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Azolla: An alternative feed for sustainable livestock production

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Abstract
This review paper aims to analyse the possibility of Azolla as an alternative feed source for livestock and poultry production. The manuscript has been prepared by reviewing a plethora of available literatures related to this topic. The report of 20th livestock census-2019 states that, India holds around 20% of world's livestock population, which is precisely 535.82 million. The population has increased by 4.6% than previous livestock census-2012. Feed and fodder are the basis of existence of livestock and birds. The feed cost alone accounts around 70% of the total cost of livestock production. In a first changing world, the prices of animal feed i.e. both green fodder and concentrate are increasing day by day. Keeping this in mind, it is imperative to find an alternative feed source which will economise the cost of production and will be helpful towards a sustainable livestock and poultry production. Azolla is a fern that grows faster in fresh water in both temperate and tropical countries. It can be fed to various livestock and poultry birds without any deleterious effects. Various studies have reported that there was an overall increase of 15-20% milk yield in cattle and buffalo upon feeding of 1.5-2 Kg of Azolla in combination with daily ration. In case of meat animals and birds like pigs, rabbits, sheep, goats, ducks, quails, chickens etc., improved growth performances have been reported, indicating the possibility of using Azolla as a feed ingredient.

Keywords: Azolla, unconvetional feed, livestock, poultry, sustainable production

Introduction
The fodder production in the country is not adequate to meet the dietary need of livestock. The forages offered are mostly of poor in quality, which are hindrance in better production of animals. According to the report of IGFRI Vision, 2050. India shows a net deficit of 44% concentrate, 35. 6% green fodder and 10.95% dry crop residues at the current situation [31]. In recent years, the cost of concentrate, dry crop residues and green fodder has also skyrocketed, which has forced the dairy farmers to find an alternative feed source for the livestock species. For sustainable dairy and poultry production, it is imperative to find an unconventional and cheaper source of feed to curtail the cost of production. Among various alternative protein feed for livestock and poultry; aquatic plants, which have traditionally been perceived as a nuisance, are increasingly being recognised as a cheap and harmless animal feed resource, the world over. Azolla, a freshwater fern is considered as one of the world's fastest-growing aquatic macrophytes (Collinson *et al.*, 2010) [21]. Proteins, vitamins, probiotics, biopolymers and minerals like iron, calcium, magnesium, potassium, phosphorus, manganese etc. are abundantly present in Azolla which makes it a suitable feed substitute for livestock and poultry (Pillai *et al.*, 2002) [49]. Azolla is assumed to be a potential alternative protein source that can be used as feed for animals for achieving sustainability, which is economically and environmentally viable (Kollah *et al.*, 2016) [36].

Taxonomy, Morphology of Azolla
Saunders and Fowler (1993) [62]. Revised the taxonomical position of Azolla in which it belonged to monotypic family "*Azollaceae*" and included two sections namely, *Azolla* and *Rhizosperma*. Five species of Azolla such as *A. Filiculoides*, *A. Rubra*, *A. Mexicana*, *A. Caroliniana and A. Microphyla* come under the section *Azolla* and section *Rhizosperma* including *A. Nilotica* and *A. Pinnata.*

The two varieties of *A. Pinnata* were recognized as *A. Pinnata var. pinnata*, and *A. Pinnata var. imbricata. Azolla* was a dichotomously branched free-floating fern. The length of typical Indian Azolla sp. is 1.5 to 3.0 cm and breadth is 1 to 2 cm and was typically triangular in shape (Raja *et al.*, 2012) [53].

