DOI: 10.54083/ResBio/6.2.2024/46-51 *Res. Bio.*, 2024, 6(2): 46-51

Research Biotica

Crossref

e-ISSN: 2582-6743

April-June, 2024

Article ID: RB211 Review Article

Azolla as a Nutrient-Rich Feed Supplement for Livestock: Enhancing Health and Productivity

Arjun Kumar Agarwal[1*], Amar Kalakar[2], Pratikshya Mishra[3], Manigopa Chakraborty[1], Sumit Kumar Mishra[1], Fatima Araish[1] and Shalvi Aishwarya Verma[1]

[1]*Dept. of Genetics & Plant Breeding,* [2]*Dept. of Horticulture, Birsa Agricultural University, Ranchi, Jharkhand (834 006), India*
[3]*Dept. of Genetics & Plant Breeding, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha (751 003), India*

Corresponding Author

Arjun Kumar Agarwal

✉: arjunagarwal016@gmail.com

Conflict of interests: The author has declared that no conflict of interest exists.

How to cite this article?

Agarwal, A.K., Kalakar, A., Mishra, P., *et al.*, 2024. *Azolla* as a Nutrient-Rich Feed Supplement for Livestock: Enhancing Health and Productivity. *Research Biotica* 6(2), 46-51. DOI: 10.54083/ResBio/6.2.2024/46-51.

Abstract

Azolla, an aquatic fern rich in nutrients, has attracted attention for its potential as a good feed additive for animals. Azolla, a tiny aquatic fern, is an excellent source of nutrients for cattle feed supplements. It has a low lignin content that facilitates easy digestion and high amount of protein, essential amino acids, vitamins and minerals. Its mutual relationship with the nitrogen-fixing cyanobacterium *Anabaena azollae* further increases its protein content, making it one of the richest alternative protein sources (25-30% protein). Incorporating Azolla into livestock diets offers numerous benefits. Its high digestibility and favorable amino acid profile promote efficient nutrient utilization, resulting in improved feed conversion ratios and reduced feed costs. Studies have demonstrated that Azolla supplementation can increase feed efficiency, average daily gain, milk production (15-20% increase) and overall productivity in various livestock species, including cattle, poultry, sheep, goats and fish. Azolla cultivation is a sustainable and cost-effective practice, as it can be grown in freshwater bodies with low input requirements. Its nitrogen-fixing capabilities and potential as a biofertilizer further contribute to sustainable agriculture practices. Additionally, Azolla farming presents entrepreneurial opportunities by providing a consistent supply of high-quality feed while aligning with the growing demand for organic and sustainable agricultural products. Overall, Azolla holds significant importance as a nutrient-dense feed supplement in the livestock sector, contributing to improved animal health, enhanced productivity, reduced production costs and the promotion of sustainable farming practices.

Keywords: Azolla, Livestock, Livestock feed, Nitrogen fixation

Introduction

Raising livestock animals like cows, chickens and pigs is very important for producing meat, milk and eggs to feed the world's growing population. However, keeping livestock healthy and productive is an ongoing challenge for farmers. One key part of keeping livestock well-nourished is having access to feed supplements that are nutrient-rich and can boost the overall health, growth and productivity of the animals. In recent years, there has been increasing interest in finding alternative feed sources that are environmentally-friendly, cost-effective and highly nutritious. Azolla, a small water fern, has emerged as a promising option in this area.

Azolla is a genus, or group, of very small ferns that live and grow in water. These unique little plants belong to the Salviniaceae family. Azolla species have gained a lot of attention recently because of their special qualities and potential uses in many different areas (Rashad, 2021). We

Article History

RECEIVED on 22nd January 2024 RECEIVED in revised form 09th May 2024 ACCEPTED in final form 16th May 2024

can find different species of Azolla all around the world, floating on the surface of calm freshwater places like ponds, lakes and slow-moving rivers. Azolla is a tiny aquatic fern that grows quickly, multiplying on the surface of freshwater lakes, rivers and drainage ditches. It makes an excellent nutrient-rich food for livestock animals like cows, chickens and pigs. Azolla contains high levels of protein, which builds muscle, amino acids, the building blocks of protein, vitamins and minerals that animals need to stay healthy. Importantly, Azolla has low levels of lignin, which is a tough woody substance that can make plants hard to digest. The low lignin content makes Azolla an easily digestible food source (Swain *et al.*, 2022). Azolla has a special symbiotic relationship with a bacterium called *Anabaena azollae* that can take nitrogen from the air and "fix" it into a form plants can use. This boosts the protein content in Azolla, making it one of the greatest alternative high-protein feed ingredients available, containing 25-30% protein, 7-10% amino acids and vitamins (El Naggar and El-Mesery, 2022).

