



Exploring Creatine in Aquafeeds: Present Status and Future Prospects

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ABSTRACT

Creatine is a multifunctional nitrogenous compound central to cellular energy buffering through the creatine-phosphocreatine system. Emerging evidence indicates its potential as a functional ingredient in aquafeeds, particularly as fishmeal is increasingly replaced by creatine-deficient plant-based ingredients. Experimental studies have reported improvements in growth, muscle accretion, body composition, feed utilization, osmo-regulatory capacity, and flesh quality; however, responses remain inconsistent across species, dietary formulations, rearing environments, and supplementation regimes. Creatine and its precursor guanidine acetic acid may also spare amino acids involved in endogenous creatine synthesis. This review critically examines current knowledge, identifies research gaps, and discusses future applications of creatine for sustainable and precision aquafeed development.

KEYWORDS

Creatine, aquafeed, growth metrics, precision formulation

Introduction

Over the past several decades, global capture fisheries have experienced a steady trajectory, largely due to the fact that majority of the commercial fisheries sector achieves its full extent or beyond its utilization limit. In contrast, the fisheries industry across the world was surged, expanding with an average annual rate of 6.7% from 1990 to 2020, establishing itself as the most rapidly growing sector in food production worldwide (FAO, 2022). Despite its ongoing expansion, aquaculture confronts significant hurdles that threaten its future sustainability, potentially compromising the functions as a economic and environmentally sustainable source of protein for a growing global population. Some underlying constraints are escalating the microbial germination through disease occurrence and stagnation in global oil and meal derived from fish. This scarcity has driven up market prices, putting additional strain on the industry (Gatlin et al., 2007; Kibenge, 2019; FAO, 2022).

In recent years, innovative strategies in developing and utilizing feed additives are crucial for enhancing the nutritional profile of aquaculture feeds, which in turn boosts feed efficiency and fish production. Among these promising additives is creatine which is a naturally occurring biochemical compound that holds potential for optimizing finfish aquafeeds. This approach could play a vital role in advancing the productivity and overall health of finfish aquaculture systems. So, through this article aim to analyze the importance of creatine in aquafeeds with its present status and future prospects.

What is creatine?

Creatine is a popular dietary supplement among athletes, known for boosting strength and endurance to elevate performance (Devries and Phillips, 2014; Waskiewicz, 2021). It is one of the important aspects of extensive research across various facets of human beings, earning recognition like a versatile and multifaceted molecule with numerous biological roles (Wallimann et al., 2011). It is a derivative of non-essential amino acids, is integral to the

creatine–phosphocreatine–creatine kinase system, which governs high-energy phosphate metabolism. This system is crucial for buffering, transporting, and regulating cellular energy. Consequently, creatine is fundamental to maintaining the energy balance and overall metabolic processes in vertebrates. Due to its pivotal role, these organisms must continually replenish their creatine reserves through dietary intake or de novo synthesis (Wyss and Kaddurah-Daouk, 2000; Turner and Gant, 2014).

Study shows that about 95% of the creatine pool is located in skeletal muscle of an organism while the remaining 5% is stored in the brain, liver and kidney (Kreider et al., 2003). In fish, the concentration of creatine per unit of body weight can be up to five times greater than in terrestrial animals, largely due to their higher proportion of skeletal muscle relative to body weight. Typically, with the help of following table we can analyse that creatine levels in fish muscle range from 2 to 7 grams per kilogram (Table 1).

Table 1: Creatine content in fish, raw meat and animal products

Sl. No.	Food source	g kg/ma ss	Reference
1.	Herring, fillet (<i>Clupea harengus</i>)	6.5–10.0	Balsom et al. (1994); Biesalski (2004)
2.	Yellowtail (<i>Seriola quinqueradiata</i>)	5	Sakaguchi et al (1982)
3.	Salmon (<i>Salmo salar</i>)	4.5	Balsom et al. (1994); Biesalski (2004)
4.	Hake (<i>Merluccius merluccius</i>)	5	Rehbein (1995)
5.	Alaska pollock (<i>Gadus chalcogrammus</i>)	4.7	Rehbein (1995)
6.	Tuna	2.7–6.5	Balsom et al. (1994);

			Biesalski (2004)
7.	Cod (<i>Gadus morhua</i>)	3–4.4	Balsom et al. (1994); Biesalski (2004)
8.	Saithe (<i>Pollachius virens</i>)	3.4	Rehbein (1995)
9.	Blue whiting (<i>Micromesistius spoutassou</i>)	3.7	Rehbein (1995)
10.	Shrimp (<i>Penaeus sp.</i>)	0.7	Rehbein (1995)
11.	Plaice (<i>Pleuronectes platessa</i>)	2	Balsom et al. (1994); Biesalski (2004)
12.	Cockle (<i>Cerastoderma edule</i>)	0.05	Rehbein (1995)
13.	Blue mussel (<i>Mytilus edulis</i>)	0.08	Rehbein (1995)
14.	Pork	5	Balsom et al. (1994); Biesalski (2004)
15.	Milk	0.1	Balsom et al. (1994); Biesalski (2004)
16.	Beef	4.5	Balsom et al. (1994);

Effect of Creatine on Product Quality, Organoleptic and Nutritional Value

Consumer demand for high-quality food has grown steadily worldwide in recent decades. In the case of meat, quality traits such as colour, flavour, and texture are central to how satisfied consumers ultimately feel with a product (Bredahl et al., 1998). Because aquaculture involves such a broad diversity of fish species, it is difficult to apply a single, universal standard for judging product quality (Kamolka et al., 2020). Nonetheless, fish flesh quality is generally understood to involve several species-specific characteristics — colour, appearance,

			Biesalski (2004)
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Purpose of creatine as supplement

The purpose of creatine supplementation is to boost both resting phosphocreatine levels and free creatine in the tissues, primarily in muscle tissue with the ultimate aim of enhancing muscular performance. Cells that have high energy demands depend on the creatine-phosphocreatine energy buffer system to regenerate adenosine triphosphate (ATP) from adenosine diphosphate (ADP), thereby ensuring a continuous supply of energy. However, once these reserves are depleted, phosphocreatine must be recycled from creatine to regenerate ATP by phosphorylating ADP (Gastin, 2001).

