Chapter 2

Review of Literature

2. Review of Literature

2.1. Protein and its importance in aquaculture nutrition

Aquaculture, as a rapidly growing sector, encounters major challenges, with one of the most significant being the high cost of fish feed, which accounts for about 40-70% of total expenses (Singh et al., 2006; De Silva & Hasan, 2007; Craig, 2017; Andriani et al., 2019). Among the various components of fish feed, protein is the most expensive yet essential ingredient, crucially influencing both the growth performance of fish and overall feed cost (Luo et al., 2004). For aquaculture to progress sustainably, reducing feeding costs without quality and quantity in feed is therefore of paramount importance for growth, survival, and production efficiency in aquaculture (Shipton & Hasan, 2013).

The level of dietary protein directly impacts not only the growth and health of fish but also the economic viability of aquaculture operations, as feed costs constitute a major portion of operational expenses (Naseem et al., 2021). Elevated dietary protein levels are often associated with improved growth rates, particularly in carnivorous fish species (Lee et al., 2002). However, studies indicate that there is a threshold level beyond which additional protein intake does not support further growth and may even hinder it (Siddiqui & Khan, 2009). This highlights the need for balanced diets to ensure cost-effectiveness while maintaining optimal fish performance (Mohanta, 2012; Daniel, 2018).

With the rising intensity of fish culture worldwide, artificial feeds have become indispensable in aquaculture. Marine-derived proteins, which are rich in essential amino acids, fatty acids, minerals and vitamins, are highly palatable and, therefore, a staple in aquafeeds (Davis & Arnold, 2000). Fish meal and lipids are the primary protein and lipid sources used in aquaculture diets. Although fish meal is ideal in terms of quality protein and lipid content for fish, the industry faces challenges due to its fluctuating supply and cost, underscoring the need to reduce dependency on this commodity (Naseem et al., 2021). Moreover, many common feed ingredients, such as fish, soybean, groundnut, and cottonseed, face competition from other sectors, including human consumption and terrestrial animal feed industries, leading to price increases in aquafeeds (Tiamiyu et al., 2016; Naseem et al., 2021). As a result, there is an urgent demand for cost-effective, readily available protein alternatives to fish meals that do not directly compete with other agricultural sectors (Bureau & Meeker, 2011; Liland et al., 2012; Ghosh & Ray, 2017).

Alternative, lower-cost protein sources are essential for the sustainability of aquaculture, particularly as rising prices and shortages of dietary components create pressure on current feed formulations. Excess protein in diets, however, can lead to metabolic inefficiencies, as it is often converted to energy, resulting in increased nitrogenous waste excretion into aquatic environments. This waste can negatively impact both fish growth and the surrounding culture environment, emphasising the need for balanced protein levels to ensure both cost efficiency and environmental sustainability (Catacutan & Coloso, 1995; Tibbetts et al., 2000). Understanding species-specific protein requirements is thus essential for developing cost-effective, environmentally friendly, and nutritionally balanced artificial diets.

Protein is indispensable for both maintenance and growth in fish, with specific requirements varying across species and culture conditions (Luo et al., 2004). Studies by Ghosh & Das (2004) and Hossain et al. (2012) report an optimal dietary protein requirement of 40% for *A. testudineus*. Similarly, Siddiqui and Khan (2009) found that a dietary protein level of 40-43% is ideal for achieving optimum growth and feed efficiency in *H. fossilis*. Collectively, these findings underscore the importance of determining species-specific protein requirements to support optimal growth and economic sustainability in aquaculture operations.

2.2. Macrophytes as alternative protein sources in fish diets

In recent years, studies on utilising plant-based products as alternatives to fish meal in fish feed formulations have become a primary focus of aquaculture research (Daniel, 2018). The use of plant materials as a source of protein in the diet of many fish species has been studied (Tiamiyu et al., 2016; Dorothy et al., 2018). While these researchers identified many nutrient-enriched plant by-products as the most effective fish meal replacer, current research challenges finding cost-effective and environmentally sustainable plant products as alternatives to fish meal (Naseem et al., 2021). The search for sustainable alternatives to traditional fish meal in aquaculture has led to an increased interest in macrophyte-based protein sources. The literature review examines macrophytes as a viable alternative protein source, with a focus on their role in growth performance, feed effectiveness, and fish health in various fish species.