Azolla has been gaining a lot of attention lately as a nutrient-rich food supplement to feed livestock animals. Azolla contains high levels of protein, which animals need to grow and be healthy. It also has all of the essential amino acids, which are the building blocks that make up protein. Animals cannot produce essential amino acids on their own, so they need to get them from the food they eat. Azolla is also a good source of important vitamins and minerals.

With its high protein, essential amino acids, vitamins and minerals, Azolla makes a valuable addition to the diets of various livestock species like chickens, pigs and fish (Singh *et al*., 2022). The nutrients found in Azolla, along with how easily it can be digested; help contribute to improved overall health in animals. Livestock that eat Azolla tend to grow better, perform better and utilize their feed more efficiently compared to those without Azolla in their diets (Magouz *et al*., 2020). So Azolla can be a nutritious and beneficial part of a balanced diet for raising livestock.

By understanding the advantages and benefits of incorporating Azolla into livestock diets, farmers and researchers can explore its potential for enhancing animal health and productivity. Moreover, the use of Azolla as a feed supplement aligns with the broader goal of sustainable and eco-friendly livestock farming practices. Through this article, it was aimed to shed light on the untapped potential of Azolla as a valuable nutrient source, opening new avenues for innovation and progress in livestock nutrition. In this article, the nutritional composition, including its protein content, amino acid profile, vitamins, minerals and various health benefits associated with Azolla supplementation, including improved digestion, enhanced growth and increased productivity in livestock is explored. The sustainable aspects of Azolla cultivation and its potential as a business enterprise are also highlighted.

Nutritional Composition of Azolla

One of the main things Azolla is known for is its very high protein content. This makes Azolla a valuable source of protein that can be used for many different purposes. Studies have found that Azolla contains between 19-35% proteins by dry weight (Nasir *et al.*, 2022). The exact percentage of protein in Azolla can vary depending on a few factors *viz.*, the specific species of Azolla, the conditions it was grown in (temperature, nutrients in the water, *etc*.) and how and when it was harvested. Azolla contains all essential amino acids required by animals, including lysine, methionine, threonine and tryptophan. Essential amino acids are those that animals cannot synthesize on their own and must obtain from their diet. The presence of these essential amino acids in Azolla makes it a nutritionally complete protein source. Furthermore, the protein in Azolla is highly digestible, which means that animals can efficiently break it down and absorb the amino acids for utilization. This digestibility is due to the relatively small size and easily digestible cellular structure of Azolla.

In addition to its high protein content, Azolla is also a rich source of many important vitamins. It contains vitamin A, vitamin B_{12} and beta-carotene, which is a precursor that the body converts into vitamin A. Azolla also has compounds that help promote growth in animals. Azolla provides a wide range of essential minerals as well, including calcium, phosphorus, potassium, iron, copper and magnesium (Tarif, 2021). These minerals play vital roles in biological processes and proper bodily functions. On the other hand, Azolla is very low in carbohydrates and oils/ fats. It does not provide much energy in the form of simple sugars or fats. While low in overall fat content, the fats that Azolla does contain are particularly healthy types. Azolla is a good source of iron, copper, manganese and chlorophyll (the green pigment in plants). Specifically, its fat content consists of 4.8-6.7% crude fat by dry weight. Of that fat amount, 6.1-7.7% comes from beneficial omega-3 polyunsaturated fatty acids, while 12.8-26.4% comes from omega-6 polyunsaturated fats (Kour *et al.*, 2020). The nutritional diversity offered by Azolla contributes to its significance as a feed supplement and highlights its potential as a sustainable and natural source of vitamins and minerals. The presence of these vitamins and minerals in Azolla makes it a valuable dietary supplement for livestock and other animals. Incorporating Azolla into their diets can help ensure that they receive a wide array of essential nutrients necessary for their overall health, growth and reproduction.