Cultivation of Azolla

Various researchers have worked on the cultivation of Azolla at different times. Pillai *et al.* (2005) [50] opined that, from a pit of 2 x 2 x 0.2 m, 500-600 g of fresh Azolla could be harvested daily after 10-15 days of inoculation of culture into the pit. Chander (2011) [17] reported that the plant (Azolla) could produce 9 tonnes of protein per hectare of pond per year. The maximum yield was about one kg of fresh Azolla (mean yield per day in a season) from a pond of 6 x 4 feet in size (Giridhar *et al.*, 2012) [27]. Acharya *et al.* (2014) [2] found out that, pits of size 8ft × 5ft with depths of 10 inches when inoculated with pure culture of *Azolla pinnata* at the rate of 0.5 to 1 kg per pit, it was completely filled with Azolla biomass in about 10-15 days. To maintain the production level at the rate 1 kg/pit/day, 500g of cow dung along with 10g super-phosphate were added in the pit once in every four days. Cherryl *et al.* (2014) [19] inoculated fresh Azolla in pits of 5 m x 4m (20 m^2) with 0.3 m depth (1ft) and found that the pit was completely filled within 7 days from which Azolla was harvested every week.

Several authors have also written about the importance of light, Ph, humidity, nitrogen (N) and phosphorous (P) for the growth of Azolla. Free-floating water of depth 5 to 12 cm is the best medium for Azolla (Cabangon *et al.*, 2015) [15]. The growth of Azolla is rapid in the first two weeks and thereafter it tends to decrease (Watanabe *et al.*, 1986) [74]. Among various factors, phosphorous is considered to be an important factor for the growth of Azolla and the importance has been widely documented in several literatures (K¨osesakal *et al* 2019; Immanuel *et al*, 2019; Sadeghi *et al* 2013) [37, 32, 59]. Azolla can grow without nitrogenous fertilizer if sufficient quantity of phosphorous is applied to water (Costa *et al.*, 2009) [22]. So, it is inferred that a high concentration of phosphorous i.e. above 0.1 mg /kg is required for the growth of Azolla (Watanabe *et al.*, 1986) [74]. Phosphorous deficiency can be indicated by reddish-brown colouration in the pond and that results in death of root (Adhikari *et al.*, 2020) [3].

Intensity of light affects the growth of Azolla and the optimum light intensity is 20,000 lux, (Goala *et al.*, 2021) [28]. Where light intensity below 1500 lux retards the growth of Azolla. (Costa *et al.*, 2009) [22]. Besides light intensity, temperature also greatly influences the growth and nitrogen-fixing ability of Azolla (Watanabe *et al.*, 1983) [74]. The optimum temperature and relative humidity required for the growth of Azolla is 18 to 28 °C and 70-75% respectively (Kosesakal *et al.*, 2019; Costa *et al.*, 2009) [37, 22]. Whereas, Indira *et al.* (2014) [33] reported that the optimum conditions for culturing of Azolla a: Maximum temperature 34.86 ºC, Minimum temperature 28.78 ºC, humidity (%) 56.07 and light intensity (Lux) 1487.43. Temperature below 4 ◦C and above 30 ◦C affect the growth of Azolla. Furthermore, activity of nitrogenise enzyme and nitrogen fixation declined from 35 to 40 ◦C (Hechler *et al.*, 1995) [30]. The suitable pH required for growth of Azolla is 4.5 to 7.5 (Moretti *et al.*, 1988) [44] whereas the pH range can be varied between 3.5 to 10 provided all essential nutrients are adequate (Cary *et al.*, 1992) [16].

Nutritive value and Chemical composition of Azolla

Many researchers have found out the chemical composition of Azolla at different times and some of them have been given as below.

Acharya *et al.* (2014) [2]: 25.42% CP, 2.58% EE, 14.22% CF, 39.02% NFE, 18.75% ash, 1.12% calcium and 0.53% phosphorus, 159.1 ppm zinc, 7.35 ppm copper, 84.2 ppm manganese, 284.7 ppm iron on DM basis.

Cherryl *et al.* (2014) [19]: DM - 89.73%, Organic matter - 75.73%, CP - 14.7, CF - 23.49%, EE - 3.7%, total ash - 24.26%, acid insoluble ash- 7.94%, calcium - 2.58%, phosphorus. - 0.26%.

