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Review Article

# Prosopis Pod Meal as an Alternative Aquafeed Ingredient

Chetan Kumar Garg* and D.K. Meena

[1]*Dept. of Fisheries Science, Gopal Narayan Singh University, Jamuhar, Rohtas, Bihar (821 305), India*

[2]*ICAR-Central Inland Fisheries Research Institute, Barrackpore Kolkata, West Bengal (700 120), India*

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**Corresponding Author**

Chetan Kumar Garg

✉: chetan.fishlove7736@gmail.com

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**Abstract**

The expanding human population raises the demand for nutritionally-rich food, and fish is the cheapest and best way to meet this requirement. Currently, the stagnation of capture fisheries encourages aquaculture as a means of providing quality proteins to a growing population. A successful aquaculture enterprise incurs a high expenditure of 50-60% on feed costs. Therefore, reducing feed costs by identifying alternative feed ingredients will improve the economic condition of the aquaculture business. Currently, the conventional ingredients used in aquafeed are becoming more expensive, raising the aquafeed's price and thus the overall cost of fish production. Hence, there is a need to transition to low-cost unconventional aquafeed ingredients, and Prosopis pod meal has excellent potential in this context. Prosopis pod meal has a high nutritional value, and it could be substituted conventional ingredients for instance corn meal, wheat flour, rice bran, *etc*., in aquafeed. This technical review comprises the scope and constraints of employing Prosopis pod meal as an ingredient in aquafeed.

**Keywords:** Aquafeed, Fish, Plant-based ingredient, Prosopis pod meal, Unconventional ingredient

## Introduction

The rapid expansion of aquaculture is giving a strong indication that the aquafeed industry is going to face a crisis in the near future. Fish feed demand is rising along with fish production, and the main challenge facing the aquafeed business is the rising price of conventional feed ingredients (Hardy, 2010). Feed cost accounts around 50-60% of overall operational costs in aquaculture. Hence, reducing the marginal amount of feed cost would increase the profitability of fish farmers (Ebenebe, 2000). The high demand and scarcity of conventional feed ingredients for aquafeed limited their use in aquafeed formulations. The conventional ingredients used in aquafeed raise the feed or production costs. The rising cost of aquafeed can be lowered by using locally available, inexpensive unconventional feed ingredients. Formulating aquafeed using locally available, economically viable and nutritionally acceptable plant ingredients could increase the profit margin of fish farmers (Gatlin III *et al*., 2007). From this perspective, the Prosopis pod meal has great potential because it is affordable and nutritionally balanced. The global availability of Prosopis pods is projected to be around 20-40 million metric tonnes (Sawal *et al*., 2004). The Prosopis tree is relatively easy to cultivate with low water requirement, and yields of Prosopis pods per hectare are higher (2-10 tonnes) (Riveros, 1992; Choge *et al*., 2007). The abundant availability of the Prosopis pod suggests that it can be utilized as an unconventional ingredient in an aquafeed instead of high-cost conventional ingredients.

## Aquafeed Ingredients

Aquaculture intensification is increasing the demand for aquafeed, which accounts for a considerable portion of total operating costs. Aquafeed prices have risen dramatically during the last few decades. The use of costly conventional feed ingredients in the preparation of aquafeed influences the cost of fish production (Gabriel *et al*., 2007). The rising cost of conventional ingredients drove feed formulators and aquaculturists to explore locally available affordable unconventional ingredients for aquafeed. These ingredients

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are neither prevalent in markets nor regularly used for commercial aquafeed formulations. Moreover, these ingredients are generally not used for human consumption and are byproducts of agricultural and processing industries (Devendra, 1988).

