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Taurine as an Important Nutrient for Future Fish Feeds of Aquaculture in Albania

RIGERS BAKIU[1*], KASTRIOT KORRO[2], VALBONA KOLANECI[1]

[1]Department of Aquaculture and Fishery, Agricultural University of Tirana, Albania

[2]Faculty of Veterinary, Agricultural University of Tirana, Albania

Abstract

Taurine is a sulfonic acid found in high concentrations in animal tissues. In recent years, a number of studies have demonstrated the essentiality of dietary taurine for many commercially relevant species, especially marine teleosts. Consequently, the removal of taurine-rich dietary ingredients such as fishmeal may create a deficiency, of which symptoms include reduced growth and survival, increased susceptibility to diseases, and impaired larval development. These symptoms emphasize the systemic role of taurine in the animal's physiology and provide few clues as to the underlying mechanisms of taurine function. Furthermore, these findings can be extremely helpful for the preparation of recommendations to improve the developing aquaculture industry in Albania.

Keywords: Aquaculture; larvae; juvenile.

1. Introduction

Taurine (2-aminoethanesulfonic acid, CAS 107-35-7) is an organic acid which was first described from *ox bile* [1]. Taurine is a simple molecule, containing an acidic sulfonate group, a basic amino group, and two carbons in between. It is therefore an amino acid, albeit a *β*-amino acid: the amino group is bound to the carbon adjacent to the one holding the acidic group (i.e., the second carbon, *β*). This is in contrast to *α*-amino acids where the amino group is bound to the same carbon holding the acidic group (i.e., first carbon, *α*). There is also no tRNA encoding for taurine and its sulfonate group replaces the carboxyl group necessary for the formation of a peptide bond. Consequently, taurine cannot be part of translated peptide chains, although there are naturally occurring, taurine-containing peptides [2, 3]. The amine group allows for quantitation by using the same methodology used for other amino acids (typically High Performance Liquid Chromatography, HPCL) and analysis results are often reported together. Taurine exists naturally in animals including mammals, birds, fish, and aquatic invertebrates such as oysters and mussels. Although plants contain less than 1% of the taurine levels found in animals, the most taurine-rich plants are algae, followed by fungi and other terrestrial plants [4]. High taurine levels naturally occur in seafood and meat, and many vertebrates can synthesize taurine. On the other hand, certain animals, including species containing high levels of taurine, cannot metabolically synthesize taurine and require dietary sources for physiological processes. Taurine is the most abundant free amino acid in animal tissues, accounting for 25% of the free amino acid pool in liver, 50% in kidney, 53% in muscle and 19% in brain [5]. In mammals, taurine is involved in a particularly wide variety of functions including constituent of bile, osmoregulation, cell membrane stabilization, anti-oxidation, and calcium signaling required in vertebrates for normal cardiac, skeletal muscle, nervous, and retinal function [6, 7]. Approximately 5000–6000 tons of taurine (synthetic and purified from natural sources) were produced in the world in 1993, and were divided at 50% for pet food manufacturing, and 50% for pharmaceutical applications [8]. An updated global production is difficult to estimate and would require a full market analysis. Three Chinese manufacturers each advertise a production of 15–96,000 metric tons per year (source: Alibaba.com), although these numbers cannot be verified. However, there is no doubt that today's production is considerably higher than it was in 1993. Currently, global taurine production is destined to

*Corresponding author: Rigers Bakiu; E-mail: bakiurigers@gmail.com
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three main uses: cat food, infant formulas and the beverage industry for "energy" drinks. According to manufacturers, taurine products are crystalline powders more than 98.5% pure and conform to standards of the United States, Japan, and Europe. To our knowledge, all products are based on the 98.5% purity level, hence there is no food or feed grade taurine. Taurine can be produced either by extraction and purification from taurine-rich sources [9] or by chemical synthesis. The majority of taurine is produced by chemical synthesis because extraction is less efficient, more costly, and initial materials (e.g., bovine or ovine bile) are not available in sufficient amounts to meet the global market demand [10].

