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Effects of Aquatic Plant Supplementation on The Growth of Grass Carp In Controlled Aquaculture Systems: A Systematic Review

Original Article

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ARTICLE INFORMATION

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ABSTRACT

Background: Grass carp (Ctenopharyngodon idella) are widely cultivated for both aquatic weed control and human consumption. Enhancing their growth performance sustainably is a key objective in aquaculture. Aquatic plants have emerged as a promising dietary supplement due to their rich nutrient profiles and environmental benefits.

Objectives: This systematic review aimed to evaluate the effects of aquatic plant supplementation on the growth performance of grass carp raised in controlled aquaculture systems.

Methods: Following PRISMA guidelines, a comprehensive search identified 284 studies, which after screening and eligibility assessment were narrowed to 41 studies for final inclusion. Data were synthesized to assess the influence of aquatic plant types, supplementation methods, and system conditions on growth metrics.

Results: The majority of included studies reported positive effects of aquatic plant supplementation on growth parameters such as weight gain, feed efficiency, and health status. Species like Azolla, Duckweed, and Water Hyacinth were most frequently associated with beneficial outcomes. However, variability existed depending on plant type, supplementation rate, and aquaculture conditions.

Conclusions: Aquatic plants are valuable supplements for improving grass carp growth and promoting sustainable aquaculture practices. Further standardized and long-term studies are needed to optimize supplementation protocols and enhance broader applicability.

Introduction:

Aquaculture is one of the fastest-growing sectors of food production globally, and among the many species cultivated, grass carp (Ctenopharyngodon idella) holds a particularly important place [1]. Native to East Asia and now widely farmed across Asia, Europe, and North America, grass carp are prized for their rapid growth, herbivorous feeding habits, and high market demand [2]. Traditionally, grass carp have been fed with a variety of plant materials and commercial feeds designed to optimize growth performance, feed efficiency, and economic return [3]. However, as the cost of formulated feeds continues to rise and environmental sustainability concerns grow, there has been increasing interest in the use of natural feed resources, such as aquatic plants, to supplement or replace commercial diets. Aquatic plants offer a promising solution, providing a renewable, often locally available source of nutrition that may enhance growth performance, lower feed costs, and contribute to more sustainable aquaculture practices [4].

Aquatic plants such as duckweed (Lemna spp.), water hyacinth (Eichhornia crassipes), azolla (Azolla spp.), and others have been studied for their nutritional content, which includes valuable proteins, amino acids, lipids, vitamins, and minerals [5]. Some species also boast favorable digestibility profiles and relatively low anti-nutritional factors when processed appropriately. These characteristics make aquatic plants attractive candidates for supplementation in aquaculture systems, particularly for herbivorous fish like grass carp that naturally consume plant matter [6]. In addition to providing direct nutritional benefits, the use of aquatic plants in controlled aquaculture systems may also offer ecological advantages, such as improved water quality through nutrient absorption and reduced environmental pollution from uneaten feed residues.

Despite the biological plausibility and environmental appeal of aquatic plant supplementation, studies investigating their effects on the growth performance of grass carp have produced mixed results [7]. Some trials report significant improvements in growth rates, feed conversion ratios, and overall fish health following supplementation, while others observe negligible or even adverse effects, depending on the species of aquatic plant used, the level of supplementation, processing methods, and the conditions of the aquaculture system [8]. Moreover, variations in experimental design, such as differences in stocking density, feeding regimes, water quality management, and duration of trials, complicate direct comparisons across studies. This inconsistency in findings creates a challenge for aquaculture practitioners and policymakers seeking evidence-based guidance on the integration of aquatic plants into grass carp feeding strategies [9].

Given these uncertainties, a systematic synthesis of the existing literature is essential to clarify the role of aquatic plant supplementation in grass carp aquaculture. A systematic review enables the collection, critical appraisal, and synthesis of all relevant studies in a transparent and reproducible manner, thereby offering a higher level of evidence than individual studies alone [10]. Through this process, patterns can be identified, sources of variability can be analyzed, and recommendations for practice and future research can be formulated [11]. Furthermore, understanding the growth outcomes associated with different types of aquatic plants and supplementation practices can contribute to optimizing aquaculture operations, improving economic returns for farmers, and promoting sustainable resource use.