**Description and Distribution of Prosopis**

Prosopis is a legume belongs to the Fabaceae family, which thrives in arid and semi-arid areas (Shukla and Kasera, 2004). The genus Prosopis comprises 44 species. Some species are important because they grow rapidly, such as *Prosopis juliflora*, *P. africana*, *P. alba*, *P. chilensis*, *P. cineraria*, *P. glandulosa*, *P. hassleri*, *P. nigra* and *P. pallida.* Prosopis trees are found all over the world and are primarily cultivated in Afghanistan, Africa, America, Australia, Brazil, Burma, India, Indonesia, Iran, Oman, Pakistan, Saudi Arabia, Sri Lanka, United Arab Emirates, United States of America, Yemen, *etc*. (Choge *et al*., 2007). The tree is known locally as Ghaf (Arabic), Jand (Pakistan) and Jandi or Khejri or Vilayati Babul (India). It is commonly termed the "wonder tree" and "king of the desert" (Jatasra and Paroda, 1981). In India, the prominent species are *P. cineraria* and *P. juliflora,* which are found primarily in Rajasthan, Telangana, Haryana, Punjab, Gujarat, Andhra Pradesh, Karnataka, Maharashtra, Orissa, Uttar Pradesh and Tamil Nadu (Parkash and Hocking, 1985; Kaushik and Kumar, 2003; Khatri *et al*., 2010). Prosopis pod has excellent nutritive value with high protein, carbohydrate, mineral and vitamin (Malik *et al*., 2013). Prosopis also has therapeutic utilities such as antimicrobial, antifungal, antioxidant, anticancer, antihyperlipidemic and antihyperglycemic activities due to the presence of a bioactive component (Pareek *et al*., 2015). Prosopis pods are primarily utilized as manure and to a lesser extent in animal feed (cattle, camels, sheep, rabbits, goats, poultry and fish) (Riveros, 1992). It is necessary to investigate the influence of Prosopis pod meal-based diets on fish growth and nutrient utilization and standardize their inclusion levels in diets of different fish species without jeopardizing fish growth and health.

**Nutritional Composition of Prosopis Pod Meal**

The available literature on the nutritional composition of Prosopis pods indicates that it could be a probable energy and protein ingredient for aquafeed (Table 1). Prosopis pods are highly nutritious and palatable (Anttila *et al*., 1993), and they have been consumed by cattle, sheep, rabbits, goats, sheep, poultry and fish (Silva, 1986; Silva *et al*., 1990; Pinheira *et al*., 1993; Ravikala *et al*., 1993; Mahgoub *et al*., 2004; Al-Beitawi *et al*., 2010; Chovatiya *et al*., 2016; Al-Harthi *et al*., 2018; Nascimento *et al*., 2019). Like other plant-based ingredients, the proximate composition of Prosopis pod meal varies with location, soil type, age, season, *etc*. (Chopra and Hooda, 2001). The variation in the proximate composition of Prosopis pod meal observed in different studies is most likely due to differences in agronomical and environmental situations, diverse species and different analytical methodologies (Girma *et al*., 2011; Kingori *et al*., 2011; Tran, 2015; Tran, 2016).

Table 1: Proximate composition (% dry matter basis) of Prosopis pod meal as well as selected conventional ingredients

| Variables | Dry matter | Crude protein | Ether extract | Crude fiber | Nitrogen free extract | Total Ash | References |
|---|---|---|---|---|---|---|---|
| Prosopis pod | 91.4 | 15.2 | 2.61 | 18.58 | 48.97 | 6.04 | Al-Harthi *et al*., 2018 |
| Prosopis pod | 90.68 | 12.05 | 3.2 | 22.4 | 48.27 | 4.76 | Chovatiya *et al*., 2016 |
| Prosopis pod | 90.2 | 12.8 | 1.1 | 18.4 | 52.8 | 5.1 | Al-Marzooqi *et al*., 2015 |
| Prosopis pod | 82-94 | 7.1-18.5 | 0.4-3.5 | 12.3-28 | 46.5-65.3 | 1.4-6.0 | Kingori *et al*., 2011 |
| Prosopis pod | 89.15 | 15.43 | 6.01 | 14.6 | 46.98 | 6.13 | Girma *et al*., 2011 |
| Prosopis pod | 82-92.6 | 7.1-16.2 | 0.4-4.0 | 12.3-27.7 | 46.3-71.1 | 1.4-6.0 | Choge *et al*., 2007 |
| Prosopis pod | 91.2 | 16.5 | 4.2 | 16.8 | 48.3 | 5.4 | Rao and Reddy, 1983 |
| Prosopis pod | 89.2 | 17.77 | 2.42 | 19.82 | 44.44 | 4.75 | Mabrouk*et al*., 2008 |
| