Oceanography & Fisheries
Open access Journal
ISSN: 2476-0536

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Review Article
Volume 8 Issue 5 - December 2018
DOI: 10.19080/OFOAJ.2018.08.555746

Oceanogr Fish Open Access J

Histidine Requirement of Cultivable Fish Species: A Review

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Submission: December 03, 2018; **Published:** December 11, 2018

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Abstract

Availability of nutritionally balanced commercial feeds is essential in producing healthy, high-quality aquatic animals. Protein is the most important component of aquaculture feeds. Fish require not only a minimum level of protein but also that the essential amino acids are balanced to meet the requirements of each single one. Histidine is an essential amino acid with several functions including protein synthesis, tissue formation and repair as well as maintenance of osmoregulation and myelin sheaths. It also regulates the immune system and acts as antioxidant in fish. Histidine deficiency depresses growth performance and feed utilization. If in excess, it causes disruption of the balance of dietary amino acids leading to toxicity or extensive necrosis in the epithelial cells. Furthermore, histidine serves as an important antioxidant and buffer in various organs of several fish species. In aquaculture, extensive research has been carried out to optimize the levels of histidine in the commercial diets for many fish species. Providing adequate levels of this amino acid is critically important for fish growth. Currently, available data suggest a wide variation in histidine requirements of different species ranging between 0.89–3.54% on protein basis.

Keywords: Histidine; Requirements; Fish; Deficiency; Toxicity; Antioxidant Response; Body Composition.

Introduction

Fish meal is the most attractive protein source for aquaculture diets because of its high protein content, well balanced amino acid, fatty acid composition, high digestibility and palatability. However, the high cost of fish meal and lack of availability are making it impracticable to use in all aquafeeds [1- 4]. Therefore, fish meal needs to be replaced by more economical alternatives feed ingredients of plant origin in order to improve the economical sustainability of aquaculture. Various scientist has evaluated efficiency and possibility of using plant protein sources as a partial [3-31] or complete replacement of fish meal in fish diets [32-44]. Most of the plant protein sources are deficient in one or more essential amino acids. Thus, there is a dire need to supplement the essential amino acid in plant protein sources containing deficient amount of amino acid.

Importance of Histidine

Histidine is an essential amino acid for hemoglobin synthesis in aquatic and terrestrial animals and is important for growth, tissue formation and repair as well as for the maintenance of osmoregulation and myelin sheaths that act as protectors for nerve cells [45, 46]. It serves as an important antioxidant and buffer in various organs of different fish species [47-49]. It is a major component of non-carbonated buffering against pH changes in fish muscle [50]. Muscle buffering prevents acidosis caused by anaerobic metabolism in white muscle [51]. Histidine and its related imidazole derivatives confer desirable taste and texture and dietary supplementation of histidine can improve sensory attributes such as flavor of the aquaculture seafoods [51]. Additionally, Forde-Skjaevik et al. [52] reported that dietary supplementation of histidine increases intramuscular histidine levels and pH, while reducing muscle gapping in Atlantic cod post-mortem. Positive action of histidine on the uptake of zinc in rainbow trout was reported by Glover et al. [53] whereas dietary zinc supplementation could improve the activities of intestinal digestive enzymes in juvenile Jian carp [54]. Another aspect of histidine stress mitigation is antioxidant status. Superoxide scavenging ability was also enhanced by histidine supplementation. Boldyrev & Severin and Bjerkas & Sveier [55,56] reported that histidine and histidine-related compounds such as anserine and carnosine have been found to act as antioxidants in the lens of an eye. Son et al. [57] reported that histidine could inhibit the inflammation induced by oxidative stress in human intestinal epithelial cells. Moreover, dietary histidine enhances the glutamate pyruvate transaminase (GPT) activities both in hepatopancreas and muscle up to a certain level [58]. A possible explanation could be that GPT is related to the synthesis of carnosine (b-alanine-L-histidine) which is an important metabolism product of histidine and is mainly synthesized from its constituent amino acids in muscle and liver [59].