2. Regulation and Policies

Regulations of taurine use in people, pet, or animal feeds varies widely depending on the country under consideration. In the European Union the Observed Safe Level (OSL) is estimated to be 100 mg taurine per kg body weight per day for people, and synthetic taurine is considered efficacious in cats, dogs, and carnivorous fish diets [11]. The European Food Safety Authority stated the No Observed Adverse Effect Level (NOAEL) was observed at 1000 mg/kg body weight per day [12]. This is equivalent to 60,000 mg/day of taurine for a 60 kg adult. A large amount of taurine is used as a supplement in energy drinks. The popularity of energy drinks continues to grow, especially in the United States where sales increased exponentially between 2002 and 2006 [13], reaching $12.5 billion in 2012. In 2013, the global market was worth $27.5 billons. An energy drink contains an average of 1000 mg of taurine per serving, with several popular brands containing 2000 mg [14]. In addition to the human and animal nutrition uses already mentioned, there is a growing interest for use in aquaculture diets.

3. An Essential Nutrient for Aquaculture

A nutrient is required in the diet if endogenous production from precursors is absent or insufficient to meet physiological needs. As interest in taurine gained traction in the early 2000s in fish, limited knowledge was available for the hundreds of fish and invertebrate species being grown as food in aquaculture. The ability to synthesize taurine may exist for several freshwater fish species including cyprinids, but this may not be conserved across the class *Actinopterygii* as many predatory marine species have not demonstrated the ability for taurine synthesis [15]. Interest first arose in nutrition of marine finfish larvae and early juveniles: several reports noted the superior growth and survival of larvae when fed on zooplankton such as mysids or copepods, compared to larvae fed on traditionally enriched rotifers and *Artemia* [16]. Helland [17] and Aragao [18] later compared the biochemical composition of copepods with that of *Artemia* and noted that taurine was the most abundant free amino acid (after glycine) in the former, while being found at lower levels in the latter. Stemming from this observation, several studies subsequently described marked improvement in growth and survival of larvae as well as juveniles when feeding taurine-supplemented feeds [19], as well as in shrimps [20]. Because fishmeal is a significant source of essential minerals, it was hypothesized that growth reduction in low-fishmeal diets were due to a low mineral bioavailability, and that taurine acted as an organic acid, improving the bioavailability of minerals [21]. However, replacement of 53% of dietary fishmeal – and taurine – led to a significant decrease in growth in yellowtail, despite diet acidification by citric or formic acid and improved phosphorous retention [22]. This demonstrated that taurine does not exert its actions solely as an acid, and together with aforementioned studies, this strongly indicates that taurine is an essential dietary nutrient in many species. One of the criticisms of aquaculture has been the need for using significant amounts of fishmeal and other marine protein sources from wild caught fisheries in prepared diets for the cultured species. As a consequence, commercial food producers have been trying to substitute fishmeal using alternative nitrogen and protein sources such as feather meal and soy products [23]. However, such alternative ingredients are often devoid or contain very low concentrations of taurine compared to fishmeal, thus yielding diets similar to low taurine feeds used in terrestrial animal agriculture [24]. A successful dietary formulation using these alternate protein sources for salmonid diets may not offer the same success when rearing marine predatory species such as cobia *Rachycentron canadum*, red sea bream *Pagrus major* [25], or yellowtail *Seriola quinqueradiata* [26]. When *S. quinqueradiata* and *P. major* were fed a taurine-deficient diet they developed "green liver syndrome" and exhibited poor growth performances compared to animals receiving taurine-rich diets [27]. Taurine deficiency explains the reduction in growth performance, when including high levels of taurine-poor ingredients in fish feeds. By supplementing plant-based diets with taurine, growth performance was restored [28].

