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Violet Ndeda
Impact Health Food Farms Organization, Indianapolis, Indiana, USA

Corresponding Author:
Violet Ndeda
Impact Health Food Farms Organization, Indianapolis, Indiana, USA

Exploring *Genus Amaranthus* as a promising fishmeal alternative in aquaculture: A mini review

Violet Ndeda

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Abstract
Fish farming often employs high stocking density (HSD) to boost productivity, despite the fact that it leads to chronic stress in fish, resulting in impaired growth, reduced reproductive capacity, and increased susceptibility to diseases. To mitigate these negative effects, incorporating appropriate levels of essential polyunsaturated fatty acids (PUFAs) into fish diets has shown promise in modulating stress responses and promoting the production of healthy fish for human consumption. The *Amaranthus* plant represents a valuable source of essential fatty acids (EFAs) and long-chain PUFAs, along with other essential nutrients. Almost every part of the *Amaranthus* plant can be processed and readily included in fish diets. This mini-review aims to provide a comprehensive understanding of the synergistic effects of *Amaranthus*-enriched fish feed on growth performance and the tissue profile of omega-3 and omega-6 long-chain PUFAs in cultured fish.

Keywords: Amaranth, fish feed, fatty acid, growth performance, omega-3, omega-6

1. Introduction

High fish stocking density is a significant factor that makes fish more susceptible to chronic stress, negatively impacting their growth, feed utilization, and overall fish yield (FAO, 2012) [1]. In commercial fish production, the availability of high-quality feeds plays a crucial role in promoting optimal growth and providing essential nutrients such as minerals, vitamins, amino acids, proteins, and lipids that contribute to fish health. In a study by (Gichana *et al*., 2019) [2], the nutritional composition of various locally available feedstuffs in the form of leaves was evaluated for their suitability in fish diets. Although most of these leaves exhibited a relatively high protein content of 25 to 35 percent (on a dry matter basis), their lipid extract content was only 10%, indicating the presence of predominantly non-lipid components. While existing literature primarily focuses on the protein levels in potential aquaculture feed formulations (Ogello *et al*., 2014) [3], there is a scarcity of studies specifically investigating the use of *Amaranthus* plant in fish feed formulation (Ngugi *et al*., 2017) [4]. However, the nutritional and health benefits of consuming *Amaranthus* have been reviewed in several articles (Ruth *et al*., 2021; Tibagonzeka *et al*., 2014; Molina-Poveda *et al*., 2017) [5-7], and Kim *et al*. (2006) [8] reported the positive effects of amaranth grain and amaranth oil supplementation on lipid and glucose metabolism in rats with diabetes. Fish are unable to synthesize certain essential fatty acids like omega-3 and omega-6, relying entirely on dietary sources for these nutrients. However, the n-6 to n-3 fatty acid ratio has been subject to debate, with studies revealing that farmed tilapia has significantly lower levels of n-3 fatty acids but higher concentrations of long-chain omega-6 fatty acids (Weaver *et al*., 2008) [9]. It is hypothesized that these two families of polyunsaturated fatty acids (PUFAs) compete, leading to a slowdown in the production of eicosanoids, which are responsible for various adverse physiological effects (Prostaglandins, 2004) [10]. Omega-6 fatty acids, by influencing gene expression, disrupt blood lipids and induce inflammation throughout the body, exacerbating inflammation-related disorders. In contrast, omega-3 fatty acids (EPA and DHA) are believed to reduce the production of these antagonistic eicosanoids, restoring a state of balance in the body. This review aims to present, discuss, and highlight the benefits of incorporating *Amaranthus* feeds in terms of growth performance and lipid composition in cultured fish.