Histidine Content in Feed Ingredients & Histidine Requirement

Since histidine is an essential amino acid, dietary inclusion is the main source of histidine for successful culture of several cultivable fish species. The content of histidine of various feed ingredients were recorded in the range of 0.89–3.54% on protein basis [60]. The ingredients such as fish meal containing salmon byproduct 3.51%, rice protein concentrate 2.02%, wheat, soft grain 2%, pea protein concentrate 2.49%, soybean meal protein concentrate 2.50%, rice bran 2.61%, wheat flour 3.54%, rice bran with germ, solvent extracted 1.93%, rice polishing 2.15%, wheat bran 2.14%, rice broken with polishing 2.57% and white fishmeal 2.16% and meat and bone meal 2% on protein basis are feedstuffs with high histidine content, whereas whey dried 1.68%, poultry byproduct meal, feed grade low as 1.88%, poultry byproduct meal 1.90%, oats 1.63%, gelatin 0.89% and hydrolyzed poultry feather meal 0.84% on protein basis have lower histidine content. The efficient use of such protein sources in fish feeds depends on appropriate supplementation of histidine to meet the requirements.

Histidine requirement have been determined for several cultivable fish species and are found to range between 0.9–4.8% of dietary protein (Table 1). The reported dietary histidine requirements among different species show a wide variation with some contradictions in the data on dietary histidine requirements for certain species. For instance, dietary histidine requirements have been established for a number of cultured fish species, such as 1.54% channel catfish *Ictalurus punctatus* [61]; 1.6% Chum salmon *Oncorhynchus keta* [62]; 1.7 % gilthead sea bream *Sparus auratus* [63]; 1.1% rainbow trout *Oncorhynchys mykiss* [64]; 2.1% Mrigal carp *Cirrhinus mrigala* [65]; 1.0% African catfish *Clarias gariepinus* [66]; 3.51% Stinging catfish *Heteropneustes fossilis* [67], 3.6% Singhi, *Heteropneustes fossilis* [68]; 2.38% *Cyprinus carpio*, 2.1% *C. carpio* [69] and 3.2% juvenile Grass carp *Ctenopharyngodon idella* [70]; 3.1% blunt snout bream *Megalobrama amblycepahala* [71]; 3.1% Nile tilapia *Oreochromis niloticus* [72] of dietary protein.

Deficiency Signs & Toxicity

If histidine is not adequately balanced in feeds, deficiency signs and the toxicity may develop. The deficiency of dietary histidine leads to reduced growth, cataract, incidence of lordosis, anorexia, allergic reaction, gastric acid secretion and high stress response [58-75]. The lower feed intake in fish fed diet containing deficient amounts of histidine has also been reported which may be due to the reason that after ingesting an amino acid imbalanced diet, animal first recognizes the amino acid deficiency and then respond by reducing their feed intake [76]. The cataract mitigating ability of histidine is due to N-acetyl histidine that is synthesized in the lens. Peachey et al. [77] found significantly higher histidine in lenses in fish fed adequate histidine when compared to histidine-deficient fish. Moreover, excessive histidine inhibited the growth of African catfish *Clarias gariepinus* [66], Indian major carp, *C. catla* [78], and rohu, *Labeo rohita* [79]. This may have occurred because excessive histidine disrupted the balance of dietary amino acids leading to toxicity in the tissues, [80] or extensive necrosis in the epithelial cells of the hepatopancreas [81] thereby influencing fish growth. Increases in free histidine could cause elevated histamine production, and excess histamine could induce proinflammatory cytokines, possibly disturbing the erythrocytes [82]. Erythrocyte osmotic fragility was significantly higher in fish fed the histidine-sufficient diet compared to those fed the histidine-deficient diet. Erythrocyte osmotic fragility, which quantifies the amount of hemolysis occurring when erythrocytes are subjected to osmotic stress, can be viewed as a measure of the quality of the erythrocytes and the integrity of their membranes. Erythrocytes break down was reported to be faster in case of improper membrane function [83]. In grass carp (Gao et al., 2016 and stinging catfish [67], erythrocyte fragility was significantly affected by dietary histidine. Arop et al. [71] reported that the relative gene expression of TOR mRNA in the liver of blunt snout bream was increased with increasing dietary histidine levels up to 9.9 g/kg, and it declined thereafter as dietary histidine levels increased. Similar trends were found in the gills of grass carp fed with graded levels of histidine [82].

Effects on Body Composition

Histidine supplementation has also been reported to affect the carcass quality, which is the most important issue for aqua culturists as it influences the yield of final product. Therefore, research has largely been focused on the means to improve the carcass quality and the efficiency of nutrient utilization for muscle growth. Since a major and most important component of tissue is protein, priority is given to increase the quantity and improve the tissue quality of protein. Histidine supplementation positively increased protein content of the whole body of the fish [58-66]. Several studies indicated that the protein content in the whole body increased with the increase in dietary histidine level and decreased significantly when dietary histidine was higher than the optimal requirement (46, 65, 66, 68, 72, 84). However, whole body composition and muscle composition was not significantly affected by dietary histidine levels in yellow croaker [85], grass carp [50], singhi [68], and red drum [77]. Dietary histidine has been reported to reduce body fat in several fish species [60, 67]. Since histidine deficiency causes reduced growth and cataract, it is necessary to ensure the optimum inclusion of dietary histidine to improve the fish growth performance [86-98] [Table 1].