Creatine supplementation in aquaculture

Creatine's versatility as a supplement or feed additive has garnered significant interest across various vertebrate species. This is evident from numerous studies conducted in mammals such as livestock, laboratory animals, and companion animals as well as in birds and fish.

In teleost species, our understanding of creatine's functions is still limited compared to what is known in mammals and birds. Therefore, more research is needed to explore the diverse effects of creatine supplementation in finfish species.

odour, taste, nutritional content, and texture. Texture in particular is considered a core quality marker, shaped largely by how dry, chewy, or juicy the flesh is (Lie, 2001).

A number of studies have examined how creatine supplementation influences fish flesh quality. Schrama et al. (2018), for example, found that adding creatine to commercial diets did not meaningfully change muscle quality in gilthead seabream when evaluated through texture analysis. They did note, however, that fish receiving the higher creatine doses (5% and 8%) showed elevated pH values (around 6.5) at 24 hours after slaughter relative to fish on unsupplemented or low-creatine (2%) diets. This pattern points to creatine potentially boosting

muscle energy reserves, which in turn could benefit flesh quality — a conclusion that aligns with earlier work by McFarlane et al. (2001) on muscle glycogen levels in rainbow trout.

Similarly, Lin et al. (2023) reported that creatine-supplemented fish had higher postmortem pH at 48 hours, together with lower activity of lactate dehydrogenase and pyruvate kinase and reduced muscle lactic acid. Separately, Ramos-Pinto et al. (2019) documented a marked rise in dorsal muscle cross-sectional area in gilthead seabream fed creatine, along with a shift toward a greater share of both small- and large-diameter muscle fibres. Although this study did not directly measure texture, the structural changes observed suggest that flesh quality could plausibly improve as a result.

Tian et al. (2022) found that a 0.6% creatine inclusion improved several texture-related traits in grass carp — including hardness, gumminess, chewiness, and cohesiveness. The authors linked this to creatine's influence on myofibre diameter, fibre density, fibre-type composition, and collagen levels, which also coincided with higher levels of total protein, total and essential amino acids, and flavour-related free amino acids in the muscle, potentially improving taste as well. In contrast, the same Lin et al. (2023) study found no meaningful shifts in textural traits such as hardness, springiness, or chewiness as a result of creatine supplementation. Given these inconsistent findings, more research is clearly needed to understand how dietary creatine affects flesh quality. Future work should take into account variables such as a species' trophic level, the composition of the diet (for instance, plant-based versus fishmeal-based), and the developmental stage of the fish. It is also worth further exploring creatine's possible antioxidant role, which could help protect proteins and lipids from oxidative damage and, by extension, influence overall meat quality (Zhang et al., 2013).

Is Creatine a “Conditionally Essential Nutrient” in Fish?

A nutrient is classed as essential when an organism either cannot make it internally or cannot make enough of it to meet its physiological requirements, meaning it must come from the diet. A conditionally essential nutrient sits somewhere in between: the body can synthesise it from precursor compounds, but under certain circumstances — such as restricted dietary intake — internal production may fall short, making dietary supplementation necessary (Meyers et al., 2006). As the aquafeed sector moves toward diets containing less or no fishmeal and relies more heavily on non-fish protein sources, particularly plant-based terrestrial ingredients (Gatlin et al., 2007), several problems arise. These include imbalanced amino acid profiles — for example, inadequate methionine and lysine relative to physiological need (NRC, 2011) — as well as shortfalls in nutrients typically supplied by animal tissue, such as taurine (Hardy, 2010) and creatine (Ringel et al., 2007). Such constraints matter most for carnivorous fish species. There is currently no direct evidence describing the exact amino acid requirements for creatine synthesis in fish, but it is reasonable to assume their needs are similar to, or perhaps greater than, those documented in mammals. In mammals, creatine biosynthesis draws heavily on daily amino acid intake — consuming roughly 10% of glycine, 22% of arginine, and 42% of methionine (Kashani et al., 2020). Two further observations support the idea that fish may have comparable or higher requirements: first, creatine levels in fish muscle can reach up to 10 g/kg, exceeding typical concentrations in mammalian meats such as beef and pork (about 4.5–5 g/kg) (Balsom et al., 1994); and second, research indicates that fish may possess a greater capacity for endogenous creatine synthesis than mammals do (Borchel et al., 2019).

Conclusion

Creatine supplementation in aquafeeds presents a promising approach to enhancing the growth performance, endurance, muscle composition, and health of finfish in aquaculture. Studies have indicated that creatine can significantly improve growth rates, muscle protein content, and various biomarkers of antioxidant and immune

responses in several fish species. Future research should focus on addressing the discrepancies in results by exploring the underlying mechanisms of creatine metabolism in different fish species, optimizing supplementation levels, and evaluating its impact under various dietary and environmental conditions. Additionally, investigating creatine's role as a conditionally essential nutrient in plant-based diets could provide further insights into its broader applications in sustainable aquaculture practices.

Overall, while creatine supplementation shows a promise, a more comprehensive understanding of its effects and mechanisms will be crucial for its effective and consistent application in aquaculture.

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