2. Background information on *Amaranthus*

The *Genus Amaranthus* has attracted significant attention due to the high nutritional value it offers in various forms, including green vegetables, grains, and ornamental plants (Ruth *et al*., 2021; Lakshmi and Vimala, 2000; Manyelo *et al*., 2020) [5, 11, 12]. It is widely recognized as an affordable green vegetable or grain in tropical regions, thanks to its rapid growth and cost-effectiveness (Shukla *et al*., 2016) [13]. Amaranth grains have been used for both feed and food purposes since 6700 BC in numerous countries such as Africa, India, China, Southeast Asia, Mexico, and North and South America. There are several wild varieties of amaranth that can be cultivated in diverse soil and climatic conditions (Katiyar *et al*., 2000) [14], displaying tolerance to heat and drought with minimal susceptibility to diseases (Nsimba *et al*., 2008) [15]. Amaranth is a notable source of protein, with a protein content ranging from 17.5% to 30.3% on a dry matter basis, including 5% lysine (Oliveira and De Carvalho, 1975; Pedersen *et al*., 1987) [16, 17]. It also contains significant levels of vitamins A and C, making it a popular food crop (Písaříková *et al*., 2005) [18]. The leaves and other aerial parts of the plant contain phenolic compounds with antioxidant properties. Previous research has focused on monogastric animals (Fasuyi *et al*., 2008; Longato *et al*., 2017; Roučková *et al*., 2004; Molina *et al*., 2018; Kambashi *et al*., 2014) [19-23]. A study by (Longato *et al*., 2017) [20] indicated that incorporating 10% amaranth leaves into broiler diets yielded the best performance. However, when broiler chickens were fed diets containing 50 and 100 g/kg of amaranth grain, their final body weight was reduced (Roučková *et al*., 2004) [21]. Interestingly, the weight gain of broiler chickens was similar when they were fed either heat-treated or raw amaranth grains (Molina *et al*., 2018) [22]. Another study demonstrated that rabbits fed amaranth at doses of 160 and 320 g/kg exhibited weight gain and maintained good health (Kambashi *et al*., 2014) [23]. Furthermore, (Kambashi *et al*., 2014) [23] observed that increasing levels of amaranth (0, 16, and 32 percent) in rabbit diets led to an increase in protein and fat content, as well as a decrease in meat moisture. Amaranth grain has also shown hypocholesterolemia effects in trials. For instance, hamsters (Berger *et al*., 2003) [24] and hypercholesterolemic rabbits (Plate and Arêas, 2002) [25] fed diets containing 20% *Amaranthus cruentus* grains and 5% crude amaranth oil exhibited lower levels of total cholesterol and low- or very low-density lipoprotein (LDL).

2.1 Nutritional Value of *Amaranthus*

Amaranth has garnered substantial evidence supporting its efficacy in addressing global health challenges. This versatile crop has demonstrated positive effects on various health conditions, including cardiovascular and retinal diseases, atherosclerosis, arthritis, emphysema, and neurological disorders. Additionally, amaranth serves as an excellent source of protein (Longato *et al*., 2017; Molina *et al*., 2018; Kambashi *et al*., 2014) [20, 22, 23]. While amaranth boasts impressive nutritional content, it is worth noting that other exotic vegetables like asparagus, broccoli, celery, parsley, and spinach also exhibit higher nutrient densities. To provide a glimpse into the composition of amaranth vegetable leaves and grains, the following table presents an approximate breakdown of their constituents. Notably, amaranth grain possesses a carbohydrate content comparable to that of other cereals, albeit at significantly lower levels (Venskutonis and Kraujalis, 2013; Arendt and Zannini, 2013; Caselato-Sousa and Amaya-Farfán, 2012) [26-28].

Table 1: Nutritional composition of amaranth leaves

Component	Amaranth leaves (value per 100 g)
Protein	13.56
Lipids	7.02
Carbohydrates	65.25
Dietary fiber	6.70
Ash	2.88
Water	11.29

Carbohydrates, primarily in the form of starch, are the main constituents found in the perisperm cells of *Amaranthus* grains. Starch typically constitutes between 48% and 69% of the dry matter content in these grains (Becker *et al*., 1981) [29]. Consequently, the carbohydrate content of amaranth grains surpasses that of amaranth leaves. Carbohydrates serve as a vital energy source for monogastric organisms, supporting essential processes such as growth, movement, and metabolism. Compared to the leaves, the nutritional value of grains often appears to be significantly higher. Research conducted by several scholars has revealed that the carbohydrate content in amaranth grains ranges from 51% to 77%, whereas amaranth leaves contain between 1.3% and 10.1% carbohydrates (Edelman and Colt, 2016; Altemimi *et al*., 2017) [30, 31]. The amylose content in grains is generally low, varying from 0.1% to 11.1%. Nevertheless, reported levels of different carbohydrates in amaranth grains and leaves exhibit wide variation, influenced by diverse climatic conditions under which the *Amaranthus* is cultivated. Amaranth grains demonstrate a dietary fiber content comparable to popular cereals like quinoa, albeit slightly lower than wheat (Alvarez-Jubete *et al*., 2010; Alvarez-Jubete *et al*., 2009) [32, 33]. Arendt and Zannini's research (Arendt and Zannini, 2013) [27] indicate that the amount of dietary fiber in amaranth ranges from 9.8% to 14.5%, depending on the specific type. In addition to containing high levels of glucose, galactose, fructose, maltose, raffinose, stachyose, and inositol, the sugar composition of amaranth is primarily composed of sucrose (O'Brien and Price, 2008) [34].