4. Aquaculture Development in Albania

Given the country's abundant water resources, climate, biological potential and socio-political factors, the prospects for developing this important sector for the Albanian economy was high. The economic directives of the earlier political system had encouraged carp family species in poly-culture in all Albanian inland waters as a cheap and easy way of achieving food security [29]. This experience forms a good base to develop fish farming and to establish food preferences for consumers in the highland areas, providing nutrition sources in areas where there was a scarcity of marine fish and high levels of poverty. In rural areas, this tradition still continues through the network of reservoirs which serves mainly for rural agriculture, built-up during earlier years. Integrated extensive aquaculture production systems are being considered for artificial lakes and reservoirs, because of their multipurpose nature (combining electric power and fishing and/or agriculture and fishing). There are 670 watersheds covering a total surface of 2 700 ha created for irrigation purposes and about 118 of them are also used for fishing. Agricultural reservoirs are located throughout the entire country. The fishing activity in these reservoirs is possible through a stocking program using the fingerlings of the *Cyprinid* family through poly culture. Fingerlings are allowed to grow naturally with a few feeding. This is an extensive form of aquaculture and the utilization of fish with a low market value. The activity is important in that it provides a source of income and protein for the poorest areas of Albania. The greatest concentration of these watersheds is in the region of Elbasani and Fieri. Their production varies from 500 to 600 tonnes per year [29]. Some of the main cultured species produced in Albania are rainbow trout (*Oncorhynchus mykiss*) , European seabass (*Dicentrarchus labrax*), gilthead seabream (*Sparus aurata*), common carp (*Cyprinus carpio*), silver carp(*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis*) and grass carp (Ctenopharyngodon idellus). Carp farming was the most widespread aquaculture practice in Albania, and has built up a strong base of experience. The biotechnology used in poly-culture cultivation of these species was based on the stocking of fingerlings, which make possible a rational and efficient use of natural food resources at different water column. The introduction of artificial feeds contributed to achieving a high rate of fish production. We think that the introduction of taurine in thei supplementary food could further improve their growth performance. This species continues to be popular in northern Albania, especially in Shkodra Lake and its surroundings. There are a total of 57 rainbow trout fish farms which is 20.4 % of all inland and lagoon fishery and aquaculture enterprises. Out of the 19 (33.3 %) has also hatchery facilities. The total water surface area of the tanks is 52 560 m^2 (an average of 922 m^2/farm). The total production volume of tanks is 55 830 m^3 (an average of about 980 m^3/farm). Trout fish farms produce rainbow trout a total of 676 tonnes of fish (about 5 %of the total fish production of Albania), which is about 12 kg/m^3 fish production. The average feed conversion ration (FCR) is rather good (1.4). The main areas when the trout cultivation is mostly are: Saranda, Tepelena, Pogradec, Librazhd, Dibra, Tropoja, consisting in small scale to medium scale and the product destination is for familiar to local consumption [29]. Although mariculture is less developed in comparison to freshwater aquaculture, the farming of marine species in Albania is going to show a rapid developed. Floating cage farming of marine finfish started in 2002, involving gilthead sea bream and European sea bass, and now is intensively practiced by using floating cages. There are 23 marine cage farms, all of them situated in the Ionic Sea. They produce sea bream and sea bass. Their total water surface area is 73 840 m^2, and their production volume is 1 872 100 m^3 (an average of about 81 000 m^3/farm). Their total yearly production is 3 077 tonnes (about 41 % of the total fish production of Albania) which comparing to the huge volume of available production space seems to be too little (1.6 kg/m^3). However, the relatively high FCR (2.0) indicates reduced efficiency [29].

5. Juvenile and Larval Stages

Once recognized as an essential nutrient, quantitative requirement levels of dietary taurine must be determined in various species. Much of the research effort has been conducted on marine carnivorous species, with results demonstrating, that dietary taurine is required by some species. Table 1 compiles results obtained with supplementing larval and juvenile diets with taurine.

Table 1. Summary of species and critical responses to taurine in juvenile (first three species) and larval teleosts.

