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Dietary histidine requirement and physiological effects of dietary histidine deficiency in juvenile red drum *Sciaenop ocellatus*

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ABSTRACT

In order to develop nutritious and cost-effective diets, the amino acid requirements of cultured fish species must be quantified. Several indispensable amino acid requirements of red drum *Sciaenops ocellatus* have already been reported; however, its requirement for histidine (His) has yet to be quantified. The aims of the present studies were to determine the minimum dietary His requirement of juvenile red drum and the physiological effects of His deficiency. A basal diet was prepared using lyophilized red drum muscle as an intact protein (10.5% of dietary protein) supplemented with crystalline amino acids (excluding His) to provide a total of 35% crude protein (CP) in the diet. Five isonitrogenous and isoenergetic experimental diets were prepared by supplementing the basal diet (0.3 g His/100 g dry diet) with increasing amounts of His (0.5, 0.7, 0.9, 1.1, 1.3 g/100 g dry diet). These diets were fed to triplicate tanks of juvenile red drum (initial average weight of 0.98 ± 0.08 g/fish) for 6 weeks in feeding trial 1 to quantify the minimum dietary His requirement. His level had significant effects on relative weight gain, feed efficiency ratio, protein efficiency ratio, and plasma free His. According to quadratic broken-line regression on relative weight gain percentage, the dietary His requirement was 0.59 (± 0.15) g/100 g dry diet (1.6% of CP). Feeding trial 2 was performed to further examine His deficiency in red drum. In that trial, the basal diet and a His-supplemented diet (~1.2 g/100 g dry diet) were fed to juvenile red drum (initial average weight of 1.53 ± 0.08 g/fish) in triplicate tanks for 8 weeks. Cataracts were found in 16.7% of eyes from fish fed the basal diet while no fish in the supplemented group developed cataracts. His-supplemented fish were found to have higher erythrocyte fragility than those fed the basal diet. Based on these results, the His requirement of red drum was defined and His deficiency was observed to affect blood parameters and increase the possibility of cataract development.

1. Introduction

As the aquaculture industry continues to grow, its use of fishmeal has increased even though the global supply of this feedstuff remains relatively static. In order to increase the sustainability and affordability of the industry, alternative protein feedstuffs need to be utilized to reduce the dependence on fishmeal. Alternative protein feedstuffs, such as plant-based meals, often are limiting in one or more indispensable amino acids (IAA) and therefore amino acids may need to be supplemented in fish diets containing such feedstuffs (NRC, 2011). Knowing the correct balance of amino acids for each fish species allows researchers to evaluate potential protein feedstuffs and estimate their value. In order to develop nutritious and cost-effective feeds, the amino acid requirements of cultured fish species must be quantified.

Red drum (*Sciaenops ocellatus*) is a euryhaline sciaenid that is native to the eastern seaboard of the United States (US) from Massachusetts south to the Gulf of Mexico. In the past, this species boasted a healthy wild population that supported both recreational and commercial fisheries. However, due to overfishing, the wild population significantly declined in the early 1980s which resulted in the closure of the commercial fishery and sparked an effort to restore the red drum population in the Gulf of Mexico by releasing juvenile fish raised in state-run hatcheries. Hatchery-raised fish are also grown to market size by commercial operations and sold for human consumption. Its ease of production in hatcheries and tolerance to a wide range of salinities make the red drum a good candidate for aquaculture (Craig and Gatlin, 1992; Faulk, 2005).

Many dietary requirements for various IAA have already been quantified for red drum using 35% CP diets. The arginine requirement was determined to be 1.8% of dry diet (Barziza et al., 2000), the

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threonine requirement 0.8% of dry diet (Boren and Gatlin, 1995), the lysine requirement 1.6% of dry diet (Craig and Gatlin, 1992), the total aromatic amino acid (phenylalanine and tyrosine) requirement 2.1% of dry diet (Castillo et al., 2015), the tryptophan requirement 0.3% of dry diet (Pewitt et al., 2017), and the total sulfur amino acid requirement (cysteine and methionine) 1.0% of dry diet (Moon and Gatlin, 1991). The branched chain AA (valine, leucine, and isoleucine) requirements have been determined to be 1.2, 1.6, and 1.1% respectively (Sergio Castillo, personal communication). However, the histidine (His) requirement of red drum is the last to be quantified.

Histidine is one of 10 IAA in fish nutrition. Along with arginine and lysine, His is categorized as a basic amino acid. With a positively charged imidazole group, His can act as an acid or a base and plays roles in osmoregulation, muscle pH buffering, and detoxification of reactive carbonyl species (Farhat, 2013; Waagbø et al., 2010). Histidine and its imidazole derivatives, such as carnosine and anserine, are thought to contribute to improved taste, texture, overall fillet quality and storage performance (Farhat, 2013; Gao et al., 2016; Ogata, 2002). Forde-Skjarvik et al. (2006) reported that supplementation of dietary His increased muscle His, which increased post-mortem fillet pH, and decreased gaping in the fillet product. As a direct precursor of histamine, His plays a prominent role in allergic and immune responses as well (Ahmed and Khan, 2005). In salmon smolts, His deficiency causes cataracts; increasing His in the diet has a positive effect on eye lens protein turnover and protects the lens from oxidative stress and variation in osmotic pressure (Breck et al., 2005a; NRC, 2011). Histidine also has been found to have an effect on the muscle buffering capacity of fish (Forde-Skjarvik et al., 2006; Ogata, 2002). In a study with juvenile grass carp, fish fed a His - deficient diet had significantly higher erythrocyte osmotic fragility (Gao et al., 2016).