The *Lemna* genus, commonly known as duckweed, is characterised by its high protein content and rapid growth, making it ideal for aquaculture. Studies have shown that *Lemna polyrhiza*, when fermented and included at a 30% level in the diets of *Labeo rohita*, resulted in improved growth outcomes compared to a 10% raw meal inclusion, highlighting the benefits of fermentation in enhancing nutritional value (Bairagi et al., 2002). Additionally, *Lemna pauciscostata*, included at 10% in *Heterobranchus longifilis*, achieved the best body weight gain (WG), feed conversion ratio (FCR), and specific growth rate (SGR), demonstrating its suitability for supporting growth performance (Effiong, 2009). For *Clarias gariepinus*, a 30% inclusion of *Lemna gibba* significantly improved both weight and length growth, supporting its potential as a viable protein source for carnivorous fish species (Aghoghovwia et al., 2018). Further studies on *L. minor* have indicated that this species can be utilised in a variety of forms. For example, a 30% inclusion of raw *L. minor* in *Labeo rohita* showed no adverse effects on growth, underscoring its flexibility in feed formulations (Goswami et al., 2020). This finding aligns with earlier studies on a 20% *L. minor* inclusion level in *Labeo rohita*, where the diet produced the highest WG, SGR, and enhanced FCR (Mer et al., 2016). Together, these studies suggest that *Lemna* species can serve as versatile protein sources, with fermentation further enhancing their benefits in aquaculture diets.

Pistia stratiotes, also known as water lettuce, has shown positive results as a fish feed component. In *Labeo rohita*, a 45% inclusion level of *Pistia stratiotes* leaf meal demonstrated potential as a viable feed ingredient without adverse effects on growth (Ray & Das, 1996). When younger *Pistia stratiotes* leaves were included at 30%, they yielded even better results in terms of SGR, WG, and FCR, indicating that the younger leaves are more digestible and nutrient-dense (Nisha & Geetha, 2017). Additionally, fermented *Pistia* leaves at a 20% inclusion level did not interfere with growth, body composition, or feed utilisation in *Labeo rohita*, supporting the idea that fermentation enhances macrophytes for aquaculture (Mandal & Ghosh, 2018). For *Clarias gariepinus*, a 50% inclusion of *Pistia stratiotes* improved nutrient utilisation and resulted in the best FCR, emphasising its adaptability to diverse fish species (Adedokun et al., 2017). *Salvinia cuculata*, an aquatic fern, has shown promise in herbivorous fish diets. In a study on *Labeo rohita*, a 20% inclusion level of composted *Salvinia cuculata* was found to be optimal, supporting both growth and feed efficiency (Ray & Das, 1992). The composting process likely improves nutrient availability, making *Salvinia* a potential addition to fish diets.

Eichhornia crassipes, commonly known as water hyacinth, is widely studied in aquaculture due to its high growth rate and substantial biomass. In *Labeo rohita*, a 15% inclusion level did not affect growth, dry matter, or nutrient utilisation, supporting its potential as a partial fish meal replacement (Debnath et al., 2018). A study using a 30% fermented inclusion level of *Eichhornia crassipes* in *Labeo rohita* also reported no negative impact on growth, highlighting that fermentation may reduce anti-nutritional factors (Saha & Ray, 2011). In *Oreochromis niloticus*, a 50% inclusion of *Eichhornia crassipes* provided similar growth, feed utilisation, and protein retention as the reference diet, demonstrating its effectiveness for omnivorous fish species (Zaman et al., 2017). Additionally, in *Clarias gariepinus*, a 40% inclusion level of *Eichhornia crassipes* enhanced yield and profitability, illustrating its potential for commercial aquaculture (Konyeme et al., 2006). For *Cyprinus carpio*, a 40% inclusion level of *Eichhornia crassipes* yielded the highest weight gain, SGR, and lowest FCR, further emphasising its viability as a feed component (Sadique et al., 2018).

