Snakehead Fishes (Channidae): Aquaculture Potential, Nutritional Composition and Molecular Regulation of Lipid Metabolism: A Mini Review

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Abstract

Snakehead fishes (family Channidae) are increasingly important in freshwater aquaculture across Asia and emerging regions such as sub-Saharan Africa, driven by high consumer preference, rapid growth, air-breathing ability and perceived medicinal value. Culture intensification has stimulated a rapid shift from trash-fish based feeding to formulated diets, raising critical questions about optimal protein lipid nutrition, lipid deposition, health, and the molecular regulation of energy and lipid metabolism. Recent studies are evaluated growth and feed efficiency responses to concentration based dietary protein and lipid levels in several snakehead species and hybrids, and has begun to clarify the roles of key metabolic regulators such as leptin paralogs, uncoupling protein 1 (UCP1) and target of rapamycin (TOR) signaling in energy balance and lipid metabolism. Similar studies have detailed proximate composition, amino acid profile, albumin content and fatty acid composition of different Channa species and products, showing their nutritional value for humans and potential as functional foods. The aim of the present study is to understand (1) the aquaculture potential and production systems for snakehead fishes; (2) their flesh and product nutritional characteristics; and (3) emerging trends into molecular and nutritional regulation of lipid metabolism, including responses to dietary lipid manipulation, novel ingredients and hepatobiliary challenge. Limitations, research gaps and priorities are identified to support sustainable intensification, feed formulation and health management in Channidae aquaculture.

Keywords: Snakehead fish, Protein content, Lipid content, Molecular regulation, Aquaculture practices, Channidae

1. INTRODUCTION

Snakehead fishes (family Channidae) are air-breathing freshwater predators distributed throughout tropical and subtropical Asia and Africa. The family currently includes the Asian genus Channa and the African genus Parachanna, with about 29–38 valid species recognized depending on the taxonomic authentication and methodology used in identification [1–4]. Most species are medium to large sized thrust predators, many of them largely piscivorous as adults, although some dwarf forms exist and several taxa show cryptic diversity and unresolved taxonomy [3,5,6]. Their obligate or facultative air breathing ability, tolerance of hypoxia, and capacity to exploit lentic and floodplain habitats represents both their success in native ecosystems and their prominence as food fishes in large parts of Asia and Africa [7–9]. In countries such as Indonesia, India, Sri Lanka and China, snakeheads rank among the most important inland fishes for capture fisheries and are deeply embedded in culinary and medicinal traditions [8,10].

Apart from their role in traditional fisheries, several snakehead species have become emerging candidates for freshwater aquaculture. In Asia, *Channa argus*, *C. maculata*, *C. striata*, *C. marulius* and *C. micropeltes* are among the most economically important, being cultured in ponds, cages and integrated systems for domestic and export markets [7–9]. In Indonesia, for example, *C. striata* contributes significantly to national snakehead production, yet 73–97% of output still derives from inland capture fisheries rather than aquaculture, leading to concerns about over exploitation and vulnerability to climate variability [9]. In sub Saharan Africa, where aquaculture is dominated by tilapias and African catfishes, the African snakehead *Parachanna obscura* has been highlighted as a promising species to diversify production and enhance resilience, drawing on lessons from rapid snakehead farming expansion in Asia [7]. At the same time, the characteristics of snakeheads such as air breathing, tolerance of poor water quality, strong parental care and fast growth have facilitated their establishment as invasive species when transported beyond native ranges. Several Channidae, especially *C. argus* and *C. marulius*, are now established in parts of North America, prompting detailed biological synopses and molecular tools (DNA barcoding, genomic scans) to support risk assessment and pathway management [4,11–13]. The properties and advantages of the Channidae family is showed in Figure 1.

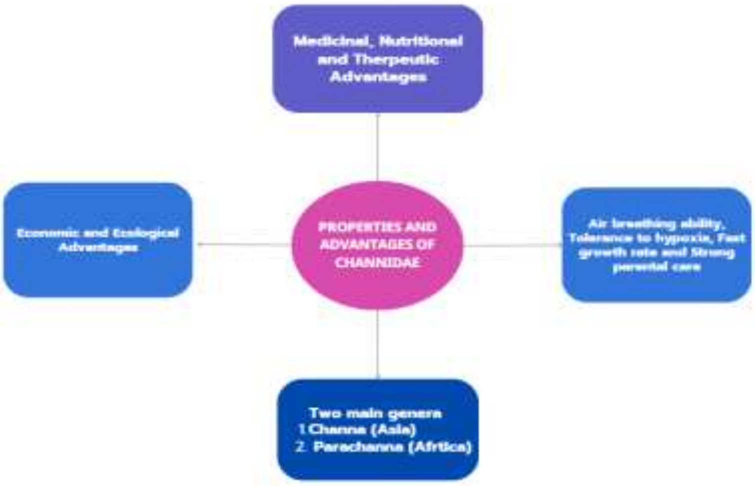

Figure 1: Properties and advantages of Channidae

In commercial aquaculture, snakeheads are attractive because they are easy to rear and have high market value. Many Channa species can survive in high density culture due to their ability to withstand hypoxia and fluctuating water quality, including in ponds, rice fields, cages, biofloc and recirculating systems [7–9]. Their high trophic status and carnivorous feeding habits yield firm, boneless flesh with high fillet yield and good consumer acceptance, often commanding premium prices [8,10]. Moreover, snakeheads are widely perceived as nutritionally superior and medicinal, particularly in Southeast Asia, where *C. striata* and related species are used in protein rich diets, postoperative recovery and traditional medicine. These advantages are supported by compositional analyses showing high crude protein, favorable essential amino acid profiles and high albumin content in muscle and derived products [8,10]. Such attributes position snakehead meat and extracts as candidates for functional foods and nutraceuticals, stimulating interest in value added processing and biotechnological approaches to albumin production [9].

