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Azolla as a Sustainable Bioresource for Environmental and Agricultural Applications

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Abstract: *The Azolla-Anabaena symbiosis, known for its rapid nitrogen fixation and high productivity, has gained significant attention for its potential applications across agriculture, animal feed, wastewater treatment, and biofuel production. Despite numerous studies, the field lacks sufficient synthesis and coordination. This review consolidates past and recent findings on Azolla, emphasizing its advantages, challenges, and diverse uses. By highlighting key research insights, this work aims to strengthen future collaborative efforts and unlock the full potential of Azolla as a sustainable bioresource.*

Keywords: Bio Fertilizer, aquatic fern, Chemical composition,

I. INTRODUCTION

Growth and Cultivation of Azolla

1. General Cultivation Practices

Azolla thrives in both temperate and tropical regions, flourishing in freshwater environments like ditches, ponds, and paddy fields. Optimal growth requires a pH of 7.2 and a temperature around 32°C (Yadav et al., 2014). Cultivation is typically conducted in small ponds or water bodies.

Pond Preparation:

Small ponds measuring approximately 480 square meters are ideal for large-scale cultivation. These ponds should maintain 10–15 cm of standing water.

Nutrient Requirements:

The application of single super phosphate (20 kg/ha) provides the necessary phosphorus. A starter culture of Azolla (50–200 g/sqm) is introduced into the pond with 15 cm of water.

Growth and Harvesting:

Within 14–21 days, Azolla rapidly multiplies, forming a green carpet-like mat. During the summer, harvesting can occur every 21 days, while in winter, slowed growth necessitates a 30-day interval (Katole et al., 2017). The harvested Azolla can be used as:

- Biofertilizer: Through composting, it enriches soil nutrients.
- Animal Feed: Rich in protein, the fresh or dried biomass is suitable for livestock.

II. ADAPTATION AT VIGYAN ASHRAM

At Vigyan Ashram, cultivation practices were tailored to local resources and space constraints:

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Pond Design:
Smaller ponds measuring **12 x 4 x 1 feet** were constructed. A black soil layer sourced from an ant farm, 2–3 cm thick, was laid at the base.

Seeding and Environmental Conditions:
1 kg of Azolla pinnata was used as the starter seed culture. The system was exposed to 6–8 hours of direct sunlight daily, with light intensities ranging from 5,000 to 10,000 lux.

Productivity:
Under these conditions, the system yielded approximately **1 kg of** Azolla **per day**.

This localized approach demonstrates the adaptability of Azolla cultivation across diverse settings while emphasizing the importance of optimizing light, nutrient availability, and environmental conditions to maximize yield.

Table with reference and highlights

Author Name	Dry matter	Crude protein	Ether extract	Crude fibre	Ash	Nitrogen	Calcium	Phosphorous
(Khursheed et al., 2019)	90.3	22.89	3.59	15.49	19.46	38.67	2.03	0.48
(Kudapa et al., 2002)	90.8	25.78	3.47	15.71	15.76	30.08	-	-
(Kashyap et al., 2018)	-	24.5	3.7	14.9	17	39.9	-	-
(Paudel et al., 2015)	89.1	24.18	3.35	15.41	16.12	30.04	-	-
(Sekhar Rout et al., 2017)	91.07	25.4	2.58	14.23	18.76	39.03	1.1	0.55
(Kumar Gupta et al., 2018)	90	22	3.25	-	18.94	-	-	-
(Shukla et al., 2018)	98.8	25.64	3.15	17.29	21.67	-	1.11	0.59
(Pinkihan, 2013)	94.68	10.6	-	23.7	23.70	44.70	1.60	0.30
(Ara et al., 2015)	-	22.06	3.62	14.3	18.1	33.4	2.04	0.65

Chemical Composition of Azolla
Azolla is a nutrient-rich aquatic fern, valued for its high protein (25–35%) and nitrogen content. The proximate composition of sun-dried Azolla, compiled from 10 research studies, is summarized as follows:

- **Dry Matter (DM)**: 89.1–98.8%
- **Crude Protein (CP)**: 10–25.78%
- **Ether Extract (EE)**: 2.58–3.59%
- **Crude Fibre (CF)**: 14.23–17.29%
- **Total Ash**: 17–23.70%
- **Nitrogen-Free Extract (NFE)**: 30–44.70%
- **Calcium (Ca)**: 1.1–2.03%
- **Phosphorus (P)**: 0.3–0.59%

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Observations and Findings

- **Dry Matter (DM)**: Consistent across studies, showing minimal variance.
- **Crude Protein (CP)**: Variance is considerably higher due to one outlier (RENE W. PINKIHAN). Excluding this, CP values typically range between 22–26%. At Vigyan Ashram, CP was estimated at 28% using the Kjeldahl method, aligning well with the expected range.
- **Ether Extract (EE), Crude Fibre (CF), and Ash**: Low variance, with ash content determined at 17% at Vigyan Ashram, consistent with the reported range.

This variability in chemical composition highlights the influence of environmental and methodological factors, emphasizing the need for standardization in future studies.

III. USE OF AZOLLA AS FEED FOR BROILER CHICKENS

Azolla, a nutrient-rich aquatic fern, has been studied as an alternative feed for broiler chickens due to its high protein content and cost-effectiveness. Various studies have demonstrated its potential to partially replace conventional protein sources like fish meal and soybean meal, leading to improved growth performance, weight gain, and profitability.

Impact of Azolla on Growth and Profitability

Shoukat Ara et al. (2015):

Conducted an experiment on 240 Cobb broiler chicks to test the effect of replacing fish meal with Azolla at 5%, 10%, 15%, and 20%. Results showed that 5% replacement improved body weight and profitability per bird, making it an economically viable option.

Cost-Effective Replacement for Soybean Meal

Dev R. Paudel et al. (2015):

A CRD experiment on Hubbard broiler chicks tested Azolla at levels of 0%, 10%, 15%, and 20% in starter and finisher rations. The diet with 10% Azolla achieved the highest live weight gain (420.3 g in week 5) and reduced production costs while maintaining feed efficiency.

Nutritional Potential and Dietary Inclusion

O.A. Alalade & Iyayi (2006):

Up to 10% of Azolla pinnata meal could be safely incorporated into chick diets without compromising performance.

Performance and Egg Quality

P. Kamalasanana Pillai et al. (2002):

Found that Azolla could replace 20–25% of commercial feed. Birds fed a 12.5% Azolla diet grew faster and achieved 10–12% higher body weight. Egg quality and production improved in layer chickens compared to control diets.

Rural Poultry Integration

R.B. Rai et al. (2015):

In a rural setting, Azolla pinnata fed to Nirbhik and Shyama strains resulted in significantly higher body weight (1810 g) and egg production (197.6 eggs) compared to non-Azolla-fed birds. The study highlighted Azolla's potential for reducing feed costs and improving rural livelihoods.

Optimal Levels of Azolla **in Diets**

Biplob Basak et al. (2002):

Broilers fed diets with 5% Azolla meal had significantly better live weight, feed conversion ratio, and production costs compared to control diets. Diets with higher inclusion levels (10% and 15%) were less effective but still viable.

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General Feeding Value

Rene W. Pinkihan et al. (2013):

Found that up to 5% Azolla meal could be safely included in broiler diets without affecting production, feed efficiency, or taste.

Benefits of Using Azolla in Broiler Diets

1. **Cost-Effectiveness**: Reduces dependency on expensive protein sources like fish meal and soybean meal.
2. **Improved Growth**: Enhances weight gain and feed efficiency at inclusion levels of 5–10%.
3. **Higher Profitability**: Lower production costs result in better economic returns for farmers.
4. **Sustainability**: Promotes eco-friendly and resource-efficient poultry farming.

IV. USE OF AZOLLA AS FEED FOR FISH

Azolla, a nutrient-dense aquatic fern, has shown potential as a sustainable alternative to fish meal (FM) in aquaculture diets. Its high protein content, essential amino acids, and nitrogen-fixing ability make it a viable option for reducing feed costs while maintaining acceptable growth performance in various fish species.