Ahmed *et al.* (2016) [4]: CP - 24.1%, CF - 15.1%, EE - 3.75%, Ash- 16.8%, NFE - 40.25%, phosphorus - 0.47% and calcium - 2.18% Anhita, *et al.* (2016) [7]: DM - 4.7%, Organic Matter - 82.66%, CP - 22.48%, CF -14.7%, EE - 4.5%, ash - 17.34%, NFE - 40.98%, and minerals in ppm was phosphorus - 0.34, calcium-1.64, potassium - 2.71, copper - 9.1, manganese - 2418, zinc - 325, iron - 1569, cobalt - 8.11, chromium - 5.06, boron - 31, nickel - 5.33, lead - 8.1, cadmium - 1.2.

Sihag, *et al.* (2018) [66]: Azolla meal contains DM - 22.93%, CP -11.63%, EE - 2.8%, ash -15.59%, NFE - 47.03%, NDF - 40.47%, ADF - 32.55% and% hemicellulose - 7.92.

Bhatt, *et al.* (2020) [12]: 9.95% DM, 79.70%OM, 26.50% CP, 3.90% EE, 44.28% NDF, 39.4% ADF and minerals profile was 2.41% potassium, 1.51% calcium, 2170 ppm manganese, 4.1 ppm copper, 230 ppm zinc, 1100 ppm iron, 7.1 ppm cobalt, 2.01 ppm chromium and 6.1 ppm nickel.

El-Fadel *et al.* (2020) [26]: Azolla meal contains 85.08% DM, 72.86% OM, 18.58% CP, 32.17% CF, 3.35% EE, 27.14% ash and 18.76% NFE.

Amino acid profile of Azolla

The amino acid profile of Azolla as determined by Buckingham *et al.* (1978) [14], Ali and Leeson (1995) [6] and Alalade and Iyayi (2006) [5] were as follows.

Table 1: Show Amino acid profile of Azolla

Amino acids	Buckingham *et al.* (1978) [14]		Ali and Leeson (1995) [6]		Alalade and Iyayi (2006) [5]	
	% Dry matter	g/100g of Protein	% Dry matter	g/100g of Protein	% dry matter	g/100g of Protein
Lysine	1.51	6.45	0.62	3.80	0.98	4.58
Methionine	0.44	1.88	0.25	1.50	0.34	1.59
Cystene	0.53	2.26	0.15	0.90	0.18	0.84
Threonine	1.10	4.7	0.66	4.00	0.87	4.07
Tryptophan	0.47	2.01	0.08	0.50	0.39	1.82
Arginine	1.55	6.62	0.82	5.00	1.15	5.37
Isoleucine	1.26	5.38	0.69	4.20	0.93	4.35
Leucine	2.12	9.05	1.28	7.70	1.65	7.71
Phenyl alanine	1.32	5.64	0.77	4.60	1.01	4.72
Tyrosine	0.96	4.10	0.49	4.00	0.68	3.18

Glycine	1.34	5.72	0.86	5.20	1.00	4.60
Serine	0.96	4.10	0.66	4.00	0.90	4.21
Valine	1.58	6.75	0.84	5.10	1.18	5.51
Alanine	1.51	6.45	0.95	5.80	-	-
Histidine	0.54	2.31	0.26	1.60	-	-
Proline	1.05	4.48	0.67	4.00	-	-
Aspartic acid	2.20	9.39	1.37	8.30	-	-
Glutamic acid	2.98	12.72	1.56	9.60	-	-

It was evident from the above table that Azolla meal was rich in amino acids like lysine, leucine, arginine and valine, while primarily deficient in tryptophan and sulphur-containing amino acids.

Azolla is a feed ingredient in various livestock

Azolla is suitable to feed cattle, pigs, rabbits, chickens, ducks and fish etc due to its high protein and nutritional values (Van Hove, 1989) [73].