There are certain limitations associated with sustainable expansion of snakehead aquaculture. Production of *C. striata* and other species in Indonesia and neighbouring countries still relies heavily on wild seed and capture based supply, and hatchery and domestication programs gained recent attention [8]. High larval and juvenile mortality, severe intracohort cannibalism, incomplete understanding of reproductive biology and larval nutrition, and the reluctance of early life stages to accept dry feeds are major bottlenecks [7,8]. In addition, traditional feeding practices relying on low-value “trash fish” or slaughterhouse offal raise economic, environmental and biosecurity concerns, including nutrient pollution, disease transmission and dependence on declining capture fisheries. Shifting to formulated feeds based on sustainable protein and lipid sources is therefore a strategic priority, but requires robust data on snakehead nutrient requirements, digestive capacity and metabolic regulation [7,9].

After these production challenges, there is growing recognition of the need for strategic planning and bioresource management of snakehead populations, exemplified by the bioresource flow model (BRFM) proposed for *Channa striata* in Indonesia, which integrates domestication and conservation, hatchery production, optimized aquaculture systems, biotechnological processing for albumin and wastewater management into a single framework for sustainable utilization [9]. At the same time, global applications of DNA barcoding and mitochondrial phylogeography have revealed unexpectedly high cryptic diversity and complex evolutionary histories within Channidae, with COI barcode libraries and expanded datasets showing many more genetic clusters than currently described species and multiple deeply divergent lineages within nominal taxa such as *C. gachua*, *C. marulius*, *C. punctata* and *C. striata* [2,4,14]. Cytogenetic analyses documenting extensive chromosomal variation and rearrangements, including pericentric inversions, fusions and polyploidization, further support the view that several nominal species likely constitute species complexes and that integrative taxonomic revision is needed [3]. The recent discovery and formal description of a morphologically distinctive sister lineage to snakeheads (family Aenigmachannidae), together with ongoing identification of new Channa species, underline how incomplete present knowledge of snakehead diversity and evolution remains [2,3]. These taxonomic and genomic advances have direct implications not only for biodiversity conservation and invasion biology but also for selective breeding and strain development in aquaculture, as illustrated by chromosome-level genomes for economically important species such as *C. argus*, *C. maculata* and *C. asiatica* and by genome wide association studies that identify growth related loci and support genomic selection [15–17]. The table 1 shows commercial importance of species of Channidae family.

Table 1: Commercial importance of species of channidae family.

Species	**Common name**	**Region**	**Commercial importance**
Channa argus	Northern snakehead	China, East Asia	Widely cultured, strong growth and high market value
Channa striata	Striped snakehead	India, Indonesia, SE Asia	Important food fish, high albumin content
Channa marulius	Bulls eye snakehead	South Asia	Fast growth and suitable for pond culture
Channa micropeltes	Giant snakehead	Southeast Asia	Large body size and high meat yield
Channa maculata	Blotched snakehead	China	Used in hybrid breeding programs
Parachanna obscura	African snakehead	Sub-Saharan Africa	Potential species for diversification in African aquaculture

Most of the previous reviews showed snakehead biology and general farming, but there is no study that provided snakeheads in the wider picture of global aquaculture and conservation, described in detail the protein, albumin and fat in their meat and products, and linked new findings on fat metabolism to feed design, fish health and product quality. This is important because snakehead farming is expanding fast in Asia, starting in Africa, and snakehead-based foods and extracts are being developed for both nutrition and medical uses. Therefore, the present review focuses to explain the species of Channidae family are promising farm fish, to bring together data on their basic composition, fatty acids, amino acids and albumin and what these mean for human nutrition and functional foods, and to summarize how hormones, mitochondria and nutrient-sensing pathways control fat use in snakeheads and affect practical issues like diet formulation, health management and breeding. This will further help to utilize omics tolls in farming systems and resource management to help make snakehead aquaculture more sustainable and higher value in both native and introduced regions

2. Commercial production systems and technological developments

Commercial production systems for snakehead culture range from traditional earthen ponds and paddy cum fish systems to more intensive floating cages, lined ponds and recirculating systems. In Asia, many farms historically relied on feeding raw trash fish or slaughterhouse by products, but this practice raises concerns about biosecurity, nutrient loading, and economic and environmental sustainability [18,19]. Recent study in China has documented the development of compound feeds for snakehead fishes and analyzed the transition from forage fish based feeding to formulated diets at regional industry level, emphasizing the need for industrial upgrading and sustainable aquaculture practices [19]. Experiences from catfish and other carnivorous species provide a roadmap for this transition.