Grass Carp (Ctenopharyngodon idella**)**

1. Adel Y. Al-Dubakel et al. (2020):

An experiment tested the replacement of FM with Azolla filiculoides meal (AM) at levels of 0% (control), 5%, 10%, and 15% for grass carp over 55 days. Fish were fed at 3% of body weight, five to six times weekly.

Results: There were no significant differences ($P>0.05$) in growth parameters among the treatment groups, indicating that up to 15% Azolla inclusion could replace FM without adverse effects on growth performance.

Conclusion: Azolla meal can serve as a partial replacement for FM in grass carp diets without compromising growth.

Tilapia Species

1. Sebastian S. Mosha (2018):

A review highlighted the nutritional profile of Azolla, which has a crude protein content of 13–30% and is rich in lysine. The study concluded that Azolla could be included at levels of 10–45% in diets for various Tilapia species, except for T. zillii, which requires higher inclusion levels (>40%).

Conclusion: Azolla is a suitable feed ingredient for tilapia, offering flexibility in dietary inclusion levels based on species-specific requirements.

General Growth Performance

1. Nobuyuki Shiomi & Shunji Kitoh (2001):

Investigated the effects of Azolla inclusion at 20.7%, 34.4%, and 48.2% of the total diet. Results showed that higher inclusion levels led to reduced weight gain in fish:

1. 20.7% inclusion resulted in a 5.2% decrease in weight gain.
2. 34.4% inclusion led to a 16.8% reduction in weight gain.
3. 48.2% inclusion caused a 17.1% reduction in weight gain.

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Conclusion: While Azolla can be used as a dietary ingredient, high inclusion levels negatively affect growth. Balanced formulations are necessary to optimize its benefits.

Rohu (Labeo rohita**)**
Surjya Narayan Datta (2011):
A feeding trial examined the use of dried Azolla in diets for Labeo rohita.
Findings:

4. Inclusion of Azolla reduced muscle fat content in fish.

5. The growth exponent "b" ranged from 2.5155 to 2.7760, reflecting acceptable growth trends.

Conclusion: Azolla is effective as a dietary ingredient for reducing fat content in fish while supporting growth.

Benefits of Using Azolla in Fish Diets

1. **Sustainability**: Reduces reliance on fish meal and other conventional feed ingredients.

2. **Cost-Effectiveness**: Offers a cheaper alternative without significant loss in growth performance.

3. **Nutritional Quality**: Rich in protein, lysine, and essential amino acids, benefiting fish health and growth.

4. **Eco-Friendly**: Supports nitrogen fixation, reducing the need for synthetic fertilizers during cultivation.

Recommendations for Azolla Inclusion

- Grass carp: Up to 15% replacement of FM without adverse effects on growth (Al-Dubakel et al., 2020).

- Tilapia: 10–45% inclusion, depending on species (Mosha, 2018).

- Labeo rohita: Incorporation for fat reduction and balanced growth (Datta, 2011).

- Caution: High inclusion levels (>20%) may negatively impact weight gain (Shiomi & Kitoh, 2001).

V. USE OF AZOLLA AS FEED FOR COWS

Azolla (Azolla pinnata), a nitrogen-fixing aquatic fern, is increasingly recognized as a cost-effective and sustainable feed supplement for dairy cattle. Its high protein content and essential nutrients make it a valuable addition to cattle diets, potentially reducing feed costs and improving milk production.

Feeding Trials and Economic Feasibility
J. Tamizhkumaran and S.V.N. Rao (2012):
A study conducted with 100 dairy farmers by a local NGO aimed to promote Azolla cultivation and feeding practices for cattle. Data from 47 farmers revealed that while Azolla supplementation showed initial promise in reducing the cost of milk production, its adoption was not sustainable when dependent on external subsidies.

1. Azolla can reduce feed costs for dairy farmers.
2. Long-term sustainability requires the establishment of self-reliant cultivation systems rather than reliance on subsidies.
3. To make Azolla cultivation sustainable, it is necessary to integrate it into regular dairy management practices and reduce dependency on external support.

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Nutritional and Performance Benefits

Nidhi Rawat et al. (2015):

The study highlighted the potential of Azolla pinnata as a sustainable and efficient feed supplement for dairy cows and broilers.