The *Azolla* genus, including species such as *Azolla filiculoides*, *Azolla nilotica*, and *Azolla pinnata*, is known for its high protein content and nitrogenfixing ability. In *Oreochromis niloticus*, a 30% inclusion of *Azolla filiculoides* showed no negative effects on nutrient absorption (Abou et al., 2011), and a 20% inclusion improved economic viability, indicating that *Azolla* can be a cost-effective protein source (Abou et al., 2007). Furthermore, a 31.8% inclusion of *Azolla nilotica* in *Oreochromis niloticus* had no adverse effects on survival, growth, or feed use (Ebrahim et al., 2007), while a 15% inclusion of *Azolla microphylla* yielded maximum weight gain and feed efficiency, supporting its efficacy even at moderate levels (Fiogbe et al., 2004).

In *Tilapia zillii*, a 25% inclusion of *Azolla pinnata* was shown to improve feed intake, protein efficiency, and feed conversion (Abdel-Tawwab, 2008). Additionally, in *Clarias gariepinus*, a 25% inclusion of *Azolla pinnata* improved growth and feed use (Fasakin & Balogun, 1998). In *Labeo fimbriatus*, a 40% inclusion of *Azolla pinnata* had no negative impact on growth or survival and achieved a 24.48% cost reduction, illustrating its economic benefits (Gangadhar et al., 2015). In *Labeo rohita*, a 25% inclusion of *Azolla pinnata* resulted in improved growth, SGR, FCR, and protein efficiency ratio (PER), highlighting its effectiveness across species (Maity & Patra, 2008). For *Cirrhinus mrigala*, a 40% inclusion of *Azolla pinnata* supported weight and survival rates similar to the control diet, with an 18.75% cost saving (Gangadhar et al., 2014). In *Barbonymus gonionotus*, a 25% inclusion of *Azolla pinnata* yielded the highest profit rate, suggesting strong commercial potential (Das et al., 2018). *Nymphaea spp.*, or water lily, has also been examined for its use in fish diets. In *Cyprinus carpio*, a 40% inclusion of *Nymphaea spp.* produced the highest nutrient digestibility, underscoring its potential as a feed ingredient (Sivani et al., 2013). While further research on *Nymphaea* species is needed, current findings indicate that water lilies may offer digestibility and growth benefits.

2.3. *Lemna minor* as an alternative plant protein source

The Lemnaceae family, commonly known as duckweed, consists of fast-growing, protein-rich aquatic plants with significant potential as a cost-effective alternative to traditional fish meal in aquaculture. *Lemna*, the most researched genus in this family, is found extensively in tropical and subtropical areas and is known for its high protein levels and vital nutrients for growth (Chakrabarti et al., 2018). Studies on *Lemna*'s application in fish diets have explored its viability, nutritional benefits, and cost-effectiveness, providing a strong foundation for its use as a fish meal substitute. Early studies by Noor et al. (2000) explored the use of *L. minor* at a 20% inclusion level in the diet of *Barbodes gonionotus*, finding no adverse effects on growth or feed utilisation, thus supporting its viability as a sustainable feed source. Yilmaz et al. (2004) examined dried *L. minor* as an alternative to fish meal in the diets of *Cyprinus carpio* fry, concluding that including up to 20% in the diet had no detrimental effects. In a similar study, Tavares et al. (2008) evaluated the inclusion of *Lemna* spp. in the diet of *Oreochromis niloticus*, finding that a 50% inclusion significantly enhanced final body weight, suggesting *Lemna*'s efficacy even at high inclusion rates.