Innovative water quality enhancing systems are being explored in recent decades. Aquaponics, which combines fish culture with hydroponic plant production, has been tested with *C. striata* and water spinach. Over a 150 day grow out, an aquaponic system achieved dramatically lower ammonia and nitrite concentrations, improved survival (almost 100% versus about 70% in conventional ponds), and approximately threefold higher fish yield; Economical advantage from both fish and vegetable crops was about four times higher than in the control system [20]. Similar comparative work on green water, biofloc and aquaponic systems for *C. striata* has indicated that biofloc provided the most stable water quality and lowest blood glucose, suggesting reduced chronic stress relative to other systems [21]. These results suggest that integrated and biofloc-based systems can enhance both environmental performance and productivity of snakehead farming when coupled with appropriate feeding strategies.

At earlier life stages, hatchery and nursery technologies for snakehead remain under active development. A comprehensive study on *C. striata* revealed that bottlenecks include incomplete knowledge of reproductive biology, larval nutritional requirements, high larval mortality, severe intracohort cannibalism and reluctance of juveniles to accept artificial diets. Strategies to mitigate cannibalism include size grading, high feeding frequency, provision of suitable shelters and careful weaning protocols from live to pelleted feeds. The adoption of hatchery-produced, pellet-weaned seed will be critical to the successful transition from capture-based to culture-based supply of snakehead in many countries [22].

3. Nutritional composition and human health significance

The nutritional composition of snakehead flesh, including high protein and albumin content, has attracted attention for both general nutrition and functional food applications. Muscle of snakehead species generally contains about 74–80% moisture, 17–20% crude protein, 0.1–1.7% fat, and around 1–2% ash, though these nutritional quantities are varying with species, size, origin and culture conditions [23–25]. The *C. argus* soup prepared from farmed fish, showed protein content is approximately 2.6% in the final product, with total amino acids approximately 390 mg/g dry matter and essential amino acids comprising about 28% of total amino acids [24]. Fatty acids in these soups include about 13–16 g/100 g total fatty acids, with monounsaturated, n-6 and n-3 polyunsaturated fatty acids contributing meaningful proportions; farmed fish provide substantial monounsaturated and n-6 PUFA, whereas wild fish may have slightly higher total fatty acids and some mineral differences, such as higher Zn content. Antioxidant capacities of snakehead soups, assessed by DPPH radical scavenging, Fe-chelating and hydroxyl radical scavenging assays, are moderate and not markedly different between wild and farmed sources [24].

Albumin content is a particular focus in several Channidae species due to its clinical applications in wound healing and as a functional ingredient. Snakehead meat is reported to contain around 25% protein, of which roughly 63% may be albumin in some *C. striata* preparations, and snakehead flour have more than 70% protein and high albumin concentrations [23,25,26]. Studies on *C. gachua* and *C. micropeltes* have shown that larger fish tend to have higher crude protein and lipid content, as well as greater total amino acids and albumin content; in giant snakehead, fish the protein content ranges from 35–300 g, which is around 17%, lipid (about 1.7%), total amino acids and albumin levels, suggesting larger sizes may be nutritionally preferable for albumin focused utilization [23,25]. In *C. gachua* from riverine environments, crude protein ranged from about 65–71% on dry basis with very low lipid (about 1–2%), and protease and lipase activities increased with fish size, likely contributing to albumin content patterns [25].

These studies revealed snakehead fish has been developed into various functional products. For instance, fortification of velvet bean tempeh with *C. striata* flour at around 9.5% result in increased product protein content to nearly 40%, while reducing fat relative to control and maintaining good sensory acceptance, indicating that snakehead-based ingredients can successfully enhance plant-based foods [26]. Combined with evidence of high calcium and phosphorus contents and essential amino acids such as lysine, arginine and leucine, these data support the significance of snakehead meat and derivatives as nutrient-dense, potentially functional foods in human diets [23,25,26].

4. Nutritional requirements and dietary lipid utilization

Optimizing dietary protein and lipid levels is essential for sustainable snakehead aquaculture, both to reduce dependence on fishmeal and fish oil and to control fat deposition and health. Multiple feeding trials on different snakehead species and hybrids have examined growth, body composition, digestive enzyme activities and metabolic responses across concentrations of dietary protein and lipid [27–29]. The table 2 describes optimal dietary requirements for snakehead culture.

A study carried out on *C. argus*, juvenile treated with three protein levels (45, 48 and 51%) and three lipid levels (9, 12 and 15%) in diets showed that the combination of 48% protein with 12–15% lipid obtained with the highest weight gain and lowest feed conversion ratio, with evidence of protein sparing as lipid increased from 9 to 12% at moderate protein levels. Diets containing only 45% protein and 9% lipid resulted in the poorest growth, whereas increasing protein above about 48% did not further improve performance under those lipid levels. Body lipid increased with dietary lipid, and viscerosomatic and hepatosomatic indices were higher in high lipid treated groups. Intestinal lipase activity increased with both dietary protein and lipid, while amylase and protease activities were less affected, consistent with a carnivorous species adapting digestive capacity to increased fat intake [18].

In hybrid snakehead (*C. maculata* × *C. argus*), a study carried out using five protein levels (34–57%) at two lipid levels (6.5 and 12%) found that weight gain improved up to about 48–51% crude protein, with estimated requirements of roughly 50.5% protein at low lipid and 47.9% protein at higher lipid for 95% of maximal growth. As dietary protein increased, body protein content increased and body lipid declined, whereas high dietary lipid (12%) did not significantly improve growth but promoted fat accumulation in whole body, liver and mesentery and elevated plasma cholesterol and alanine aminotransferase activity, indicating a risk of hepatic steatosis and metabolic stress at excessive lipid levels [30]. These results align with another study on hybrid snakehead where graded dietary lipid (about 6–17%) at constant protein content (42%) increased growth and protein efficiency ratio up to the highest lipid level, but also progressively increased liver and body lipid deposition; the highest lipid diet led to reduced hepatic alkaline phosphatase and catalase activity, elevated malondialdehyde, and increased serum transaminases and triglycerides. An intermediate lipid level around 14% was judged optimal for liver health, balancing growth performance and oxidative status [31].