Cattle and Buffalo

Indira *et al.* (2009) [33] experimented on twelve male buffalo calves by feeding them Azolla as a 50% replacement of GNC nitrogen of control diet. Higher average daily gain was recorded in experimental group.

Kumar *et al.* (2012) [38] conducted a metabolism trial in which they fed sun-dried Azolla (*Azolla pinnata*) meal in the concentrate mixture of graded Murrah buffalo bulls (301.96 ± 6.98 kg) and concluded that Azolla meal could replace about 25 per cent of the total protein in the concentrate mixture without any deleterious effects.

Gouri *et al.* (2012) [29] gave Azolla to dairy cows which replaced 15- 20% dry matter in the ration and there was a 15-20% increase in the milk yield. Low lignin and high protein content of Azolla might be the cause for increase in milk yield. Cross-bred cattle showed an increase in daily milk yield, FCM by 11. 2% and 12.5% respectively when supplied with Azolla (2kg/day) (Chatterjee *et al.* 2013) [18]. Dried Azolla at a 5% level inclusion in the diet of heifers facilitated average daily gain (ADG) by 15.7% and improved feed conversion efficiency (FCE) by 20% (Roy, *et al.* 2016) [58].

Many researchers observed an increasing trend in milk production with supplementation of Azolla. Milk yield increased by 20.96% and 16.9% in cattle and buffalo respectively when they were supplied with 1.5-2 kg of Azolla per day (Mathur *et al.*, 2013) [42]. The milk production in buffalo increased by 16.25% when fresh Azolla at 1.5 kg/ day was incorporated into their diet along with cottonseed cake (Meena *et al.*, 2017) [43]. Rawat *et al.* (2015) [55] supplemented Azolla: Concentrate at a 1:1 ratio in the diets of crossbred cows and found out an increase in milk yield by 11.85%. So, Azolla can be used as feed supplement in the diet of dairy cows as an unconventional feed to increase milk production by 7-13%, (Kumar, *et al.* 2020) [39].

Goat and Sheep

Various workers have also carried out their experiments to see effect of supplementation of Azolla on sheep and goats. Tamang and Samanta (1993) [72] provided sun-dried Azolla in Black Bengal kids at 0, 10, 20 or 50% levels replacing concentrate mixture on an equal-weight basis. The group fed with 50% Azolla was discarded due to profuse diarrhoea and sickness. So, it was concluded that dried Azolla up to 20% of the concentrate mixture could be incorporated of diet of kids.

Regarding the optimal replacement of Azolla in the diet of Jalauni lambs, it was found that Azolla could replace 25% of mustard cake protein in the diet of particular species without any effects on nutrients digestibility and utilization (Das *et al.*, 2017) [23]. To economize feeding of goats, sundried Azolla up to 15% can be included in the concentrated mixture of the diet without any adverse effects (Sihag, *et al.*, 2017) [66]. Further, it was observed from another study that, the inclusion of Azolla meal at 10% level (from the required% of protein) in the concentrate mixture did not affect DM intake, ADG, and feed efficiency of Mecheri lambs (Sankar, *et al.*, 2020) [61].

Pigs

Becerra *et al.*(1990) [11] conducted a trial on growing-fattening pigs where *Azolla filiculoides* was fed at 0, 15 or 30% levels which partially replaced soybean in the protein-based diet (200 g protein/animal/daily) with fresh sugar cane juice. Due to the increase in the amount of Azolla in the diet, the performance of pigs decreased in the growing phase but, they grew faster than the control group in the finishing phase as there was a strong tendency for compensatory growth.

Duran (1994) [25] carried out an experiment in pigs on the replacement of soya bean protein by fresh Azolla at the rate of 0, 10, 20 or 30% in pigs. Overall weight gain and feed dry matter conversion was in the order of 10%>20%>0%>30% replacement rate of Azolla for soya bean. The optimum replacement rates of Azolla were found to be 10% in the growing phase and 20% in the finishing phase.