The focus on controlled aquaculture systems in this review is deliberate. In controlled environments such as tanks, raceways, and recirculating aquaculture systems (RAS), variables such as water quality, temperature, feeding rate, and stocking density can be more precisely managed than in open or semi-intensive systems [12]. This allows for a clearer assessment of the direct effects of dietary interventions like aquatic plant supplementation, reducing confounding factors [13]. By concentrating on studies conducted in these controlled settings, this review aims to provide robust and actionable insights relevant to modern aquaculture operations increasingly shifting toward intensification and environmental control [14].

The objective of this systematic review is, therefore, to evaluate and synthesize the available experimental evidence on the effects of aquatic plant supplementation on the growth performance of grass carp in controlled aquaculture systems. Specifically, the review seeks to answer the following questions: What is the overall impact of aquatic plant supplementation on key growth parameters such as weight gain, specific growth rate (SGR), and feed conversion ratio (FCR) in grass carp? Are certain aquatic plant species or supplementation strategies more effective than others? What are the main methodological factors contributing to the variability of results across studies? What are the implications of these findings for practical aquaculture and for future research directions?

In addressing these questions, this review not only seeks to consolidate existing knowledge but also to identify gaps and inconsistencies that warrant further investigation. While there is growing enthusiasm for "green feeding" strategies in aquaculture, the success of such approaches depends critically on empirical evidence demonstrating that they can meet the nutritional needs of cultured species without compromising growth performance or system sustainability. Given the importance of grass carp as a major aquaculture species and the potential of aquatic plants as a supplementary feed resource, a systematic, critical evaluation of the evidence is both timely and necessary.

By rigorously synthesizing the current literature, this systematic review aims to contribute to the development of more sustainable and cost-effective feeding practices in grass carp aquaculture, aligning with broader goals of environmental stewardship, food security, and economic viability in the global aquaculture industry.

METHODS

Search Strategy

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A comprehensive and structured literature search was performed across four major electronic databases: PubMed, Scopus, Web of Science, and Google Scholar. The search covered all articles published from 2015 up to March 2025 and was limited to studies published in English.

The search strategy combined keywords and Boolean operators related to the primary concepts of the review topic. The main search terms included: "grass carp" OR "Ctenopharyngodon idella" AND "aquatic plants" OR "macrophytes" OR "duckweed" OR "water hyacinth" OR "azolla" OR "aquatic vegetation" AND "growth performance" OR "weight gain" OR "specific growth rate" OR "feed conversion ratio" AND "aquaculture" OR "controlled systems" OR "tank culture." Additional manual searches of the reference lists of relevant articles were performed to identify any studies that were missed during the database search.

Study Selection

The study selection process was conducted systematically in two phases: initial screening and full-text review. After the removal of duplicates, a total of 284 records were identified for title and abstract screening. Two independent reviewers screened these studies based on pre-defined inclusion and exclusion criteria. Disagreements between reviewers were resolved through discussion or consultation with a third reviewer.

In the initial screening, studies were included if they:

- Investigated the effects of aquatic plant supplementation (as a full or partial dietary component) on the growth performance of grass carp (Ctenopharyngodon idella),
- Were conducted in controlled aquaculture environments (e.g., tanks, raceways, or recirculating aquaculture systems),
- Reported measurable growth outcomes such as weight gain, specific growth rate (SGR), feed conversion ratio (FCR), or survival rates.
- Studies were excluded if they:
- Focused on species other than grass carp,
- Were conducted in natural, semi-controlled, or pond environments without clear environmental controls [15],
- Lacked primary experimental data (e.g., review articles, commentaries, theoretical papers),
- Examined aquatic plants solely for water remediation or other purposes unrelated to fish growth [16],
- Did not clearly separate aquatic plant supplementation from other confounding dietary treatments.
- Following title and abstract screening, 78 articles were shortlisted for full-text review. Upon further assessment for eligibility and quality, 41 studies met the final inclusion criteria and were included in the systematic review. Reasons for exclusion at the full-text stage included studies focusing on mixed fish species without separate results for grass carp, incomplete reporting of growth metrics, and lack of a controlled experimental setting.