In *C. striata*, a study showed optimal dietary lipid around 7% for growth, with decrease in growth when dietary lipid exceeds roughly 19% [7,27]. In bulls eye snakehead (*C. marulius*), a recent 90-day trial on fingerlings comparing 0–12% fish oil at fixed protein showed that 12% lipid produced the highest weight gain and best feed conversion, along with significantly higher digestive enzyme activities and improved hematological parameters, suggesting a relatively high capacity for lipid utilization at this stage [28]. In another study carried out for a period of three months on *C. marulius* tested 40–55% crude protein at constant lipid and found linear increases in growth as dietary protein rose to 55%, with concentration dependent increase in fillet protein and decreases in body lipid; higher protein elevated intestinal protease activity but reduced lipase and amylase activities, showing the complex interaction of macronutrient balance and digestive physiology [29].

These studies clearly indicated about the species and life stage specific nutritional requirements and growth performance in Channidae family. Juvenile and grow out stages typically require relatively high protein (about 45–55% of dry diet) and moderate lipid (around 7–15%), with some capacity for protein sparing by lipid yet clear risks of excessive adiposity and hepatic dysfunction at very high lipid levels [7,18,28,30,31]. Moreover, responses in body composition and enzyme activity suggest that dietary formulation can be used to shape partitioning between protein accretion and lipid deposition, which is important for both production efficiency and fillet quality.

Table 2: Optimal dietary requirements for snakehead culture.

Species	**Protein requirement**	**Lipid requirement**	**Important findings**
Channa argus	~48 %	12–15 %	Best growth and feed conversion
Hybrid (*C. maculata* × *C. argus*)	48–51 %	6–12 %	Higher lipid increases body fat
Channa striata	~45–50 %	~7 %	Excess lipid reduces growth
Channa marulius	40–55 %	up to 12 %	Higher lipid improves digestive enzymes

5. Molecular regulation of energy balance and lipid metabolism

The classical nutrition experiments have provided practical recommendations, more recent research has begun to explore the molecular mechanisms describing energy balance and lipid metabolism in snakehead fishes, particularly focusing on endocrine and cellular regulators sensitive to feeding status, dietary composition and hepatobiliary health (Fig 2).

5.1. Leptin paralogs and energy homeostasis

Teleost fishes typically possess multiple leptin genes due to whole genome duplication. In *C. argus*, two leptin paralogs (lepA and lepB) have been cloned and characterized. These genes encode proteins of 158–159 amino acids and share structural features with leptins in other vertebrates. Tissue distribution studies revealed distinct expression patterns: lepA was predominantly expressed in liver, whereas lepB showed higher expression in brain and some peripheral tissues, suggesting division of labour between systemic energy status signalling and central regulation of appetite or neuroendocrine functions. In post prandial experiments, hepatic lepA and brain lepB exhibited similar temporal transcription patterns, increasing after feeding, which is consistent with a role in signalling positive energy balance. During a 2-week fasting and refeeding trial, hepatic lepA and brain lepB both responded strongly to food deprivation, yet their responses diverged after refeeding, indicating differential regulation and potentially distinct roles in hunger–satiety cycles [32]. These findings support the idea that snakehead leptin paralogs function as key regulators of energy metabolism and food intake, analogous but not identical to mammalian leptin, and may constitute useful markers or targets in nutritional and growth regulation strategies.

5.2. Uncoupling protein 1 and fatty acid metabolism

Uncoupling protein 1 (UCP1) is a mitochondrial carrier protein best known for non-shivering thermogenesis in mammalian brown adipose tissue, but its functions in fishes, which lack classical brown fat, are less clear. In *C. argus*, UCP1 has been cloned and shown to have high sequence identity with other teleost UCP1 orthologs, while being more divergent from mammalian UCP1. Expression analysis indicated that ucp1 is widely expressed in snakehead tissues, with significantly high levels in liver. Both short-term and long-term fasting conditions significantly up-regulated hepatic ucp1, and expression further increased upon refeeding, suggesting a role in metabolic flexibility during transitions between catabolic and anabolic states [33]. Given the association of UCPs with fatty acid oxidation and regulation of reactive oxygen species, these data imply that snakehead UCP1 may participate in modulation of hepatic fatty acid metabolism and energy expenditure, possibly contributing to adaptations to fluctuating food availability in natural habitats and intensive culture.

5.3. TOR signaling, lipid metabolism genes and diet composition

At the intracellular level, the target of rapamycin (TOR) pathway is a central integrator of nutrient signals, especially amino acids, and controls protein synthesis and cell growth. In hybrid snakehead, liver expression of TOR was significantly increased as dietary protein increased from low to moderate levels (34–52% of diet) and then did not increase further at the highest protein level tested. This pattern mirrors the growth response and suggests that TOR activation reflects adequate amino acid supply for maximal protein increase; beyond a threshold, additional protein does not further stimulate growth or TOR transcription, which may relate to saturation of translational machinery or feedback inhibition. Along with the protein it was also observed that high dietary lipid increased hepatic expression of lipoprotein lipase (LPL), a key enzyme in triglyceride hydrolysis and lipid uptake, consistent with enhanced lipid handling and storage in high-fat diets [30]. These molecular responses help explain observed increases in liver and visceral fat with high dietary lipid and link macronutrient composition to specific metabolic regulators.