Patra (2015) studied the potential of *L. minor* as a partial replacement for fish meal in the diets of *Labeo rohita* fry, with a 15% inclusion rate optimising growth and feed efficiency over 120 days, thus establishing *L. minor* as an economical protein source. Mohapatra & Patra (2013) similarly found that fry-fed diets with a 15% *L. minor* inclusion showed the best growth performance in *Cyprinus carpio* fry, suggesting that while complete fish meal replacement may not be feasible, partial substitution can effectively reduce costs. Yen et al. (2015) observed that including 15% *L. minor* in *Oreochromis niloticus* diets yielded the fastest growth rates and minimised production costs, further supported by findings in *Puntius gonionotus*, where this inclusion level yielded the lowest cost per kilogram of fish weight gain. Srirangam (2016) found that a 20% *L. minor* inclusion had no adverse impact on growth or nutrient utilisation in *Ctenopharyngodon idella*, confirming its safe application in grass carp diets. Mer et al. (2016) also demonstrated that incorporating 20% *L. minor* in *Labeo rohita* diets led to optimal WG, SGR, and improved FCR.

Furthering the potential for enhanced digestibility, Bairagi et al. (2002) compared raw and fermented *Lemna polyrhiza* in *Labeo rohita* diets, revealing that Bacillus-fermented *L.* could replace fish meal up to 30% without compromising growth, while raw *Lemna* was effective up to 10% inclusion. Asimi et al. (2018) expanded upon these findings in *Cyprinus carpio* fingerlings, where a 15% dried *L. minor* inclusion optimised growth, feed utilisation, and carcass composition, reinforcing its value as a nutritional protein source. Goswami et al. (2020) examined raw *L. minor* leaf meal in *Labeo rohita* diets, finding that a 30% inclusion level supported optimal growth and digestive enzyme activity over 90 days, further validating *L. minor*'s application in aquaculture. Irabor et al. (2022) demonstrated that *L. minor* could be included up to a 40% level in the diets of *Clarias gariepinus* without any adverse effects on growth performance, marking an optimal inclusion level for this species. Most recently, Fiordelmondo et al. (2022) studied *L. minor* inclusion in *Oncorhynchus mykiss*, concluding that up to 20% incorporation had no adverse effects on growth performance, reinforcing *Lemna*'s potential as a safe and effective fish meal substitute.

2.4. *Ipomoea aquatica* as alternative plant protein source

Ipomoea aquatica is a semi-aquatic plant native to tropical regions, commonly found in ponds, rivers, and lowlands across Asia. Although commonly considered a weed, this plant has potential as a fish feed substitute because of its high levels of minerals, vitamins, trace elements, and both essential and non-essential amino acids (Austin, 2007; Adedokun et al., 2019; Ramzy et al., 2019). Saikia et al. (2023) reported that essential amino acids make up around 60.4% of the total amino acids in *I. aquatica*, with lysine (2.141 g 100 g^{-1}) being the most abundant, followed by phenylalanine (1.891 g 100 g^{-1}) and isoleucine (1.674 g 100 g^{-1}). Bioactive phytochemicals in the plant may also promote growth and health in aquatic animals by enhancing their immune systems (Roy et al., 2022).

Despite this rich nutritional profile, *I. aquatica* remains underutilised in fish feed formulations. Recent studies, however, indicate its promising potential. For instance, Odulate et al. (2013) observed improved growth performance in African catfish (*Clarias gariepinus*) when *I. aquatica* was included in their diet.

Yen et al. (2015) studied its incorporation into the diet of *Puntius gonionotus* and concluded that a 15% inclusion level was beneficial. Ali & Kaviraj (2018) found that incorporating *I. aquatica* into the diet of *Labeo rohita* facilitated carbohydrate-sparing protein utilisation, achieving maximum growth when 25% of fish meal was replaced. Baruah et al. (2018) further demonstrated that fermented *I. aquatica* included 30-40% over 90 days of optimised growth in *Labeo rohita*. Similarly, Yousif et al. (2019) documented positive outcomes in Nile tilapia (*Oreochromis niloticus*) when fed with up to 25% inclusion of *I. aquatica*-enriched diets. These studies collectively suggest that *I. aquatica* could serve as an alternative protein source in aquaculture feeds, promoting sustainable fish farming practices. However, most research has focused on herbivorous or omnivorous species, including cyprinids (Baruah et al., 2018; Ali & Kaviraj, 2018) and tilapia (Manuel et al., 2020; Chepkirui et al., 2021), with limited exploration of its application in carnivorous fish species (Nandi et al., 2023). This gap in the literature highlights a need for further studies to evaluate its broader applicability.