Benefits for Livestock Health and Productivity

Azolla offers numerous benefits for livestock health and productivity, making it a valuable feed supplement in the livestock industry. Azolla is a nutrient-rich feed supplement for livestock that can increase feed efficiency, promote animal growth and increase milk and meat production. The presence of essential amino acids in Azolla supports protein synthesis and tissue development, promoting healthy weight gain and muscle development in livestock.

It is a sustainable and cost-effective alternative to conventional feed resources; making it an attractive option for farmers seeking to minimize the cost of animal

production. Azolla supplementation enhances feed efficiency and conversion ratios in animals. The easily digestible nature of Azolla's protein and its favorable amino acid composition enable animals to efficiently utilize the nutrients, resulting in optimized feed utilization and reduced feed wastage. This, in turn, leads to improved feed efficiency and can help reduce the overall feed costs for livestock farmers (Arora *et al.*, 2023).

Azolla is very easily digested by farm animals like cows, pigs and chickens. This allows the animals to make full use of the rich nutrients that Azolla contains. As mentioned before, Azolla is packed with high levels of protein, amino acids, vitamins and minerals. These make Azolla an excellent nutrient-dense feed supplement for livestock. The minerals found in Azolla are especially beneficial for the nutrition of livestock animals. These minerals support proper growth and development, boost productivity levels, strengthens the immune system's ability to fight off diseases and promote healthy reproductive growth and breeding (El-Sabrout *et al.*, 2023). Minerals are also required for many important enzymatic reactions to function correctly inside the bodies of livestock. Because of its highly nutritious and easily digested composition, Azolla can be used as an alternative supplement to conventional livestock feeds. Adding Azolla to animal diets provides an efficiency boost - it increases growth rates, milk production in dairy cows and meat yields from animals, all while using feed resources economically. Incorporating Azolla makes livestock farming more productive and cost-effective.

Studies have shown that incorporating Azolla into animal feed provides several benefits. It increases the efficiency at which the animals convert their feed into body mass and products like milk or eggs. Azolla supplementation also boosts the average daily weight gain of livestock animals as they grow. For dairy cows, adding Azolla can increase milk production by 15-20% (Meena *et al.*, 2017; Brouwer *et al*., 2018). Specifically looking at poultry, research found that including 1.5-2 kg (3.3-4.4 lbs) of Azolla along with regular chicken feed leads to improved outcomes. Broiler chickens raised for meat gain more body weight when fed Azolla. And for egg-laying hens, Azolla supplementation increases their egg production levels (Riaz *et al.*, 2022).

Azolla also provides some medicinal benefits. Studies have shown Azolla has several pharmacological effects - it acts as an antioxidant, helping protect cells from damage. Azolla can also boost the immune system and reduce inflammation in the body (Elrasoul *et al.*, 2020). The rich nutrients found in Azolla, like vitamins, minerals and amino acids, contribute to stronger immune function and increased disease resistance in livestock animals that consume it. One of the biggest advantages of using Azolla is that it requires much less investment to cultivate compared to other crops and feed sources. Growing Azolla does not need expensive equipment or large amounts of space, labor and other inputs. Therefore, Azolla serves as an inexpensive yet good quality alternative for both livestock feed and as a biofertilizer, making it a cost-effective choice for farmers and producers.

Method of Azolla Cultivation

Azolla is a sustainable and cost-effective alternative to conventional feed resources, making it an attractive option for farmers seeking to reduce the production cost. Here are some techniques for Azolla cultivation:

1. Selection of Cultivation Site: Choose a suitable location for Azolla cultivation, preferably an area with access to sunlight and a stable water source. Ensure that the water is free from pollutants and chemicals that may adversely affect Azolla growth.

2. Preparation of Cultivation Containers: Azolla can be cultivated in various containers, such as cement tanks, plastic trays, or earthen ponds (Figure 1). Clean the containers thoroughly to prevent the growth of competing organisms. The containers should have a depth of 10-15 cm and be filled with clean water.

3. Sourcing Azolla Starter Culture: Obtain a starter culture of Azolla from a reliable source. This can be acquired from a local agricultural department, research institute, or from existing Azolla ponds. Ensure that the starter culture is healthy, free from contaminants and contains a good biomass of Azolla plants.

4. Inoculation of Azolla: Add the starter culture of Azolla to the cultivation containers. Gently scatter the Azolla evenly across the water surface. Avoid overcrowding, as it can lead to competition for nutrients and hinder growth.