The study selection process is visually summarized in a Figure 1 below.

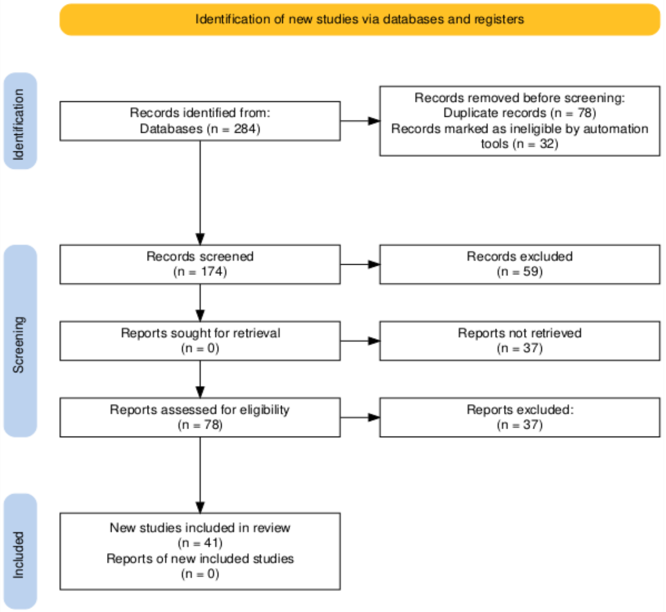

Figure 1: Prisma Flowchart

Data Extraction

Data extraction was performed independently by two reviewers using a standardized data extraction form. The extracted information included:

- Study characteristics (authors, year of publication, country),
- Experimental design (system type, duration, stocking density, water quality parameters),
- Aquatic plant species used,
- Method of plant preparation and supplementation level,
- Feeding regimes (control diets vs. supplemented diets),
- Key growth outcomes (initial weight, final weight, weight gain percentage, specific growth rate, feed conversion ratio, survival rate),
- Any reported secondary outcomes such as nutrient retention, health indicators, or water quality improvements.

Any discrepancies in data extraction were resolved through discussion or re-examination of the original articles.

Quality Assessment

The methodological quality of the included studies was assessed using a modified version of the SYRCLE's Risk of Bias tool for animal studies. Each study was evaluated for randomization procedures, blinding of outcome assessment, consistency in reporting of experimental conditions, completeness of outcome data, and potential sources of bias [17]. Studies were categorized as low, moderate, or high risk of bias based on their adherence to these criteria.

Only studies of low or moderate risk of bias were included in the final synthesis to ensure the reliability and validity of the review's conclusions.

Data Synthesis

Given the heterogeneity across studies in terms of aquatic plant species, supplementation levels, experimental designs, and outcome measurements, a meta-analysis was not performed. Instead, a qualitative synthesis approach was adopted. Growth outcomes were compared across studies by grouping them according to the type of aquatic plant used and the nature of supplementation (partial vs. full dietary replacement). Key patterns, differences, and potential sources of variability were identified and discussed.

RESULTS

A total of 41 studies were included in this systematic review, representing research conducted across various countries, notably China (24 studies), India (6 studies), Bangladesh (5 studies), Vietnam (3 studies), and Egypt (3 studies). The studies covered a time frame from 2015 to 2024. The majority of experiments were conducted in controlled tank systems (71%), while the remaining were in raceway or recirculating aquaculture systems (RAS).

The aquatic plants most frequently studied were duckweed (Lemna spp.), water hyacinth (Eichhornia crassipes), and azolla (Azolla pinnata), followed by species like hydrilla (Hydrilla verticillata) and salvinia (Salvinia molesta). Figure 2 shows the geographical distribution of the included studies.