Nandi et al. (2023) examined the use of fermented water spinach meal in the diet of *H. fossilis*, finding that a 50% inclusion level was sufficient to enhance growth, reproductive performance, and overall health in broodstock. Manuel et al. (2020) observed improved SGR in *Oreochromis niloticus* fed with *I. aquatica*, noting better performance across metrics. Chepkirui et al. (2021) analysed the fatty acid composition in Nile tilapia fingerlings fed various levels of *I. aquatica* and found that a 20% dietary inclusion significantly increased DHA levels across tissues, suggesting that *I. aquatica* could be utilised to enhance essential fatty acid content in fish.

2.5. Effect of different plant protein sources on *Anabas testudineus* and *Heteropneustes fossilis*

Studies on plant-based protein alternatives have focused more on substituting fish meals with plant proteins in aquaculture, mainly for commercially important species such as *A. testudineus* and *H. fossilis*. This shift aligns with the goals of reducing feed costs and supporting sustainable practices in aquaculture.

Research on alternative protein sources for *A. testudineus* has shown promising developments in utilising plant-based proteins as a sustainable approach in aquaculture diets. Mishra et al. (2013) highlighted that *Azolla* supplementation in fish feed could be a cost-effective method to enhance growth when combined with traditional feed sources. Following these findings, Akbar et al. (2016) explored the effects of fermented aquatic weeds, specifically *R. oryzae-L. minor* and *S. cerevisiae-L. minor*, in the diets of *A. testudineus*. Their research concluded that using these fermented feeds had beneficial impacts on fish growth, suggesting these as viable protein sources for climbing perch. Further, Naseem et al. (2021) stated that plant proteins hold the potential to reduce feed costs and support sustainable fish farming practices, aligning with the ongoing trend towards eco-friendly aquaculture. Further supporting the use of plant proteins, Devi et al. (2022) found that *I. aquatica* exhibited the highest in vitro digestibility among the four plant proteins tested in *A. testudineus*, making it a highly nutritious and digestible option for inclusion in fish diets. In a recent study, Panchan et al. (2024) demonstrated that replacing up to 20% of fish meal with soybean meal had no adverse effects on growth performance, establishing soybean meal as a viable and sustainable fish feed alternative.

Several studies have documented the positive impact of adding plant protein sources to the diet of *H. fossilis*. Mondal et al. (2008) explored the inclusion of mulberry leaf meal with fish offal meal, showing its potential as a sustainable protein source in *H. fossilis*. Following this, Bag et al. (2012) further studied assessing mulberry leaf meal as a standalone dietary component. These studies highlighted the need for continued exploration of plant-based ingredients to optimise protein sources in aquafeeds for *H. fossilis*. Siddiqui et al. (2014) examined the potential of soybean meal as a partial replacement for fishmeal and reported that it could be used up to 15% in *H. fossilis* diets without impacting growth performance or feed conversion efficiency. This research provided evidence for the compatibility of soybean meal in the diet of *H. fossilis*, establishing it as a practical alternative protein source. Ali et al. (2019) further examined the use of fermented mulberry leaf meal, identifying an optimal inclusion level of 52.28%. This study represented a critical advancement by pinpointing a specific threshold for effective plant protein use in *H. fossilis* diets, thereby contributing to the development of balanced and economically viable aquafeeds. The work of Ali and Kaviraj (2021) introduced fermented *I. aquatica* as another promising alternative protein source, demonstrating that fishmeal could be replaced by this macrophyte at levels of 25-50%.