Dietary inclusion of functional ingredients can also modulate lipid metabolism. In hybrid snakehead, partial or full replacement of high gluten flour with kelp meal for 60 days did not alter protein and lipid content of the isonitrogenous, isolipidic diets but significantly affected systemic antioxidant status, intestinal morphology and gene expression. Kelp-supplemented fish exhibited higher serum antioxidant enzyme activities and lower malondialdehyde, indicating reduced oxidative stress, and histological analysis showed increased intestinal villus surface area, which may enhance nutrient absorption. Transcriptomic and qRT-PCR data revealed that kelp increased expression of intestinal immune-related genes such as MHC I and HSPA1, while reducing some pro-inflammatory markers, and significantly up-regulated several lipid metabolisms related genes, including DGAT2, FABP2, RXRα and PLPP1, associated with triglyceride synthesis, fatty acid binding, nuclear receptor signaling and phospholipid metabolism, respectively [34]. Hence, the dietary kelp can promote intestinal lipid synthesis and transport, improve immune function, and potentially alter systemic lipid metabolism in snakehead.

5.4. Hepatobiliary stress, bile acid metabolism and antioxidant defense

Intensive culture and high-energy diets can predispose snakehead to hepatobiliary disorders. Experimental models have been developed to understand pathogenesis and test protective interventions. In *C. argus*, dietary lithocholic acid (LCA), a hydrophobic secondary bile acid, at 0.2–0.6% induced cholestasis characterized by elevated serum alanine aminotransferase, aspartate aminotransferase, alkaline phosphatase and total bile acids, increased mortality, and histopathological liver damage. Liver transcriptome analysis identified more than 200 differentially expressed genes between control and LCA-challenged fish, including key bile acid metabolism genes such as bile salt export pump (bsep), small heterodimer partner (shp), farnesoid X receptor (fxr), multidrug resistance-associated proteins (mrp2, mrp3, mrp4), several cytochrome P450 enzymes (cyp7a1, cyp8b1, cyp27a1) and HMG-CoA reductase[35]. Altered expression of these genes reflects dysregulated bile acid synthesis, transport and cholesterol metabolism, offering mechanistic insight into hepatobiliary syndrome in farmed snakehead and potential biomarkers for diagnosis or selection.

Other studies have also examined mitigation of feed-borne toxins. Aflatoxin B1 (AFB1), a common mycotoxin in contaminated plant ingredients, causes liver toxicity and growth suppression in *C. argus*. Dietary supplementation with alpha-lipoic acid (α-LA) at 600–900 ppm in AFB1-contaminated diets attenuated growth inhibition, reduced serum transaminases and alkaline phosphatase, decreased AFB1 bioaccumulation, and improved liver histology 6. At the molecular level, α-LA up-regulated phase I detoxification genes (cytochrome P450 isoforms), activated the Nrf2 pathway and downstream antioxidant genes such as HO-1 and NQO1, increased glutathione-related enzymes, and reduced markers of oxidative DNA damage and reactive oxygen species. It also attenuated endoplasmic reticulum stress markers, reduced expression of pro-apoptotic genes and inflammatory mediators including NF-κB and TNFα, while enhancing anti-apoptotic and inhibitory κB expression [36]. These results showed that, the potential for nutraceuticals to support hepatic health and maintain normal lipid and energy metabolism under mycotoxin challenge. The table 3 depicts the diet manipulations and lipid metabolism/health markers

Table 3: Diet manipulations and lipid metabolism/health markers

Diet factor	**Levels tested**	**Growth effect**	**Liver/serum lipid & oxidative stress**	**Key genes/enzymes affected**
Lipid level	Concentration(%)	↑ to optimum, ↓ or harm at excess	Liver lipid, ALT/AST, MDA, antioxidant enzymes	mTOR, ACC, PPARα, FAS
Phospholipids	Concentration g/kg	Improved growth	↓ liver lipid, TG, LDL-C; ↑ HDL-C	↑ CPT-1, SOD, CAT; ↓ FAS
Carbohydrate	0–25%	Optimum ~11%	Changes in CHOL, TG, HDL-C, LDL-C, ALT/AST	SOD, GSH-PX, IL-1β, IL-8 expression
Kelp meal / multienzymes	Replacement levels; enzyme doses	Often improved growth	Better antioxidant status, less glycogen/lipid, improved immunity	Lipid-metabolism genes (DGAT2, FABP2, etc.), glycolysis/gluconeogenesis enzymes