For some readily cultured species, the His requirement has been summarized by the National Research Council (Table 1) (NRC, 2011). Differences in the reported His requirement values of various fish species may be due to numerous factors including differences in metabolic needs, natural feeding habits or experimental procedures, including dietary protein levels.

Due to the importance of red drum to the aquaculture industry and the lack of a complete set of quantified IAA requirements for this species, the goal of this study was to determine the dietary His requirement of juvenile red drum and characterize the effects of His deficiency on this species.

2. Methods

In feeding trial 1 (FT1), lyophilized red drum muscle, to be used as the main protein source in the diet, was analyzed to determine crude protein, lipid, and ash. A basal diet was prepared by including lyophilized red drum muscle and crystalline amino acids, excluding His, to provide a total of 35% crude protein in the diet (Table 2). Dietary lipid and dextrin were included to provide, in combination with protein, a total of 13.4 kJ estimated digestible energy/g diet (Table 2). The amount of His provided by red drum muscle, which contributed 10.5% crude protein, was determined to be 0.28% of dry diet. Five experimental diets were prepared by supplementing the basal diet (0.3% of dry diet, Table 2) with increasing amounts (0.2% of dry diet) of His (0.5, 0.7, 0.9, 1.10, 1.30% of dry diet). The range of dietary His levels were chosen based on His requirements previously established for other fish species (NRC, 2011). The experimental diets were kept isonitrogenous by adjusting the amount of an aspartate/glutamate premix as His levels were varied.

All diets were mechanically mixed and pressure pelleted using well established procedures (Castillo et al., 2015). Amino acid levels in all diets were analyzed via ultra-performance liquid chromatography (UPLC) with an Acquity UPLC system with integrated TUV detector and MassTrak AAA Solutions Kit (Waters Corporation). Diets also were subjected to proximate analysis to determine crude protein, lipid, and ash (AOAC, 1990). Crude protein was quantified using the Dumas protocol (AOAC, 2005) and crude lipid using the Folch procedure (Folch et al., 1957).

Table 2
Formulation and analyzed proximate composition of the basal diet.

Ingredient	Dry weight, g/100 g
Red drum muscle meal[a]	12.32
Crystalline amino acid premix[b]	22.53
Dextrinized starch	35.00
Menhaden oil	8.20
Vitamin premix[c]	3.00
Mineral premix[c]	4.00
Carboxymethylcellulose	1.00
Calcium phosphate	1.00
Aspartate/glutamate premix	2.70
Histidine	0.02
Glycine	3.50
Celufil	6.73
Analyzed composition[d]	
Crude protein (%)	36.85
Crude lipid (% DM Basis)	11.46
Dry matter (%)	85.97

[a] Lyophilized from wild fish.
[b] Provided as crystalline L-amino acids (each per 100 g diet) as follows: 0.86 g taurine, 2.25 g serine, 1.59 g arginine, 1.23 g threonine, 1.65 g alanine, 2.00 g proline, 0.71 g cysteine, 2.35 g lysine, 1.10 g tyrosine, 0.89 g methionine, 1.98 g valine, 1.69 g isoleucine, 2.26 g leucine, 1.55 g phenylalanine, 0.42 g tryptophan.
[c] Same as study by Nematipour and Gatlin, 1993.
[d] Means of 2 replicate analyses.

Table 1
Summary of histidine requirements of commonly cultured species (NRC, 2011).

Species	Requirement (% of diet)	Requirement (% of crude protein)	Reference
African catfish (*Clarias gariepinus*)	0.4	1.0	Khan and Abidi, 2009
Channel catfish (*Ictalurus punctatus*)	0.4	1.5	Wilson et al., 1980
Chinook salmon (*Oncorhynchus tshawytscha*)	0.7	1.8	Klein and Halver, 1970
Chum salmon (*Oncorhynchus keta*)	0.7	1.6	Akiyama et al., 1985
Coho salmon (*Oncorhynchus kisutch*)	0.7	1.8	Klein and Halver, 1970
Common carp (*Cyprinus carpio*)	0.8	2.1	Nose, 1979
Grass carp (*Ctenopharyngodon idella*)	1.2	3.2	Gao et al., 2016
Indian major carp (*Catla catla*)	0.6–0.7	1.9–2.0	Zehra and Khan, 2015
Large yellow croaker (*Pseudosciaena crocea*)	0.9	2.0	Yan et al., 2014
Mrigal carp (*Cirrhinus mrigala*)	0.9	2.1	Ahmed and Khan, 2005
Nile tilapia (*Oreochromis niloticus*)	1.0	1.7	Santiago and Lovell, 1988
Rainbow trout (*Oncorhynchus mykiss*)	0.5–0.6	1.0–1.2	Rodehutscord et al., 1997
Stinging catfish fry (*Heteropneustes fossilis*)	1.5–1.6	3.5–3.6	Khan and Abidi, 2014
Stinging catfish juveniles	0.5	1.4	Ahmed, 2013