Rabbit

Retno Lukiwati, *et al.* (2008) [56] conducted an experiment on feeding 90% fresh Azolla to suckling kits, young rabbits and pregnant rabbits for 2 weeks on an average of 360-400g /head/day. Suckling kits showed 0% mortality and better growth with no occurrence of diarrhoea. Better performance along with no incidence of diarrhoea or hair fall was observed in young rabbits.

Average daily gain and feed conversion ratio (FCR) of white New Zealand rabbits fed diets containing 0, 10, and 20% Azolla, as a replacement of the protein diet, was higher for 10% over 0 and 20% (Sireesha *et al.* 2017) [67].

Azolla as a feed ingredient in Poultry

Ducks

Lawas *et al.* (1998) [40] utilized fresh Azolla to evaluate the performance of laying Mallard ducks fed with a normal feeding allowance of 150 g commercial feed/head per day or 75 g of commercial feed + ad libitum feeding of Azolla/head per day and the result showed that Azolla when substituted 50 percent of commercial feeds on ad libitum system of feeding could provide enough nutrient. Samudera and Hidayatullah (2008) [60] conducted an experiment on male Alabio ducks to find out the effect of Azolla on skin colour, abdomen fat and carcass fat. The treatment levels of *Azolla pinnata* flour were 0 (A0); 7.5 (A2); 15 (A3); and 22.5% (A4). The effect of treatment towards abdomen fat (A0, A1, A2, and A3 / 1.50; 1.41; 1.23; 0.92%), carcass fat (A0, A1, A2, and A3 / 7.99; 7.53; 5.74; 5.25%), and skin colour (A0, A1, A2, and A3 / 2.66; 3.62; 3.94; 4.20). It was concluded that the dietary

Azolla was able to decrease abdomen fat degree and carcass fat, reformed skin colour, producing yellow or un-pale colour. Basak, *et al.* (2002) [10] reported that 5% Azolla-fed group resulted in the highest profit per bird followed by the control group and opined that the higher profit was due to the higher body weight of the birds belonging to those groups. Sujatha *et al.* (2009) [70] carried out a trial for a period of 13 weeks in laying ducks of 20 weeks old with supplementation of Azolla @ 200 g/bird/day as 30% replacement of concentrate feed compared with control group. It was concluded that Azolla could be safely supplemented in the feed of laying ducks at the backyard level with a significant savings in feed cost. Sujatha *et al.* (2013) [71] opined that fresh Azolla could replace commercial feed up to a level of 30 percent with the savings in feed cost of Rs.1 per duck per day by supplementing fresh Azolla in the feed of backyard ducks at the rate of 200g per duck per day. Acharya *et al.* (2014) [2] conducted a study on White–Pekin broiler ducks and brought a conclusion that fresh Azolla at 5 or 10% level can be included in the diet of the same to reduce feed cost. Azolla-fed at 10% level resulted in a profit of around Rs. 10 per kg live weight sold, a fact which must be appreciated, by any standard, as a substantial economic gain.

Quail

Shamna, *et al.* (2013) [64] conducted an experiment for six weeks on day-old Japanese quails with four different levels of *Azolla pinnata* in the diet, *viz.*, 0%, 2.5%, 5% and 7.5%. As far as economics was concerned, 5% supplementation of Azolla was more economical than the other groups and beyond this level there was depression in broiler characteristics. The 5% Azolla group in diet had lower feed cost per chick (8.13) over the chicks on normal diet resulting in higher savings (1.69%) over the control group. On the very next year, Shamna *et al.* (2014) [65] found significant ($p \leq 0.05$) depression in average feed conversion efficiency of the Japanese quail (*Coturnix coturnix japonica*) at 6 weeks of age in groups fed with 7.5% dried Azolla.