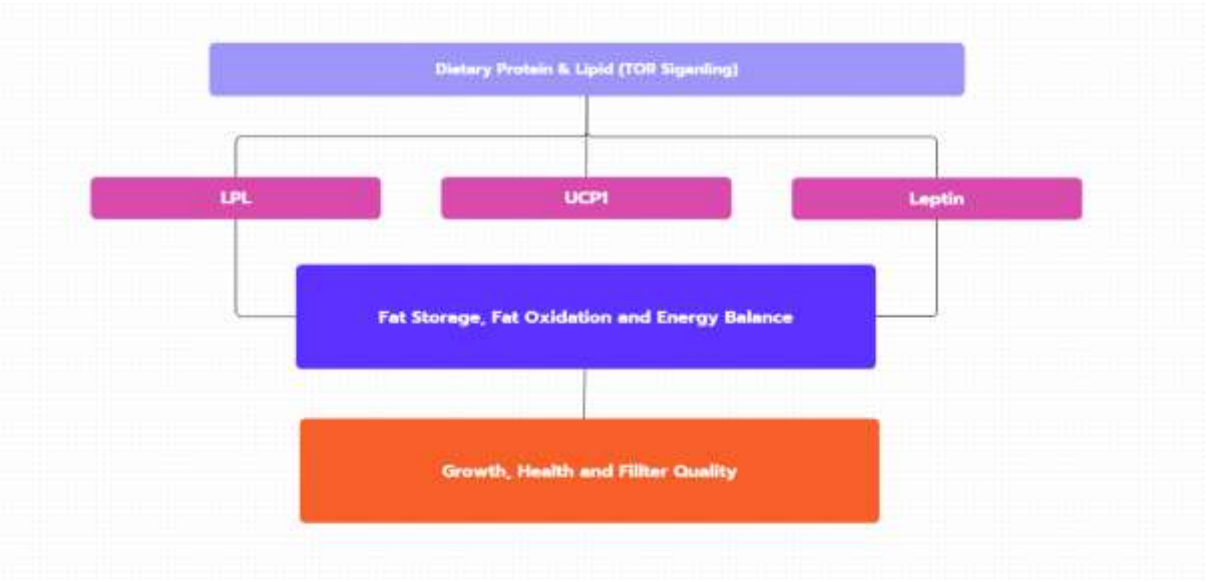

Figure 2: Dietary protein & lipid (TOR signalling)

6. Limitations, Research Gaps and Future Perspectives

Despite rapid advances, there are certain limitations and gaps remain in understanding and exploiting the aquaculture potential of Channidae and their lipid metabolism.

1. The comparative nutrition across snakehead species is incomplete. Most detailed protein–lipid requirement studies focus on *C. argus*, its hybrids and *C. marulius*, while *C. striata, C. micropeltes, C. gachua* and *African P. obscura* have fewer, sometimes inconsistent, data on macronutrient needs, optimal energy density and tolerance to plant protein and lipid sources. Standardized dose response trials across species and life stages, including brood stock and larvae, are needed to refine feeding tables and support species diversification.
2. The molecular basis of lipid metabolism and energy regulation in snakehead is only partially understood. While leptin paralogs, UCP1, TOR, LPL and selected intestinal lipid metabolism genes have been investigated, broader networks including peroxisome proliferator-activated receptors, sterol regulatory element-binding proteins, adiponectin, ghrelin and fibroblast growth factors remain largely unexplored in this family. Integrating transcriptomics, proteomics and metabolomics under controlled nutritional manipulations could map regulatory circuits and identify markers for selection of robust, feed-efficient strains.
3. There are links between diet composition, molecular markers and production-level outcomes such as fillet quality, fat distribution, disease resistance and reproductive performance require more integrative study. For instance, the observation that some snakeheads may compensate for limited n-3 fatty acids via endogenous synthesis, inferred from similar DHA levels on different fat sources, calls for direct investigation of desaturase and elongase gene expression and activity. Understanding these capacities would inform sustainable replacement of fish oil by plant oils in formulated feeds.
4. The system-level interactions between aquaculture technologies and fish metabolism merit attention. Biofloc and aquaponic systems not only alter water chemistry and stress profiles but also supply additional microbial or plant derived nutrients, which may influence lipid deposition and metabolic health. Controlled comparisons that include metabolic, histological and gene-expression endpoints alongside growth and water quality would clarify the metabolic adaptations of snakehead to these novel environments.
5. The human nutrition and functional food potential of snakehead deserves more systematic clinical and epidemiological evaluation. While compositional work clearly demonstrates high protein, essential amino acids, minerals and albumin, and product development studies show promising enhancements of plant foods, rigorous trials linking snakehead consumption or albumin-rich extracts to health outcomes are limited. Such studies would support value-addition and market diversification, benefiting both producers and consumers.

Conclusion

Snakehead fishes of the family Channidae have emerged as important and versatile aquaculture species, supported by favourable biological traits, strong consumer demand and expanding technological solutions to key bottlenecks. Their flesh and processed products offer high-quality protein, essential amino acids, minerals and albumin, underpinning both general nutritional value and potential functional food applications. Nutritional studies demonstrate that these carnivorous fishes require relatively high dietary protein and moderate lipid for optimal growth, and that fine-tuning dietary lipid can modulate growth, body composition, hepatic health and digestive enzyme activity. Emerging molecular research reveals that leptin paralogs, UCP1, TOR signaling, lipid metabolism genes and bile acid homeostasis pathways are responsive to feeding status, diet composition and toxic challenges, linking nutrition to endocrine and cellular regulation of lipid metabolism. Continued integration of classical nutrition, molecular physiology, health management and innovative production systems will be crucial to fully realize the aquaculture potential of snakehead fishes in Asia, Africa and beyond.