5. Water Management: Maintain a water depth of 5-10 cm to ensure optimum growth of Azolla. Regularly monitor the water level and top up if necessary. Avoid stagnant water by providing a gentle water flow or regular stirring to prevent the formation of algae or mosquito breeding.

6. Nutrient Management: Azolla requires a balanced supply of nutrients for healthy growth. Organic sources such as cow dung or poultry manure can be applied at regular intervals. Maintain the nutrient levels within the recommended range to avoid excessive growth or nutrient deficiencies. For successful cultivation of Azolla, it is necessary to apply a specific amount of phosphorus fertilizer. The recommended amount is between 0.5 to 1.0 kg of phosphorus fertilizer ha^{-1} of cultivation area, applied once $week^{-1}$.

7. Temperature and Light: For optimal Azolla growth, the pH of the water used for cultivation should be between 4.5 and 7 according to multiple sources (da Silva *et al*., 2022; Adzman *et al.*, 2022). While Azolla can survive in a broader pH range of 3.5 to 10, its growth will be strongest when the water pH is in that 4.5 to 7 range. Azolla grows best at temperatures between 18 °C (64 °F) and 28 °C (82 °F). It can tolerate a wider temperature range of 20 °C (68 °F) to 35 °C (95 °F) and still grow well, but temperatures outside of 18-28 °C are not optimal. Increased salinity levels in the water negatively impact Azolla's growth rate. As the saltiness rises, Azolla's growth gradually declines. Azolla requires high humidity to thrive. At relative humidity below 60%, Azolla will become dry and fragile. The ideal relative humidity range for maximum Azolla growth is between 85-90% (da Silva *et al*., 2022).

8. Maintenance and Harvesting: Regularly inspect the Azolla cultivation for any signs of pests, diseases, or weed infestation. Remove any unwanted materials or dead plant matter from the water surface. Harvest the mature Azolla by gently scooping it from the water using a sieve or mesh net. Leave a small portion of Azolla in the container as a starter culture for the next cycle.

9. Storage and Utilization: After harvesting, rinse the Azolla thoroughly to remove any impurities. Use the fresh Azolla immediately as livestock feed or store it in a cool and shaded area. Azolla can be sun-dried and preserved for future use as well. Ensure proper storage conditions to maintain the quality and nutritional value of Azolla.

Figure 1: Azolla Farming

Entrepreneurial Opportunity of Azolla Farming in Livestock Sector

Azolla cultivation offers a promising business opportunity with numerous benefits in the livestock feed industry, biofertilizer production, wastewater treatment and sustainable agriculture practices. Some key entrepreneurial opportunities include:

1. Livestock Feed Production

• With its high protein, vitamin and mineral content, Azolla has huge potential as a nutrient-rich livestock feed supplement.

• Entrepreneurs can establish Azolla farming operations to supply the growing demand for this sustainable feed from livestock producers raising cattle, poultry, pigs, *etc*. (Sharma *et al.*, 2021). Azolla provides a cost-effective way to produce high-quality feed locally.

• Azolla can be fed fresh or dried to various livestock like cattle, poultry, sheep, ducks, goats, pigs and rabbits. It can be given directly or mixed into other concentrated feed (Baruah and Kalita, 2022).

2. Organic Biofertilizer Production

• Azolla's ability to fix atmospheric nitrogen makes it a valuable organic biofertilizer.

• There are entrepreneurial opportunities in producing and selling Azolla as an eco-friendly fertilizer for organic farming operations at very low production costs compared to synthetic fertilizers (Prabakaran *et al*., 2022).

3. Wastewater Treatment

• Azolla can be used for cost-effective wastewater treatment by absorbing nutrients, heavy metals and other contaminants.

• Entrepreneurial opportunities exist in using Azolla treatment systems for industrial or municipal wastewater management (Sayanthan *et al.*, 2024).

4. Sustainable Aquaculture

• Azolla can be incorporated into fish feed and fertilizer aquaculture ponds naturally (Mosha, 2018).

• Entrepreneurship potential in integrating Azolla for more sustainable aquaculture practices.

Overall, the low investment required and ability to produce a high-value product make Azolla farming an attractive entrepreneurial opportunity, especially in alignment with growing sustainability trends in agriculture.