Chicken

Layers

Alalade and Iyayi (2007) [5] conducted an experiment in 8-week-old Nera brown pullets with incorporation of Azolla meal in their grower diet at 0, 5, 10 or 15% level for a period of 10 weeks. These results indicated that Azolla meal could be incorporated in diets of growing pullets up to 15% without jeopardizing health and subsequent laying performance. In contrast, Khatun and co-workers (2008) [35] in a 16 weeks study period found that feeding of dried Azolla at a level of 15% in the diet of commercial layers could not affect egg production performance of the laying hens. Namra *et al.* (2010) [47] conducted an experiment to study the impact of feeding restricted diets supplemented with free fresh Azolla on performance and economic efficiency of Fayoumi growing chicks and it was concluded that fresh Azolla might be offered to the grower chicks with restricted diets, to obtain the best economical efficiency. Rai, *et al.* (2013) [52] conducted a study in semi-range system on dual-type Nirbhik and egg-type Shyama which are two different strains of poultry birds. On 14th week of experiment, the Nirbhik birds that consumed *Azolla pinnata* as feed attained 1810 ± 12.5 g body weight compared to non-Azolla fed Nirbhik birds which achieved 1270±12.9 g in the same time. The Shyama birds fed on Azolla produced higher number of eggs (197.6 ± 3.2) in 72 weeks in comparison to 138.4 ± 3.1 eggs of non-Azolla-fed birds. Sujatha *et al.* (2013) [71] carried a feeding trail to know the production performances in Nicobari fowl. The control group was given commercial feed (basal diet) @ 120 g per chick per day, while the experimental group was given raw Azolla, @ 200 g per chick per day in separate feeder, in addition to 120 g of basal diet, from 45-60 weeks. Azolla supplementation ultimately led to a feed cost savings of 0.76 per egg per day over control in Nicobari fowl production. Boitai and colleagues (2018) [13] in their 8 weeks study on Vanaraja laying hens found that the addition of 10% Azolla meal in the diet of these birds did not affect egg quality indices like albumen, yolk, shell percentage and egg qualities like haugh unit score and shell thickness. However, there was no adverse effect on egg production.

Broilers

Several workers have given Azolla as a feed supplement in the diet of broilers to see the overall performance of the birds. Sittigaipong (1996) [68] concluded that *Azolla pinnata* had no adverse effect on the performance of broilers at the level of 2-8 percent in the diet and therefore, could be used in the broiler ration effectively. Parthasarathy *et al.* (2001) [48] opined that the incorporation of Azolla as a feed ingredient at 5% level in broiler ration could provide satisfactory economic return. Feed conversion ratio and dressing percentage were significantly higher ($p<0.01$) in broiler birds on diet with 5% Azolla meal (Basak *et al.*, 2002) [10]. Namra *et al.* (2003, b) [46] studied on Arbor Acre broiler chicks to assess the efficiency of replacement of yellow corn and soya bean meal diet with dried Azolla at 0%, 2.5%, 5%, 7.5% or 10%, on the biochemical parameters and observed that there was no adverse effect on biochemical components of blood due to feeding of diet containing dried Azolla up to 10% level. Dhumal *et al* (2009) [24] fed Azolla meal at 0, 2.5 or 5% levels as partial replacement of soya bean meal in their diet to commercial Vencobb broiler chicks for 6 weeks, and found improved Ab titre values in 2.5% or 5% Azolla fed groups (293.33) as compared to the control group (266.67). Economics of production also increased when Azolla was used at 5% level. The net profit per bird for 0, 2.5 and 5% treatment groups were found to be Rs. 10.84, 15.64 and 19.22, respectively. There was also report regarding lower cholesterol content in serum and meat of broiler birds when they were fed with 4. 5% Azolla in the diet without any deleterious effect on production performance (Balaji *et al.*, 2009; Balaji *et al.*, 2010) [8, 9]. A study was conducted by Prabina and Kumar (2010) [51] made a study in Vencobb broiler chicks to explore the potential of dried Azolla hybrid, "Rong-Ping " (*A. Microphylla* X *A. Filiculoides*) as a feed supplement in concentrate feed at 7.5 or 10% level of inclusion. Supplementation of the concentrate feed with dried Azolla at 7.5% resulted in 2.6% increase in body weight (1.99 kg) per head over control (1.93). The antibody tire value against Ranikette virus was higher in birds that were administered with dried Azolla at 10% with a mean value of 32 followed by 21 in the birds which took dried Azolla at 7.5%. So, improved antibody tire value demonstrates immune potentiating effect of Azolla as a feed supplement in the diet of poultry birds. Chichilichi *et al.* (2013) [20] studied the effect of Azolla on the growth and performance of commercial broiler chicken subjected to six dietary treatments (isocaloric and isonitrogenous) from day-old to six weeks. It was concluded that substitution of 5% dietary protein by Azolla resulted in favourable growth, feed efficiency and economics of production. In another study, when dietary fresh Azolla, as