2.2 Utilizing Amaranth Leaf and Grain Meals as Beneficial Alternatives in Aquaculture Feeds

Amaranth leaf meal, derived from the amaranth plant, serves as a valuable by-product. Amaranth leaves exhibit a protein content of 17.5% to 30.3% in terms of dry matter, with lysine comprising 5% of this total. Consequently, amaranth is recognized as a significant protein source. Various research studies have demonstrated the positive effects of amaranth-enriched meals on the health and weight gain of rats, intensively farmed pigs, chicks, calves, lambs, sheep, and ruminants (Olufemi *et al*., 2003; Zralý *et al*., 2004; Ravindran *et al*., 1996; Vaseeharan and Thaya, 2014; Gebrehiwot and Unakal, 2013) [35-39]. Additionally, investigations have revealed that amaranth meal enhances the immune systems, growth performance, and gut microbiota enzymatic activity of fish (Virk and Saxena, 2003; Maiyo *et al*., 2010) [40, 41]. For instance, Ngugi *et al*. (2017) [4] reported that amaranth leaf meal improved the growth performance of tilapia. In their study, fish were fed a diet containing 2.5% amaranth leaf meal based on their body weight. After eight weeks, the fish fed with the amaranth leaf meal diet exhibited higher body weights and lengths compared to those without the amaranth leaf meal diet. Similarly, Virk and Saxena (2003) [40] observed that *Amaranthus* seeds, which are rich in protein but low in fat, enhanced the weight gain of fish species when incorporated into their diets at different levels (20%, 35%, and 50%). Notably, the protein content of *Amaranthus* seeds (16% crude protein) was not higher than that of regular fishmeal. The positive effects were attributed to *Amaranthus* improving the absorption and utilization abilities of the fish. Moreover, fish fed with amaranth leaf meal demonstrated improved survival rates compared to those fed with conventional meals. Ngugi *et al*. (2017) [4] further demonstrated that amaranth leaf protein concentrates could substitute up to 80% of fishmeal without affecting growth performance or nutrient utilization. However, differences were observed between the amaranth leaf meal and 100% fishmeal diets. The amaranth leaf meal exhibited lower amounts of certain essential amino acids such as threonine, lysine, methionine, and cysteine, which could hinder fish growth, particularly in lysine-deficient environments. Additionally, amaranth leaf meal contained antinutritional elements like phytates and oxalates, which could be bound to specific proteins and reduce protein digestibility, potentially affecting amino acid absorption and inhibiting fish growth. Molina-Poveda *et al*. (2017) [7] found that amaranth leaf meal improved the growth performance of various fish species when included in their diets at a level of 5% based on body weight. Their research highlighted the health benefits of phenolic compounds present in amaranth, which are abundant in fiber, proteins, vitamins, and minerals. It is worth noting that the antinutritional elements in amaranth can be reduced through various processing techniques (Tang and Tsao, 2017) [42]. Furthermore, amaranth's utilization in monogastric feeding has shown positive outcomes, enhancing productivity without adversely affecting animal performance. Consequently, it is evident that amaranth leaves and grains can be effectively incorporated into monogastric animal diets with appropriate processing techniques to eliminate antinutritional components. Notably, the utilization of amaranth leaf meal resulted in higher survival rates, aligning with the findings of Ngugi *et al*. (2017) [4]. In an experiment conducted by Poczyczyński *et al*. (2014) [43] involving rainbow trout *Oncorhynchus mykiss*, amaranth feeds were substituted for fish meal. The feed with the highest amaranth oil content resulted in a growth rate of 3.75% per day for the fish. Notably, crustacean meat exhibited the highest concentrations of crude protein and fat in various research studies. Therefore, it can be concluded that amaranth leaf meal can also serve as a partial replacement for fish meal in aquaculture feeds. In conclusion, the utilization of amaranth leaf and grain meals as alternatives in aquaculture feeds offers several benefits. These meals provide a valuable source of protein, as evidenced by their high protein content and lysine composition. Numerous studies have demonstrated the positive effects of amaranth-enriched diets on the growth performance, immune systems, and gut microbiota enzymatic activity of various animals, including fish. However, it is important to consider certain factors such as variations in essential amino acid content, antinutritional elements, and the need for appropriate processing techniques to optimize their utilization. Further research and development efforts are necessary to explore the full potential of amaranth as a sustainable and beneficial ingredient in aquaculture feeds.