Socioeconomic and Ecosystem Services Rendered by Azolla

Azolla, a small aquatic fern, has drawn a lot of interest in the past few years for its potential for contributing to agricultural sustainability. Azolla provides a variety of socioeconomic and environmental services that can be advantageous to farmers and the community at large when integrated into agricultural systems.

a) Socioeconomic Benefits

1. Low-Cost Biofertilizer: By fixing atmospheric nitrogen in a mutual relationship with the cyanobacterium *Anabaena azollae*, Azolla can the requirement for nitrogen fertilizers that are synthetic and save farmer input costs (Kollah *et al.*, 2016).

2. Higher Crop Yields: Azolla's capacity to fix nitrogen helps increase soil fertility, which raises crop yields and agricultural production.

3. Income Generation: Farmers may make extra income by selling extra Azolla biomass, which can be used as animal feed or a valuable biofertilizer.

4. Improved Livelihoods: The use of Azolla-based agriculture can help reduce poverty, increase food security and enhance livelihoods, especially for small-scale farmers in developing nations.

The flow diagram (Figure 2) illustrates how the cultivation of Azolla, a small aquatic fern, can provide socioeconomic services when integrated into agricultural systems.

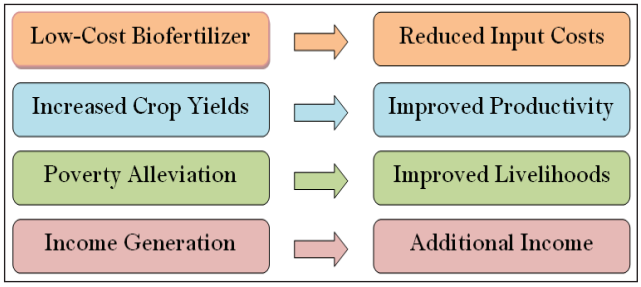

Figure 2: Socioeconomic services rendered by Azolla cultivation

b) Ecosystem Services

In addition to providing farmers with financial gains, the use of Azolla in agriculture supports a variety of ecosystem services, encouraging environmentally friendly farming methods and sustainable agricultural practices (Figure 3). Farmers may improve biodiversity, lower input costs, increase soil fertility, mitigate the effects of climate change and improve water quality by utilizing the special qualities of Azolla.

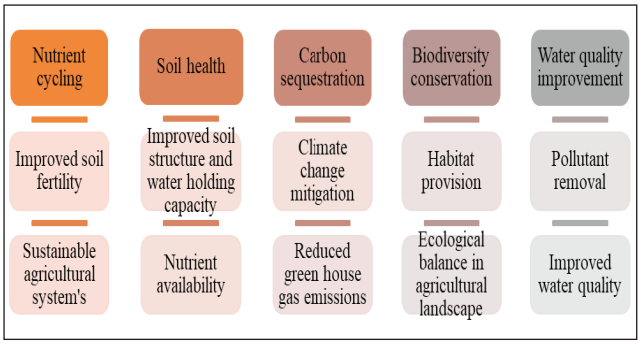

Figure 3: Ecosystem services of Azolla cultivation

1. Nutrient Cycling: Azolla is essential to the long-term sustainability of farming systems because it fixes atmospheric nitrogen and improves soil fertility.

2. Soil Health: By enhancing soil structure, water-holding ability and microbial activity, Azolla used as green manure can enhance soil health in its entirety (Bhardwaj *et al*., 2014).

3. Carbon Sequestration: By growing and then becoming incorporated into the soil, Azolla can help reduce emissions of greenhouse gases from agriculture (Hamdan and Hauri, 2022).

4. Conservation of Biodiversity: Azolla-based farming can help conserve biodiversity by giving a range of aquatic and terrestrial creatures a place to live and food.

5. Improvement of Water Quality: Azolla can aid agricultural fields by absorbing and accumulating heavy metals and other impurities from water bodies (Kurniawan *et al*., 2021).

6. Erosion Control: Azolla, when grown in rice fields or other areas with water, can function as a living mulch, shielding the top layer of the soil from erosion brought on by precipitation, wind and water flow.