References:

1. Courtenay Jr, Walter R., and James D. Williams. *Snakeheads (Pisces, Channidae): a biological synopsis and risk assessment*. No. 1251. US Geological Survey, 2004.. https://doi.org/10.3133/cir1251
2. Conte-Grand C, Britz R, Dahanukar N, Raghavan R, Pethiyagoda R, Tan HH, et al. Barcoding snakeheads (Teleostei, Channidae) revisited: Discovering greater species diversity and resolving perpetuated taxonomic confusions. PLoS One. 2017;12(9):e0184017.
3. Cioffi M, Bertollo L, Villa MA, De Oliveira E, Tanomtong A, Yano C, et al. Genomic Organization of Repetitive DNA Elements and Its Implications for the Chromosomal Evolution of Channid Fishes (Actinopterygii, Perciformes). PLoS One. 2015;10. https://doi.org/10.1371/journal.pone.0130199
4. Serrao N, Steinke D, Hanner R. Calibrating Snakehead Diversity with DNA Barcodes: Expanding Taxonomic Coverage to Enable Identification of Potential and Established Invasive Species. PLoS One. 2014;9. https://doi.org/10.1371/journal.pone.0099546
5. Britz R, Dahanukar N, Anoop V, Philip S, Clark B, Raghavan R, et al. Aenigmachannidae, a new family of snakehead fishes (Teleostei: Channoidei) from subterranean waters of South India. Sci Rep. 2020;10. https://doi.org/10.1038/s41598-020-73129-6
6. Wang J, Li C, Chen J, Wang J, Jin J, Jiang S, et al. Phylogeographic structure of the dwarf snakehead (Channa gachua) around Gulf of Tonkin: Historical biogeography and pronounced effects of sea-level changes. Ecol Evol. 2021;11:12583–95. https://doi.org/10.1002/ece3.8003
7. Wuertz S, Amoutchi AI, Ogunji J. Diversification of Aquaculture in the Sub-Saharan Region—The Obscure Snakehead. Fishes. 2024; https://doi.org/10.3390/fishes9120526
8. Ansyari, Pahmi. "Food habits and biolimnology of snakehead larvae and fingerlings from different habitats." *Aquaculture, Aquarium, Conservation & Legislation* 13, no. 6 (2020): 3520-3531.
9. Gustiano R, Kurniawan K, Iriana Kusmini I. Bioresources and diversity of snakehead, Channa striata (Bloch 1793): a proposed model for optimal and sustainable utilization of freshwater fish. IOP Conf Ser Earth Environ Sci. 2021;762:12012. https://doi.org/10.1088/1755-1315/762/1/012012
10. COAD BW. Contribution to the knowledge of the Snakeheads of Iran (Family Channidae). Iran J Ichthyol. 2016;3(1 SE-Articles):65–72. https://doi.org/10.22034/iji.v3i1.144
11. Resh C, Galaska M, Benesh K, Gardner J, Wei K, Yan R-J, et al. Using Genomics to Link Populations of an Invasive Species to Its Potential Sources. 2021;9. https://doi.org/10.3389/fevo.2021.575599
12. Xu T, Zhang W, Li Y, Wang J, Bai Y, Liu H. The Complete Mitogenomes of Two Species of Snakehead Fish (Perciformes: Channidae): Genome Characterization and Phylogenetic Analysis. Diversity. 2024; https://doi.org/10.3390/d16060346
13. Harrington LA, Mookerjee A, Kalita M, Saikia A, Macdonald DW, D'Cruze N. Risks associated with the global demand for novel exotic pets: A new and emerging trade in snakehead fish (Channa spp.) from India. Biol Conserv. 2022;265:109377. https://doi.org/https://doi.org/10.1016/j.biocon.2021.109377
14. Duong T-Y, Uy S, Chheng P, So N, Tran T-HT, Nguyen N, et al. Genetic diversity and structure of striped snakehead (Channa striata) in the Lower Mekong Basin: Implications for aquaculture and fisheries management. Fish Res. 2019; https://doi.org/10.1016/j.fishres.2019.05.014
15. Liu H, Cui T, Zhang J, Zhang Y, Luo Q, Fei S, et al. Identification of sex determination region and candidate genes in blotched snakehead (Channa maculata) through genome-wide association studies and transcriptome analysis. Aquac Reports. 2025; https://doi.org/10.1016/j.aqrep.2025.102825
16. Cui T, Liu H, Zhang J, Ou M, Luo Q, Fei S, et al. Development and evaluation of a 50 K SNP array for blotched snakehead (Channa maculata). Aquaculture. 2024; https://doi.org/10.1016/j.aquaculture.2024.742020
17. Cui T, Zhang J, Ou M, Luo Q, Fei S, Chen K, et al. Potential of genome-wide association studies to improve genomic selection for growth traits in blotched snakehead (Channa maculata). Aquaculture. 2024; https://doi.org/10.1016/j.aquaculture.2024.741895
18. Sagada G, Chen J, Shen B, Huang A, Sun L, Jiang J, et al. Optimizing protein and lipid levels in practical diet for juvenile northern snakehead fish (Channa argus). Anim Nutr. 2017;3:156–63. https://doi.org/10.1016/j.aninu.2017.03.003
19. Li C. Analysis of the Development of Snakehead (Channa argus) Industry in Shandong, China and Comparison with the Substitution of Forage Fish with Compound Feed. Pak J Zool. 2023; https://doi.org/10.17582/journal.pjz/20220930080918
20. Bich TTN, Tri D, Yi-Ching C, Khoa HD. Productivity and economic viability of snakehead Channa striata culture using an aquaponics approach. Aquac Eng. 2020;89:102057. https://doi.org/10.1016/j.aquaeng.2020.102057
21. Rizki RR, Kanya MR, Puteri RE, Prariska D, Lestari S, Guttifera, et al. Effectiveness Test of Aquaculture Systems: Green Water, Biofloc, and Aquaponic Systems on the Stress Response of Snakehead Fish (Channa striata). J Fish Heal. 2025; https://doi.org/10.29303/jfh.v4i4.7838
22. Raizada S, Rawat A, Srivastava P, Lal K. Cannibalism mitigation in striped murrel, Channa striata , with hatchery seed weaned on pellet diet: A review. Rev Aquac. 2021; https://doi.org/10.1111/raq.12646