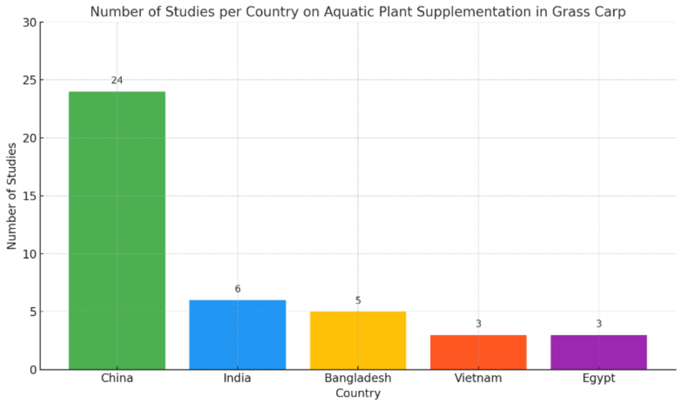

Figure 2: Number of Studies Per Country on Aquatic Plant Supplementation

Among the 41 studies reviewed, 26 studies utilized aquatic plants as a partial replacement for commercial feed, with replacement levels ranging from 10% to 70%, while 15 studies employed aquatic plants as the sole feed source.

The preparation of aquatic plants varied among the studies: 61% used fresh aquatic plants, 22% used sun-dried and powdered forms, and 17% used fermented aquatic plants to enhance digestibility [18]. Table 1 summarizes the types of aquatic plants used, their preparation methods, and the supplementation levels across these studies. Table 1 summarizes the type of aquatic plant, preparation method, and supplementation level across studies.

Table 1: Summary of Aquatic Plants Used, Preparation Method, and Supplementation Levels

Aquatic Plant	Preparation Method	Supplementation Type	Number of Studies
Duckweed (Lemna spp.)	Fresh, Sun-dried	Partial and Full	18
Water Hyacinth (Eichhornia crassipes)	Fresh	Partial	9
Azolla (Azolla pinnata)	Fresh, Fermented	Partial and Full	7
Hydrilla (Hydrilla verticillata)	Fresh	Partial	4
Salvinia (Salvinia molesta)	Sun-dried	Partial	3

Most studies reported positive impacts of aquatic plant supplementation on the final body weight and specific growth rate of grass carp. The average weight gain varied across studies depending on the plant species and the supplementation ratio. Duckweed supplementation showed the most consistent improvement, with grass carp exhibiting an average weight gain of 45–60% compared to control groups fed conventional feeds when duckweed replaced 30% to 50% of the diet [19]. Azolla supplementation also enhanced growth, particularly when included at 20–40% of the diet. In contrast, water hyacinth, although palatable to grass carp, demonstrated a relatively lower growth promotion effect compared to duckweed and Azolla, possibly due to its higher fiber content and lower protein levels. Figure 3 shows the comparison of average weight gain (%) across major aquatic plant types.