Conclusion

Azolla holds significant potential as a highly nutritious feed supplement for livestock. Its rich composition, including high protein content, essential amino acids, vitamins and minerals, positively impacts animal health, growth rates and productivity parameters like milk and meat yields. Incorporating Azolla into livestock diets increases feed efficiency and promotes efficient animal growth. As a sustainable and cost-effective alternative to conventional feed resources, Azolla presents an attractive option for livestock farmers aiming to minimize production costs. Azolla can be easily cultivated in freshwater bodies like lakes, rivers and wetlands across temperate and tropical regions with relatively low input costs. The cultivation of Azolla specifically for the livestock sector opens up several entrepreneurial opportunities. Establishing Azolla farming operations to supply this nutrient-dense feed to livestock producers aligns with the growing demand for sustainable agricultural practices. With its low investment requirements, Azolla farming offers an economically viable business model for providing a cost-effective, high-quality feed solution that supports efficient and productive livestock rearing.

References

Adzman, N., Goh, S.J., Johari, A., Alam, M.N.H.Z., Kamaruddin, M.J., 2022. Preliminary study on *Azolla* cultivation and characterization for sustainable biomass source. *Journal of Physics: Conference Series* 2259, 012018. DOI: https://doi.org/10.1088/1742-6596/2259/1/012018.

Arora, A., Nandal, P., Chaudhary, A., 2023. Critical evaluation of novel applications of aquatic weed Azolla as a sustainable feedstock for deriving bioenergy and feed supplement. *Environmental Reviews* 31(2), 195-205. DOI: https://doi.org/10.1139/er-2022-0033.

Baruah, M.S., Kalita, H., 2022. Effect on growth and economics of Vanaraja poultry on Azolla feed supplementation. *Research Biotica* 4(3), 150-155. DOI: https://doi.org/10.54083/ResBio/4.3.2022/150-155.

Bhardwaj, D., Ansari, M.W., Sahoo, R.K., Tuteja, N., 2014. Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell Factories* 13, 66. DOI: https://doi.org/10.1186/1475-2859-13-66.

Brouwer, P., Schluepmann, H., Nierop, K.G., Elderson, J., Bijl, P.K., van der Meer, I., de Visser, W., Reichart, G.J., Smeekens, S., van der Werf, A., 2018. Growing Azolla to produce sustainable protein feed: the effect of differing species and CO_2 concentrations on biomass productivity and chemical composition. *Journal of the Science of Food and Agriculture* 98(12), 4759-4768. DOI: https://doi.org/10.1002/jsfa.9016.

da Silva, M.E.J., Mathe, L.O.J., van Rooyen, I.L., Brink, H.G., Nicol, W., 2022. Optimal growth conditions for *Azolla pinnata* R. Brown: Impacts of light intensity, nitrogen addition, pH control and humidity. *Plants* 11(8), 1048. DOI: https://doi.org/10.3390/plants11081048.

El Naggar, S., El-Mesery, H.S., 2022. *Azolla pinnata* as unconventional feeds for ruminant feeding. *Bulletin of the National Research Centre* 46, 66. DOI: https://doi.org/10.1186/s42269-022-00752-w.

El-Sabrout, K., Khalifah, A., Mishra, B., 2023. Application of botanical products as nutraceutical feed additives for improving poultry health and production. *Veterinary World* 16(2), 369-379. DOI: https://doi.org/10.14202/vetworld.2023.369-379.

Elrasoul, A.S.A., Mousa, A.A., Orabi, S.H., Mohamed, M.A.E.G., Gad-Allah, S.M., Almeer, R., Abdel-Daim, M.M., Khalifa, S.A.M., El-Seedi, H.R., Eldaim, M.A.A., 2020. Antioxidant, anti-inflammatory and anti-apoptotic effects of *Azolla pinnata* ethanolic extract against lead-induced hepatotoxicity in rats. *Antioxidants* 9(10),

1014. DOI: https://doi.org/10.3390/antiox9101014.

Hamdan, H.Z., Houri, A.F., 2022. CO_2 sequestration by propagation of the fast-growing *Azolla* spp. *Environmental Science and Pollution Research* 29, 16912-16924. DOI: https://doi.org/10.1007/s11356-021-16986-6.

Kollah, B., Patra, A.K., Mohanty, S.R., 2016. Aquatic microphylla *Azolla*: A perspective paradigm for sustainable agriculture, environment and global climate change. *Environmental Science and Pollution Research* 23, 4358-4369. DOI: https://doi.org/10.1007/s11356-015-5857-9.

Kour, M., Khan, N., Singh, R., Mahajan, V., Amrutkar, S.A., Kumar, D., 2020. Effect of Azolla (*Azolla pinnata*) supplementation on milk yield, composition and economics in crossbred HF Cows. *International Journal of Current Microbiology and Applied Sciences* 9(10), 2661-2666. DOI: https://doi.org/10.20546/ijcmas.2020.910.320.