23. Pratama W, Nursyam H, Hariati A, Islamy R, Hasan V. Short Communication: Proximate analysis, amino acid profile and albumin concentration of various weights of Giant Snakehead (Channa micropeltes) from Kapuas Hulu, West Kalimantan, Indonesia. Biodiversitas. 2020;21. https://doi.org/10.13057/biodiv/d210346
24. Ren M, Yin T, You J, Liu R, Huang Q, Xiong S. Comparative Study of the Nutritional Composition and Antioxidant Ability of Soups Made from Wild and Farmed Snakehead Fish (Channa Argus). Foods. 2022;11. https://doi.org/10.3390/foods11203294
25. Hariati A, Yuniarti A, Endariani, Kusuma W, Wiadnya D. Albumin and enzyme profiles of dwarf snakehead, Channa gachua caught from River Brantas, East Java. J Phys Conf Ser. 2019;1146. https://doi.org/10.1088/1742-6596/1146/1/012041
26. Syauqibik A, Junianto J, Fitrianto N, Rostini I. Variations In The Addition Of Snakehead Fish (Channa Striata) Flour On The Level Of Favorability And Nutritional Profile Of Velvet Bean Tempeh. J Perikan Unram. 2025; https://doi.org/10.29303/jp.v15i3.1484
27. Chander M. Biochemical Alteration in Channa Striatus (Bloch) Fed with High Dietary Lipid. African J Biomed Res. 2024; https://doi.org/10.53555/ajbr.v27i4s.6904
28. Amin N, Khan N, Fatima M, Bano S, Tanveer A, Aftab S, et al. Dietary energy requirement in Bullseye snakehead (Channa marulius). J Zool Syst. 2025; https://doi.org/10.56946/jzs.v3i2.771
29. Nazir S, Khan N, Fatima M, Azmat H, Naveed S, Ramzan MM, et al. The influence of dietary protein concentration on digestive enzyme activities, growth, and body composition in juvenile bullseye snakehead (Channa marulius). PLoS One. 2023;18(2):e0281274. https://doi.org/10.1371/journal.pone.0281274
30. Zhang Y, Sun Z, Wang A, Ye C, Zhu X. Effects of dietary protein and lipid levels on growth, body and plasma biochemical composition and selective gene expression in liver of hybrid snakehead (Channa maculata ♀×Channa argus ♂) fingerlings. Aquaculture. 2017;468:1–9. https://doi.org/10.1016/j.aquaculture.2016.09.052
31. Zhao P -f., Li F, Chen X-R, Chen Y, Lin S, Zhang L, et al. Dietary lipid concentrations influence growth, liver oxidative stress, and serum metabolites of juvenile hybrid snakehead (Channa argus × Channa maculata). Aquac Int. 2016;24:1353–64. https://doi.org/10.1007/s10499-016-9993-0
32. Wen Z, Qin C, Wang J, He Y, Li H-T, Li R, et al. Molecular characterization of two leptin genes and their transcriptional changes in response to fasting and refeeding in Northern snakehead (Channa argus). Gene. 2020;144420. https://doi.org/10.1016/j.gene.2020.144420
33. Qin C, Wen Z, Wang J, He Y, Yuan D, Li R. Uncoupling protein 1 in snakehead (Channa argus): Cloning, tissue distribution, and its expression in response to fasting and refeeding. Comp Biochem Physiol A Mol Integr Physiol. 2018;225:1–6. https://doi.org/10.1016/j.cbpa.2018.06.010
34. Wang S, Sun D, Ye B, Xu G, Zou J. Dietary kelp meal improves serum antioxidants, intestinal immunity, and lipid metabolism in hybrid snakehead (Channa maculata ♀× Channa argus ♂). J Sci Food Agric. 2024; https://doi.org/10.1002/jsfa.13566
35. Kong Y, Li M, Xia C-G, Liu X, Wang G. A novel model construction of lithocholic acid-induced cholestasis and transcriptome analysis in snakehead fish (Channa argus). Aquaculture. 2021;543:737014. https://doi.org/10.1016/j.aquaculture.2021.737014
36. Li M, Fang Q, Xiu L, Yu L, Peng S, Wu X, et al. The molecular mechanisms of alpha-lipoic acid on ameliorating aflatoxin B1-induced liver toxicity and physiological dysfunction in northern snakehead (Channa argus). Aquat Toxicol. 2023;257:106466. https://doi.org/10.1016/j.aquatox.2023.106466