水肉食性鱼类的营养需求[8]。已发表的许多实验中对照饲料内鱼粉含量超过60%[2, 14, 20, 39, 40, 44-46]。当对照饲料中鱼粉含量超出实际需求时,实验得出的鱼粉替代水平(相对比例)可能高于实际替代水平。

(3)已发表的实验多数周期较短,并且评价指标主要是鱼生长性能、饲料利用效率和鱼体组成等,涉及改变饲料中蛋白源对组织学、血液学、酶学和病理学指标影响方面内容的研究较少。连续90d摄食含28%肉骨粉饲料的金头鲷尽管与摄食含60%的鱼粉的对照饲料的鱼在鱼体增重、摄食量、蛋白质效率(PER)、蛋白质生产效价(PPV)、肝指数(HSI)、鱼体组成等方面未表现出明显差别,但前者肝细胞部分极化甚至坏死[20]。因此,有必要通过长期实验,结合对鱼组织、器官结构和生理功能的观察,综合评价鱼类对廉价蛋白原料的利用能力。

(4)关于使用廉价蛋白原料替代饲料中鱼粉后对养殖鱼类的风味、肉质和体色,以及对养殖水域生态环境的影响方面的研究有待加强。

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