Table 1: Histidine requirements of various cultivable fish species.

Species	Crude protein (% of dry diet)	Histidine requirement (% of dietary protein)	Criteria for requirement determination	Fish weight (g)	Dietary protein source	References
Anguilla japonica	30	2.1				[86]
Catla	40	2.5			CS; GL; AA	[78]
	33	2.06	AWG;FCR;PG	0.65	CS; GL; AA	[87]

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Chanos chanos	40	2	WG;FE;SR	≤ 8.0	CS; GL;FM	[88]
Cirrhinus mrigala	40	2.1	LWG;FCR;PER	0.6	CS; GL; AA	[65]
Clarias gariepinus	40	1.5	AWG;FCR;PER;S-GR;PRE	0.2	CS; GL; AA	[66]
Clarias macro-cephalus x Clarias gariepinus		1.2				[89]
Cyprinus carpio	32	2.3	SGR;FE;PER	8.7	FM;GL;AA	[58]
	48	2.1	WG	1.7		[90]
	40	4.8				[91]
Ctenopharyngodon idella	38	3.2	WG; SGR; FCR; FI	3.68	CS; GL; AA	[50]
Dicentrarchus labrax	62	1.64				[63]
Heteropneustes fossilis	38	2.48	AWG;PG;FCR	6.6	CS; GL; AA	[67]
	43	3.5	LWG; FCR;PER;PRE	5.2	CS; GL; AA	[68]
	40	1.35	LWG; FCR;PER	4.6	CS; GL; AA	[46]
Ictalurus punctatus	24	1.5	WG	200	CS; GL; AA	[61]
Labeo rohita	40	2.25	WG;SGR;FCR		CS;GL;AA	[79]
	40	2.25	LWG;SGR;FCR;PER	3.5	CS;GL;AA	[84]
Megalobrama am-blycephala	33	3.6	WG;SGR;FCR SR	23.3	FM;CS;GL;AA	[71]
Onchorhynchus tshawytscha	40	1.8	GAIN; FEED/GAIN	2.9	CS;GL;AA	[92]
Oncorhynchus kisutch	40	1.8	GAIN; FEED/GAIN	3.1	CS;GL;AA	[92]
		0.9				[93]
Onchorhynchus keta	40	1.6	WG	1.5	CS;GL;AA	[62]
		1.6				[94]
Oreochromis niloticus	26	3.1	WG; FCR;PER	4.8	RC;MBM;PB-M;FEM	[72]
	34	1.1.2	WG;PD	40	WG;AA	[64]
	28	1.7	WG	0.08	CS;GL;AA	[95]
Oncorhynchus mykiss	40	1.6				[91]
Pseudosciaena crocea	44	2.0	WG;FE;SR	6	FM; CG;GL	[85]
Salmo salar	40	2.0	LWG;FCR;SGR	62	CS;CG	[96]
	45	4.0				[97]
Sciaenops ocellatus	35	1.7				[98]
	35	1.6	RWG; FER; PER;PR; PH	0.98	RDM;AA	[77]
Scophthalmus max-imus	70	1.5				[63]
Sparus aurata	57	1.7				[63]
	40:36	3.5	LWG;DDP	2.2	FM;SB;WB	[99]

LWG: live weight gain; WG: weight gain; SGR: specific growth rate; FCR: feed conversion ratio; PER: protein efficiency ratio; PRE: protein retention efficiency; FE: feed efficiency; DDP: daily deposition; SR: survival; WGM: wheat gluten meal; FEM: feather meal; RC: rice; SB: soybean meal; FM: fish meal; MBM: meat and bone meal; WB: wheat bran; PBM: poultry by product meal ; CS: casein; GL: gelatin; AA: amino acids mixture; RDM: red drum meal; PH; plasma histidine.

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How to cite this article: Mukhtar A Khan. Histidine Requirement of Cultivable Fish Species: A Review. Oceanogr Fish Open Access J. 2018; 8(5): 555746. DOI: 10.19080/OFOAJ.2018.08.555746.

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