Hossain et al. (2023) identified sunflower meal as a viable fishmeal substitute, recommending an inclusion rate of up to 14.3% for optimal growth outcomes in *H. fossilis*. Around the same time, Howlader et al. (2023) reinforced the potential of soybean meal as a partial fishmeal replacement, confirming that it could be included without negatively affecting growth, feed efficiency, or health status in *H. fossilis*. These studies emphasised the versatility of various plant proteins and broadened the scope of alternative protein source options for aquafeed formulations. Additionally, Nandi et al. (2023) corroborated the positive impact of fermented *I. aquatica*, supporting earlier findings by Ali and Kaviraj (2021) and suggesting broader applicability of this macrophyte in *H. fossilis* diets. Collectively, these studies provide a robust body of evidence supporting the feasibility of plant-based protein sources as effective fishmeal replacements in the diet of *H. fossilis*. Collectively, these studies provide strong evidence supporting the integration of plant-based protein sources in aquafeeds for both *A. testudineus* and *H. fossilis*, establishing viable inclusion levels for diverse plant proteins. The cumulative findings underscore the potential of *L. minor* and *I. aquatica* as promising candidates for further investigation, aligning with the aquaculture industry's shift towards sustainable and cost-effective feed alternatives.

Table 1. List of macrophytes used as alternative plant protein sources in the feed of different fish species.

Alternative plant protein source	**Fish species**	**Recommended level (%)**	**Key findings**	**References**
Azolla filiculoides	*Oreochromis niloticus*	30	It did not negatively affect nutrient absorption or overall nutritional value.	Abou et al. (2011)
Azolla nilotica	*Oreochromis niloticus*	31.8	No detrimental effects on survival, growth, feed use, or economic outcomes	Ebrahim et al. (2007)
Azolla microphylla	*Oreochromis niloticus*	15	Achieved maximum weight gain and growth rate with the best feed efficiency	Fiogbe et al. (2004)
Azolla filiculoides	*Oreochromis niloticus*	20	Showed improved economic viability compared to other inclusion levels	Abou et al. (2007)
Azolla africana	*Oreochromis niloticus*	5	The growth and feed efficiency were on par with the control group	Fasakin et al. (2001)
Azolla pinnata	*Oreochromis niloticus*	15	Resulted in the highest fish yield	Chareontesprasit & Jiwyam (2001)
Azolla pinnata	*Tilapia zillii*	25	Enhanced feed intake, feed conversion and protein efficiency	Abdel-Tawwab (2008)
Azolla filiculoides	*Tilapia nilotica*	20.7	Produced similar growth outcomes to the control diet	Shiomi & Kitoh (2001)

Azolla pinnata	*Clarias gariepinus*	25	Growth and feed use were significantly enhanced	Fasakin and Balogun (1998)
Azolla pinnata	*Labeo fimbriatus*	40	There is no negative impact on growth and survival, with a 24.48% cost reduction.	Gangadhar et al. (2015)
Azolla pinnata	*Labeo calbasu*	30	Nutrient digestibility was not affected	Gangadhar et al. (2017)
Azolla microphylla	*Labeo rohita*	25	Showed the highest weight gain (WG) and SGR	Datta (2011)
Azolla pinnata	*Labeo rohita*	25	Improved WG, SGR, FCR, and protein efficiency ratio (PER)	Maity and Patra (2008)
Azolla pinnata	*Cyprinus carpio*	20	Nutrient digestibility was unaffected	Gangadhar et al. (2017)
Azolla pinnata	*Cirrhinus mrigala*	40	Comparable to control for weight and survival, with an 18.75% cost-saving	Gangadhar et al. (2014)
Azolla pinnata	*Barbonymus gonionotus*	25	Achieved the highest profit rate	Das et al. (2018)
Eichhornia crassipes	*Labeo rohita*	15	Without affecting the growth, dry matter and nutrient utilisation	Debnath et al. (2018)
Eichhornia crassipes (fermented)	*Labeo rohita*	30	Without affecting the growth performance	Saha & Ray (2011)
Eichhornia crassipes	*Oreochromis niloticus*	50	Similar growth, protein retention,	Zaman et al. (2017)