Findings:

1. Supplementing dairy cattle feed with Azolla resulted in improved cumulative feed intake.
2. Cows fed with Azolla-based diets demonstrated improvements in body weight and feed conversion ratios (FCR).
3. In broilers, the inclusion of Azolla meal at a 5% level showed significant improvements in FCR and body weight, reflecting its versatility across livestock categories.

Conclusion: Azolla at a 5% inclusion level is an efficient and sustainable feed supplement for cows, with benefits extending to improved growth and feed utilization efficiency.

Benefits of Azolla for Dairy Cows

1. **Cost Reduction**: Reduces dependency on conventional feed ingredients, cutting down feed costs.
2. **Nutritional Value**: Provides high levels of protein (up to 25–30%), essential amino acids, and trace minerals that support milk production.
3. **Eco-Friendly Cultivation**: Requires minimal inputs and can be grown on small landholdings using water bodies.
4. **Improved Feed Intake**: Enhances the palatability of feed and contributes to better overall cattle health.

Challenges in Adoption

- **Sustainability**: Reliance on subsidies, as observed by Tamizhkumaran and Rao, can hinder the long-term adoption of Azolla cultivation.
- **Training and Awareness**: Farmers need proper training to integrate Azolla cultivation into their dairy systems.

Recommendations for Successful Integration

1. Promote training programs for farmers to establish self-sustaining Azolla cultivation units.
2. Encourage mixed feeding strategies, incorporating Azolla as a partial supplement rather than a complete feed replacement.
3. Develop local support systems, including community-based Azolla production hubs, to ensure consistent supply.

VI. GENERAL USES OF AZOLLA

Azolla is a genus of aquatic ferns commonly found in tropical and subtropical regions. Its rapid growth rate, high protein content, and nitrogen-fixing ability make it an attractive resource for sustainable development. Historically,

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Azolla has been used in Asia as a biofertilizer in paddy fields, where it enhances soil fertility and reduces the need for chemical fertilizers.

Agriculture

Azolla is widely used as a biofertilizer due to its ability to fix atmospheric nitrogen through its symbiotic cyanobacteria. It is particularly effective in rice cultivation, improving soil fertility, and reducing the need for synthetic fertilizers. Studies show that incorporating Azolla into paddy fields can increase rice yields by 15–20% (Singh et al., 2020).

Animal Feed

Due to its high protein content (20–30%), Azolla serves as an affordable and nutritious feed for livestock, poultry, and fish. Feeding trials have shown improved growth rates and productivity in animals when supplemented with Azolla (Yadav et al., 2019).

Wastewater Treatment

Azolla efficiently absorbs heavy metals and nutrients like nitrogen and phosphorus from wastewater, making it a valuable tool for bioremediation. Research indicates that Azolla can reduce chemical oxygen demand (COD) and biological oxygen demand (BOD) levels significantly in polluted water (Kumar et al., 2021).

Biofuel Production

As a fast-growing plant with a high biomass yield, Azolla is being explored as a potential feedstock for bioethanol and biogas production. Studies on its carbohydrate content have demonstrated promising results for energy generation (Reddy et al., 2022).

Advantages of Azolla

- **Sustainability**: Its ability to grow rapidly without the need for extensive inputs makes it eco-friendly.
- **Cost-Effectiveness**: Low production costs and multifunctionality enhance its utility in resource-limited settings.
- **Environmental Benefits**: Azolla reduces greenhouse gas emissions by replacing synthetic fertilizers and mitigating wastewater pollution.

Challenges and Limitations

Despite its benefits, the large-scale utilization of Azolla faces challenges:

- **Cultivation**: Sensitive to environmental conditions like temperature and pH.
- **Storage and Transportation**: Its high moisture content complicates storage and transport.
- **Public Awareness**: Limited knowledge among stakeholders about its multifaceted applications.

Future Prospects

Advances in biotechnology and genetic engineering could enhance Azolla's resilience and productivity. Integrating Azolla into circular economy models, such as combining wastewater treatment with biofuel production, offers a pathway for sustainable development.

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