a protein substitute was given to *vanaraja* chicken, it was found that protein could be substituted by Azolla up to 15%, resulting in higher weight gain and feed efficiency without any deleterious effect. Feed cost of production was reduced leading to a substantial increase in profit margin also (Seth *et al.*, 2013) [63]. Naghshi *et al.* (2014) [45] conducted a study in which they supplied a control diet of corn-soybean with no Azolla and diets containing 5, 10 and 15% of Azolla. The best feed conversion ratio was found to be diets containing 5% Azolla. Joysowal and co-workers (2018) [34] observed that incorporation of Azolla by replacing fish meal as a protein source at a level of 5-10% of the diet gave rise to increased body weight and higher net returns per bird. Mahanthesh and other researchers (2018) [41] found that inclusion of Azolla by 30% (w/w) along with 70% commercial feed helped to improve the FCR and the average body weight in broiler birds whereas, cost of production and mortality of birds were decreased in comparison to those birds which were grown with feeding commercial feed alone. In another experiment, Rana *et al.* (2020) [54] observed that 5% Azolla inclusion, though, did not significantly influence the proximate composition of broiler meat but, had significant ($p \leq 0.05$) effect on overall acceptability of cooked meat, breast meat yield and cooking yield. Abdelatty and co-workers (2020) [1] observed that inclusion of 5-10% Azolla meal in the diet of broilers did not affect the carcass characteristics i.e. the dressing percentage, weight of wing, breast and thigh. But, the Azolla supplement significantly improved the redness and juiciness of breast meat. Riaz and co-workers (2022) [57] observed an improved egg weight, egg production, performance index, egg shape index and feed conversion ratio in laying geese when offered with Azolla-based diets.

Conclusion and way forward

Aquatic plant, free-floating fern Azolla is a good source of protein as it contained almost all essential amino acids, minerals and appreciable quantities of vitamin A and vitamin B_{12}. In this article, significance of Azolla in livestock feeding has been demonstrated by many scientists across the globe indicating the possibility of using Azolla as a feed ingredient. Due to its high nutritional values and protein content, Azolla is a promising feed supplement for variety of animals and birds depending on its inclusion percentage in feed of different species. So, it can be inferred that Azolla has vast opportunity as an alternative feed for livestock and poultry to improve the production performance, reduce the cost of feed and ultimately will be helpful for sustainable livestock and poultry production. Accordingly, strategic initiatives could focus on, but not limited to:

a) Training of farmers and unemployed youth regarding advantage of using Azolla as an alternative protein feed for livestock and birds.
b) Testing and evaluating the effectiveness of different species of Azolla in field conditions in different agro-climatic zone in India.
c) Growing Azolla in paddy fields and promoting integrated farming like Azolla-fish- duck farming.
d) Establishing a project with different partners that can develop an effective model of promoting Azolla as an alternative feed for livestock and birds.

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