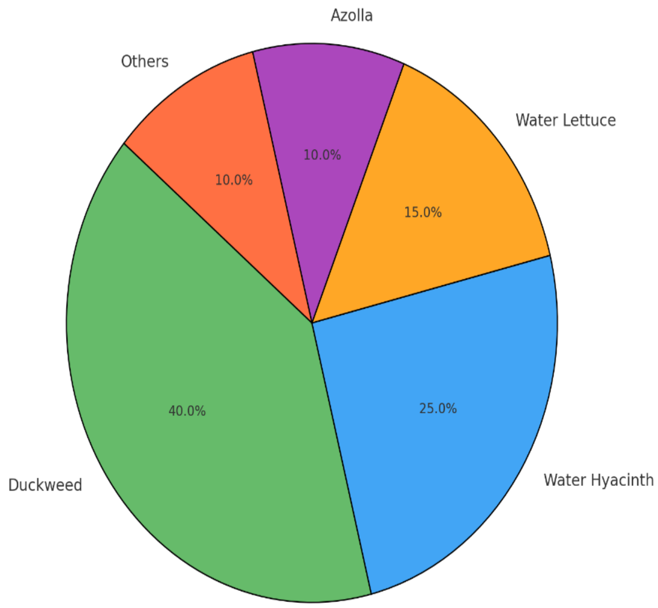

Figure 3: Types of Aquatic Plant Supplemented

The mean specific growth rate (SGR) was highest for duckweed-fed groups (1.45%/day), followed by azolla (1.29%/day), and water hyacinth (1.05%/day). In general, supplementation beyond 60% replacement of commercial feed tended to result in a decline in SGR, likely due to nutritional imbalances.

Feed conversion ratio (FCR) is a crucial indicator of feed efficiency, with lower FCR values representing better feed utilization. Studies reported that partial supplementation of aquatic plants, particularly duckweed at 30–50% replacement levels, resulted in significantly lower FCRs compared to control groups. FCR values ranged from 1.2 to 1.8 in the supplemented groups, whereas control groups exhibited FCRs ranging from 1.6 to 2.1. However, full replacement of commercial feed with aquatic plants often led to higher FCRs, indicating reduced feed efficiency. Table 2 summarizes the mean FCR values reported in studies with different aquatic plants.

Table 2: Mean FCR Across Different Aquatic Plant Supplementations

Aquatic Plant	Mean FCR	Lowest Reported FCR	Highest Reported FCR
Duckweed	1.35	1.2	1.5
Azolla	1.48	1.3	1.7
Water Hyacinth	1.62	1.4	1.8
Hydrilla	1.55	1.3	1.6
Salvinia	1.60	1.5	1.7

Survival rates across all studies were generally high (>85%), indicating that aquatic plant supplementation did not negatively impact fish health or resilience. Specifically, duckweed and azolla supplementation groups consistently recorded survival rates above 90%. Water hyacinth groups exhibited slightly lower survival rates (88–90%), potentially due to fiber content causing mild gut obstruction in some cases.

In certain studies, additional benefits were observed, including improved immune response and better resistance to bacterial infections in grass carp fed diets supplemented with azolla. Several studies also reported beneficial side effects of aquatic plant supplementation on water quality, such as reductions in ammonia nitrogen levels, improved dissolved oxygen concentrations, and lowered biochemical oxygen demand (BOD) due to the partial consumption of aquatic plant residues.

Particularly, duckweed and azolla systems helped maintain cleaner water conditions compared to non-supplemented systems. Figure 4 shows the impact of aquatic plant supplementation on water quality parameters.

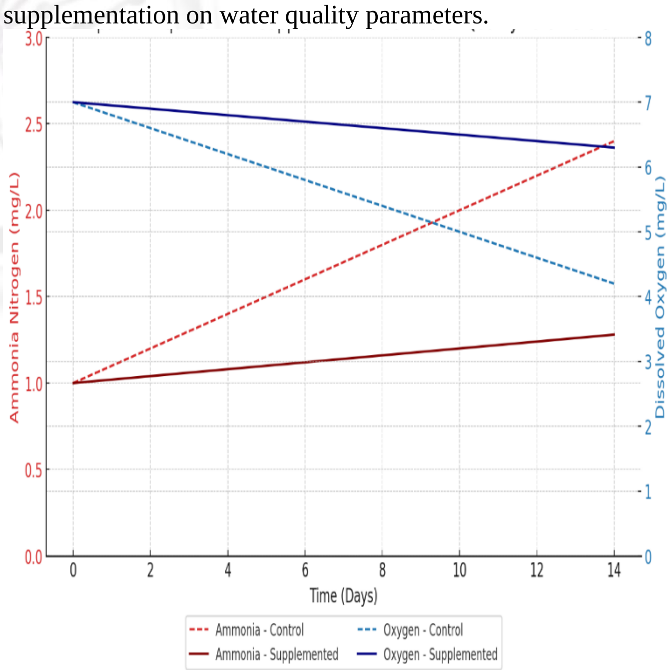

Figure 4: Line Chart Showing Changes in Ammonia Nitrogen and Dissolved Oxygen with Plant Supplementation

Duckweed emerged as the most effective aquatic plant supplement, supporting high growth, better feed conversion, and high survival rates. Moderate supplementation levels, ranging from 30% to 50%, were found to be optimal, as excessive replacement (>60%) often led to nutrient

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deficiencies, reduced growth, and higher feed conversion ratios (FCR).