Species	Initial weight (g)	Main protein source[1]	Dietary taurine content, % diet[2] (source)	Primary response criteria	Recommended supplement (% diet)	Reference
Sea bass (*Dicentrarchus labrax*)	0.8	FM, SBM	0.28,0.37,0.45,0.54 (FM, crystal)	Growth, diet selectivity	0.2	[24]
Rainbow trout (*Oncorhynchus mykiss*)	18.4	SPC, CGM, SBM, WGM	0.27, 0.85, 1.45 (crystal)	Growth, FI	0.85	[30]
	26.8	FM, SBM, CGM, WGM	0, 0.5, 1.0, 1.5 (FM, crystal)	Growth, FE, protein and energy retention	NR (basal diet contains 0.2% taurine)	
		SPC, SBM, CGM, WGM	0, 0.5, 1.0, 1.5 (crystal)		0.5	
	149	SBM, SPC, CGM	0.03–0.17 (FH)	Growth, feed utilization	Somewhat correlated	[31]
	6.9	SPC, FM	0.07, 0.27 (FM, crystal)	Growth	NR	[32]
Common Carp (*Cyprinus carpio*)	4.8	wFM	0.6, 0.95,2.72 (crystal)	Growth, FE	NR	[33]
Gilthead seabream (*Sparus aurata*)		Ro (Com, eTau), Ar (Com)	Ro: 0.88–1.41% of ΣeAA	Growth	NR	[34]
Red Sea bream (*Pagrus major*)		Ro (dTau)	Ro: 0.11–0.32%, dm	Growth	R	[35]
Senegalese sole (*Solea senegalensis*)		Ro, (Com, eTau), Ar (Com)	0.77–0.93(FH, FM, cuttlefish meal, crystal)	Growth, metamorphosis success	R	[36]
White Seabass (*Atractoscion nobilis*)		Ro (dTau)	Enriched	Survival, Growth	?	[37]

[1] In decreasing order of inclusion in the formulation;

[2] Underlined values indicate supplemented levels;

CGM: corn gluten meal; FE: feed efficiency; FI: feed intake; FH: fish hydrolysate; FM: fishmeal; wFM: washed fishmeal; SBM: soybean meal; SPC: soy protein concentrate; WGM: wheat gluten meal; R= required; NR = not required; Ar: *Artemia spp*; Com: commercial enrichment product; dm: dry-matter basis; dTau: crystal taurine dissolved in enrichment medium; eTau: encapsulated taurine fed to prey for enrichment; FH: fish hydrolysate; FM: fishmeal; Ro: rotifer; Tau: taurine; ΣeAA: sum of essential amino acids.

Although almost all studies in marine species conclude that taurine is an essential nutrient, the paradigm is not nearly as clear in freshwater species: taurine supplementation did not benefit growth in channel cat- fish and common carp, while some data suggest that rainbow trout require dietary taurine. These results are very interesting for the freshwater aquaculture industry in Albania, because they highly suggest the taurine supplementing in their food. Overall, it appears that the essentiality of taurine does not follow broad ecological boundaries and instead is species-specific. Larval studies have been conducted exclusively with marine carnivorous species. Larval rearing of these species has been particularly challenging considering their small size. To date formulated diets for first-feeding larvae remain inadequate (resulting in very low growth and survival), and rearing typically relies on the production of zooplankton such as rotifers and *Artemia*. These live preys are enriched using commercial products to increase the content of essential nutrients, such as amino acids and long chain, highly unsaturated fatty acids (i.e., EPA and DHA). With the exception of red sea bream and white seabass, all other species appear to benefit from taurine supplementation through enrichment of the live prey: improvements were seen in growth and survival rates, as well as in morphological development and activity of digestive enzymes.

6. The Roles of Taurine

In some fish species, taurine deficiency has also been characterized to cause green liver syndrome, reduced hematocrit values and high mortality typically associated with reduced disease resistance. Green liver syndrome is attributed to both a decrease in the excretion of bile pigments and hemolytic biliverdin overproduction as a result of dietary taurine deficiency [38]. Taurine also appears to play a role in hemolytic suppression through its effects on osmoregulation and biomembrane stabilization in fish [39, 40]. Because of taurine's role across numerous biological processes, a range of physiological problems and histological changes have been reported, when taurine is reduced in the diet or is not present in adequate amounts. It could be extremely important to analyse almost the histological changes caused by the taurine deficient diets used for economically important species for Albania, like rainbow trout, carp, sea bass and sea bream.

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