2.3 Total Lipid Content of *Amaranthus* Seeds

The lipid fraction of *Amaranthus* seeds primarily consists of triacylglycerols (TAGs), phospholipids, squalene, and lipid-soluble vitamins such as tocopherols. Lipids play a crucial role as nutritional components in *Amaranthus* seeds. Additionally, different species of *Amaranthus* have been found to contain various minor components, including phytosterols, waxes, and terpene alcohols (Chaturvedi *et al*., 1993) [44]. The composition of these components in amaranth seeds is determined by the plant species and cultivar, as well as the extraction methods and solvents used. Processing techniques, including heat treatments, also influence the lipid content and structure of amaranth seeds (He and Corke, 2003) [45]. Studies have reported lipid contents ranging from 4.8% to 8.1% in amaranth seeds (Dengate and Pomeranz, 1984) [46]. However, recent research has revealed that the concentrations can be much higher and vary depending on factors such as species, cultivar, agrotechnological practices, and growing regions. The variability in lipid content is broader than previously understood. For instance, in a study involving various accessions of eight amaranth species, the crude fat contents ranged from 5.2% to 7.7% based on the dry weight of the seeds (Budin *et al*., 1996) [47]. In another study investigating 14 selections from four species (*A. caudatus*, *A. hybridus*, *A. cruentus*, and *A. hypochondriacus*), the fat content ranged from 7.7% to 12.8% (Bressani *et al*., 1992) [48] and from 10.6% to 16.7% (Kraujalis and Venskutonis, 2013) [49]. Notably, *A. spinosus* and *A. tenuifolius* exhibited lipid contents as high as 17.0% and 19.3%, respectively, indicating a relatively high fat content in amaranth seeds (Singhal and Kulkarni, 1990) [50]. A comparison between 48 *A. hypochondriacus* lines and 11 *A. caudatus* lines showed that *A. caudatus* lines had a higher fat content than *A. hypochondriacus* lines (Kaur *et al*., 2010) [51].

2.4 Fatty Acids

The fatty acid composition of amaranth oils has been the subject of several studies, revealing variations in percentages of palmitic, linoleic, and oleic acids among different species and cultivars (Venskutonis and Kraujalis, 2013) [26]. Palmitic (19.1% to 23.4%), oleic (18.7% to 38.9%), and linoleic (36.7% to 55.9%) acids were found to be the most abundant fatty acids in the oils of 11 genotypes from four grain amaranth species, with a S/U ratio ranging from 0.26 to 0.32 (He *et al*., 2003) [52]. In *A. paniculatus* seed oil, notable concentrations of epoxy and cyclopropenoid fatty acids such as vernolic (7.8%), malvalic (1.5%), sterculic, palmitic (19.4%), stearic (3.9%), and oleic (21.9%) acids were observed (Mahmood *et al*., 1992) [53]. The oils extracted from 14 different selections of *A. caudatus*, *A. hybridus*, *A. cruentus*, and *A. hypochondriacus* contained varying amounts of palmitic (16.83% to 23.83%), stearic (1.863% to 4.113%), oleic (20.29% to 35.463%), and linoleic (38% to 58%) acids (Kabuage, 1996) [54]. Another study on *A. cruentus* varieties and locations demonstrated that palmitic acid ranged from 17.06% to 21.35%, stearic acid from 3.05% to 3.80%, oleic acid from 20.26% to 32.01%, and linoleic acid from 33.56% to 43.88% (Berganza *et al*., 2003) [55]. The predominant fatty acids in amaranth oil are palmitic (22.2%), oleic (29.1%), and linoleic (44.6%) acids, while smaller concentrations of linolenic (3.86%), arachidic (5.1%), and gadoleic acids are also present (Rodas and Bressani, 2009) [56]. As fish cannot synthesize linoleic, oleic, or linolenic acids, which are considered essential fatty acids, the omega-6 fatty acids found in amaranth oil become crucial as a dietary supplement for fish growth. In a study with rainbow trout *Oncorhynchus mykiss*, it was observed that higher levels of amaranth oil led to decreased levels of eicosapentaenoic acid (C20:5n-3, EPA) and docosahexaenoic acid (C22:6n-3, DHA) (Poczyczyński *et al*., 2014) [43]. Similar findings were reported in previous studies involving freshwater predatory fish such as rainbow trout, European catfish, and pike (Bieniarz *et al*., 2000) [57]. These results indicate that amaranth oil can serve as an alternative to fish oil in the diets of certain fish species. However, it is important to note that the study period in the mentioned research was relatively short, and the number of fish in the experimental groups was limited (Manyelo *et al*., 2020) [12].