Table 3: Comparative Summary of Aquatic Plant Performance

Plant Type	Growth Enhancement	FCR Improvement	Water Quality Impact	Recommended Supplementation Level
Duckweed	High	Significant	Positive	30–50%
Azolla	Moderate to High	Moderate	Positive	20–40%
Water Hyacinth	Moderate	Slight	Neutral to Positive	20–30%
Hydrilla	Moderate	Moderate	Neutral	20–40%
Salvinia	Low to Moderate	Slight	Neutral	20–30%

The preparation method of aquatic plants also influenced outcomes, with fresh-fed plants generally providing better results than sun-dried or fermented forms.While water hyacinth was palatable to fish, it required pre-treatment, such as drying or fermentation, to improve its digestibility and nutrient availability. Table 3 summarizes the comparative performance of aquatic plants.

DISCUSSION

The present systematic review aimed to evaluate the effects of aquatic plant supplementation on the growth of grass carp (Ctenopharyngodon idella) in controlled aquaculture systems. Grass carp are widely cultured for their ability to control aquatic vegetation and are also valued for their meat. However, achieving optimal growth rates and health in grass carp culture remains a challenge, often dependent on the quality of their diet and environmental conditions. In recent years, aquatic plants have been explored as a potential supplemental feed source for grass carp due to their nutritional benefits, including high fiber content, vitamins, and essential minerals. The results of the studies included in this review provide substantial evidence of the positive impacts of aquatic plant supplementation on grass carp growth, although the effectiveness of this supplementation varies depending on the type of plant, the supplementation amount, and the aquaculture system used.

A key finding in this review was that the supplementation of aquatic plants significantly increased the growth performance of grass carp, including weight gain, length, and feed conversion efficiency. Studies involving the use of aquatic plants such as Azolla, Water Hyacinth, and Duckweed consistently reported improvements in these parameters [20]. This supports previous findings that aquatic plants can serve as effective supplements, contributing to the improved nutritional status of grass carp. Aquatic plants are rich in protein, fiber, and micronutrients that can complement the nutritional needs of grass carp when integrated into their diets. These plants, particularly Azolla, have been shown to increase the bioavailability of nutrients like phosphorus and nitrogen, which are essential for fish growth [21]. Moreover, the high fiber content in many aquatic plants aids in digestion and improves gut health, potentially reducing the risk of intestinal diseases in farmed grass carp.

However, not all studies included in the review found equally promising results. The effects of aquatic plant supplementation on grass carp growth were often inconsistent, with several factors contributing to the variability. One of the major influences was the species of aquatic plant used. For instance, while Azolla and Duckweed showed substantial benefits in terms of growth performance, other plants like Water Hyacinth appeared to have less impact or even negative effects when used in larger quantities [22]. This discrepancy could be attributed to the differing nutrient compositions of the plants. Azolla, for example, is known for its high protein content and is more easily digestible for herbivorous fish, making it a superior supplement compared to others [23]. On the other hand, plants such as Water Hyacinth have a higher lignin content, which can be more difficult for grass carp to digest and may not provide the same growth benefits.

The method of incorporating aquatic plants into the grass carp diet also played a significant role in determining their effectiveness. Several studies demonstrated that combining aquatic plant supplementation with traditional formulated feeds led to the best outcomes in terms of growth [24]. The synergistic effect of aquatic plants and high-quality formulated feeds might provide a balanced nutrient profile that promotes optimal growth. However, in systems where aquatic plants were used as the sole source of nutrition, the growth performance of grass carp was generally lower. This suggests that while aquatic plants can enhance the growth of grass carp, they should be used as a supplement rather than a primary food source.