Kurniawan, S.B., Ahmad, A., Said, N.S.M., Imron, M.F., Abdullah, S.R.S., Othman, A.R., Purwanti, I.F., Hasan, H.A., 2021. Macrophytes as wastewater treatment agents: Nutrient uptake and potential of produced biomass utilization toward circular economy initiatives. *Science of the Total Environment* 790, 148219. DOI: https://doi.org/10.1016/j.scitotenv.2021.148219.

Magouz, F.I., Dawood, M.A.O., Salem, M.F.I., Mohamed, A.A.I., 2020. The effects of fish feed supplemented with *Azolla* meal on the growth performance, digestive enzyme activity and health condition of genetically-improved farmed Tilapia (*Oreochromis niloticus*). *Annals of Animal Science* 20(3), 1029-1045. DOI: https://doi.org/10.2478/aoas-2020-0016.

Meena, G.S., Dhaka, B.L., Singh, B., Meena, R.K., Meena, K.C., 2017. Effect of Azolla as feed supplement on milk yield in buffaloes. *International Journal of Current Microbiology and Applied Sciences* 6(12), 3490-3494. DOI: https://doi.org/10.20546/ijcmas.2017.612.406.

Mosha, S.S., 2018. A review on significance of *Azolla* meal as a protein plant source in finfish culture. *Journal of Aquaculture Research and Development* 9(7), 544. DOI: https://doi.org/10.4172/2155-9546.1000544.

Nasir, N.A.N.M., Kamaruddin, S.A., Zakarya, I.A., Islam, A.K.M.A., 2022. Sustainable alternative animal feeds: Recent advances and future perspective of using Azolla as animal feed in livestock, poultry and fish nutrition. *Sustainable Chemistry and Pharmacy* 25, 100581. DOI: https://doi.org/10.1016/j.scp.2021.100581.

Prabakaran, S., Mohanraj, T., Arumugam, A., Sudalai, S., 2022. A state-of-the-art review on the environmental benefits and prospects of *Azolla* in biofuel, bioremediation and biofertilizer applications. *Industrial Crops and Products* 183, 114942. DOI: https://doi.org/10.1016/j.indcrop.2022.114942.

Rashad, S., 2021. An overview on the aquatic fern *Azolla* spp. as a sustainable source of nutrients and bioactive compounds with resourceful applications. *Egyptian Journal of Aquatic Biology and Fisheries* 25(1), 775-782. DOI: https://doi.org/10.21608/EJABF.2021.150205.

Riaz, A., Khan, M.S., Saeed, M., Kamboh, A.A., Khan, R.U., Farooq, Z., Imran, S., Farid, M.U., 2022. Importance of Azolla plant in poultry production. *World's Poultry Science Journal* 78(3), 789-802. DOI: https://doi.org/10.1080/00439339.2022.2054752.

Sayanthan, S., Hasan, H.A., Abdullah, S.R.S., 2024. Floating Aquatic macrophytes in wastewater treatment: Toward a circular economy. *Water* 16(6), 870. DOI: https://doi.org/10.3390/w16060870.

Sharma, A., Raghavan, M., Shi, Z., Bang, N.T.H., 2021. Utilization of protected cultivation for crop production and preservation in India. *Environment Conservation Journal* 22(1&2), 13-17. DOI: https://doi.org/10.36953/ECJ.2021.221203.

Singh, D.N., Bohra, J.S., Tyagi, V., Singh, T., Banjara, T.R., Gupta, G., 2022. A review of India's fodder production status and opportunities. *Grass and Forage Science* 77(1), 1-10. DOI: https://doi.org/10.1111/gfs.12561.

Swain, B.K., Naik, P.K., Beura, C.K., 2022. Nutritive value of Azolla as poultry feed - A review. *Indian Journal of Animal Nutrition* 39(1), 1-11. DOI: https://doi.org/10.5958/2231-6744.2022.00001.9.

Tarif, S.T.O., 2021. Use of Azolla as a substitute poultry feed and its effect on growth and production: A review. *Plant Archives* 21(Suppl. 1), 947-950. DOI: https://doi.org/10.51470/PLANTARCHIVES.2021.v21.S1.147.