3. Potential use of amaranth on the lipid composition of fish considering fatty acid tissue profiles (omega-3 and omega-6 fatty acids)

Fatty acids play a vital role in the metabolic pathways of fish and other seafood organisms, impacting their overall health and well-being. Research has demonstrated that replacing fish oil with plant fats in the diets of marine fish can enhance the nutritional value of fatty acid composition in juvenile fish, resulting in increased levels of EPA+DHA, total n-3 PUFA concentrations, and an improved n-3/n-6 ratio (Pedersen *et al*., 1987) [17]. However, for fish to maintain good health, weight gain, and fertility, their diet should consist of appropriate values and a balanced composition of proteins (amino acids), fats (fatty acids), vitamins, and minerals. Given the nutraceutical and nutritional profiles of Amaranth, it presents a potential alternative to traditional fish meal and feed sources. Plant fats, including Amaranth, are naturally well-balanced in terms of fatty acid profiles, thanks to their high levels of highly unsaturated fatty acids (HUFAs). The use of balanced nutrients, particularly in terms of fatty acid profiles, has been shown to promote lower instances of pathological conditions such as intestinal lipid accumulation (Písaříková *et al*., 2005) [18].

Numerous studies have identified the main fatty acids in Amaranth oil as palmitic acid (36.7% to 55.9%), linoleic acid (19.1% to 23.4%), and oleic acid (18.7% to 38.9%) (Fasuyi *et al*., 2008) [19]. However, the concentration of omega-3 alpha-linolenic acid can vary among different varieties of Amaranth, influenced by genotype characteristics and environmental factors such as cultivation year, soil conditions, salinity, pH, and climate (Longato *et al*., 2017) [20]. Omega-6 and omega-3 fatty acids are classified as essential fatty acids (EFA), with linoleic acid and alpha-linolenic acid serving as the parent compounds for each class, respectively, and giving rise to longer-chain derivatives within the body. Considering Amaranth's richness in terms of linoleic acid (LA) and alpha-linolenic acid (ALA), it holds promise as a valuable supplement to fish meal, particularly through incorporating different components of the Amaranth diet such as seeds and oil seeds, which serve as reservoirs of beneficial fatty acids and other lipids like squalene.

4. Conclusion

To summarize, Amaranth is widely regarded as a "superfood" due to its remarkable concentrations of phytochemicals such as flavonoids, phenolic acids, tocopherols, tocotrienols, vitamins, and other antioxidants. Furthermore, it boasts high levels of protein, dietary fiber, unsaturated oils, fatty acids, calcium, iron, and magnesium. Amaranth has the potential to replace up to 80% of fish meal in aquaculture without compromising the growth performance and lipid composition of cultured fish. Its exceptional protein quality and favorable fatty acid profiles, including linoleic acid, alpha-linolenic acid, and squalene, make Amaranth a valuable source of omega-3 and omega-6 fatty acids, which are crucial for tissue development. Amaranth leaves, with their high protein content, essential lipids, minerals, and vitamins, offer a composition similar to or even superior to that of fish meal. Amaranth leaf meal can be utilized as a partial or complete substitute for fish meal in aquaculture diets, enhancing fish growth performance by providing a highly digestible protein source rich in essential amino acids. Additionally, the leaf contains an array of essential lipids, minerals, and vitamins necessary for the proper growth and development of fish species. Incorporating Amaranth plants into fish feed processing and aqua feeds represents a sustainable approach to sourcing nutritional feeds in aquaculture.

4.1 Conflicts of Interest: The author declares no conflict of interest.

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