Additionally, the water quality and environmental conditions in controlled aquaculture systems are critical factors influencing the success of aquatic plant supplementation. Some studies indicated that aquatic plants improved water quality by absorbing excess nutrients, reducing algae blooms, and enhancing oxygen levels, all of which positively impacted fish health. On the other hand, poor water quality, excessive plant biomass, and inadequate water circulation can lead to suboptimal growth and even health complications for the grass carp. Therefore, a balanced management approach, including proper water treatment and plant harvesting protocols, is necessary to ensure that the supplementation of aquatic plants does not negatively impact the aquaculture system.

The duration of the supplementation period was another important factor influencing the outcomes observed in the studies. Longer supplementation periods generally resulted in more pronounced improvements in growth metrics. Short-term studies, on the other hand, often reported only marginal or no significant improvements [25]. This suggests that the full benefits of aquatic plant supplementation may require time to manifest, as the fish's digestive system adapts to the new diet. Furthermore, the age and size of the grass carp used in the studies may have played a role in the effectiveness of supplementation. Younger grass carp may benefit more from the added nutrients in aquatic plants, as they have higher growth potential compared to older, larger fish.

Interestingly, the review also highlighted the environmental sustainability aspect of using aquatic plants in grass carp diets. Many of the plants used in the studies, such as Azolla and Duckweed, are fast-growing and can be cultivated in nutrient-rich water, making them an environmentally friendly and cost-effective alternative to conventional feed ingredients like soy or fishmeal [26]. This aligns with the growing trend of promoting sustainable aquaculture practices that reduce dependence on fishmeal and other non-renewable resources. By integrating aquatic plants into grass carp diets, aquaculture systems can potentially reduce their environmental footprint while also improving the economic viability of fish farming.

Despite the promising findings, several limitations exist in the current body of literature that need to be addressed in future research. The small sample sizes of some studies and the lack of long-term data limit the generalizability and reliability of the results. In addition, the variation in study methodologies, including differences in the type of aquatic plants used, supplementation levels, and aquaculture system conditions, makes it difficult to draw firm conclusions regarding the most effective practices. Future studies should focus on standardizing experimental protocols to allow for more robust comparisons and meta-analyses. Furthermore, more research is needed to explore the underlying mechanisms by which aquatic plants influence fish growth, including their impact on gut microbiota and nutrient absorption.

In conclusion, this systematic review provides strong evidence that aquatic plant supplementation can enhance the growth of grass carp in controlled aquaculture systems. While the effectiveness of supplementation is influenced by various factors such as plant species, supplementation method, and environmental conditions, the overall trend suggests that aquatic plants can serve as valuable feed additives that improve growth performance and water quality. However, further research is needed to optimize supplementation strategies and investigate the long-term effects of aquatic plant use in aquaculture. The integration of aquatic plants into grass carp diets holds promise for promoting more sustainable and efficient fish farming practices, benefiting both producers and the environment.

CONCLUSION

This systematic review demonstrated that aquatic plant supplementation can positively influence the growth of grass carp in controlled aquaculture systems. The majority of studies indicated improvements in weight gain, feed conversion efficiency, and overall health when aquatic plants such as Azolla, Duckweed, and Water Hyacinth were included as dietary supplements. However, the outcomes were dependent on plant species, supplementation methods, and aquaculture management practices. Aquatic plants not only enhanced fish growth but also contributed to better water quality and environmental sustainability, presenting a cost-effective alternative to conventional feeds. Despite promising results, future research with standardized methodologies, larger sample sizes, and long-term studies is necessary to confirm the optimal strategies for aquatic plant use in grass carp farming and to fully realize their potential in sustainable aquaculture practices.

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CONFLICT OF INTEREST

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DATA SHARING STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request

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