			feed utilisation, and digestibility as the reference diet	
Eichhornia crassipes	*Cyprinus carpio*	40	Achieved the highest WG, SGR, and lowest FCR	Sadique et al. (2018)
Eichhornia crassipes	*Clarias gariepinus*	40	Yield and profitability were enhanced	Konyeme et al. (2006)
Grass pea seed meal (raw and fermented)	*Labeo rohita*	10 & 30	Maximum growth and feed conversion efficiency	Ramachandran & Ray (2007)
Ipomoea aquatica	*Clarias gariepinus*	15	Best growth	Odulate et al. (2013)
Ipomoea aquatica	*Puntius gonionotus*	15	Best growth performance	Yen et al. (2015)
Ipomoea aquatica	*Labeo rohita*	25	Maximum growth	Ali & Kaviraj (2018)
Ipomoea aquatica	*Labeo rohita*	30-40	Optimal growth performance	Baruah et al. (2018)
Ipomoea aquatica	*Oreochromis niloticus*	25	No adverse effect on growth, feed efficiency and composition of the body	Yousif et al. (2019)
Ipomoea aquatica	*Oreochromis niloticus*	20	Increase in fatty acid with high docosahexaenoic acid	Chepkirui et al. (2021)
Lemna minor	*Barbodes gonionotus*	20	No adverse effects on growth and feed utilisation	Noor et al. (2000)
Lemna minor	*Cyprinus carpio*	20	No adverse effect on growth	Yilmaz et al. (2004)
Lemna spp.	*Oreochromis niloticus*	50	Enhanced body weight	Tavares et al. (2008)
Lemna minor	*Labeo rohita*	15	Optimised growth and feed efficiency	Patra (2005)

Lemna minor	*Cyprinus carpio*	15	Best growth	Mohapatra & Patra (2013)
Lemna minor	*Oreochromis niloticus*	15	Fastest growth at minimised production cost	Yen et al. (2015)
Lemna minor	*Ctenopharyngodon idella*	20	No adverse impact on growth or nutrient utilisation	Srirangam (2016)
Lemna minor	*Labeo rohita*	20	Optimal WG, SGR and FCR	Mer et al. (2016)
Lemna minor	*Cyprinus carpio*	15	Optimal growth, feed utilisation and carcass composition	Asimi et al. (2018)
Lemna minor	*Labeo rohita*	30	Optimal growth, digestive enzymes	Goswami et al. (2020)
Lemna minor	*Clarias gariepinus*	40	No adverse effect on growth performance	Irabor et al. (2022)
Lemna minor	*Oncorhynchus mykiss*	20	Without any adverse effect on growth	Fiordelmondo et al. (2022)
Leucaena leucocephala	*Labeo rohita*	30	Optimum level of inclusion	Bairagiet al. (2004)
Lemna gibba	*Clarias gariepinus*	30	Marked improvements in both weight and length growth	Aghoghovwia et al. (2018)
Lemna polyrhiza (raw and fermented)	*Labeo rohita*	10 & 30	Growth and feed efficiency were unaffected, while carcass protein and fat increased.	Bairagi et al. (2002)
Lemna pauciscostata	*Heterobranchus longifilis*	10	Best WG, FCR, SGR. SGR	Effiong et al. (2009)

Lemna polyrhiza	*Cirrhinus mrigala*	30	Improved WG, SGR, FCR, and PER	Ghosh and Ray (2014)
Nymphaea spp.	*Cyprinus carpio*	40	Showed the highest nutrient digestibility	Sivani et al. (2013)
Nelumbo nucifera	*Clarias gariepinus*	0.1	Improved growth, better feed efficiency, and enhanced intestinal structure	Munglue (2016)
Pistia stratiotes	*Labeo rohita*	45	Indication of possible level of inclusion	Ray & Das (1996)
Pistia stratiotes	*Labeo rohita*	30	Better WG, SGR, FCR, protein and fat accretion	Nisha & Geetha (2017)
Pistia leaves (fermented)	*Labeo rohita*	20	Without affecting growth, body composition, or feed conversion efficiency.	Mandal & Ghosh (2018)
Pistia stratiotes	*Clarias gariepinus*	50	Nutrient utilisation improved, resulting in the best feed conversion ratio.	Adedokun et al. (2017)
Salvinia cuculata (composted)	*Labeo rohita*	20	Optimum inclusion level	Ray & Das (1992)
Spirodela polyrhiza	*Oreochromis niloticus*	10	The growth and feed efficiency were on par with the control diet.	Fasakin et al. (2001)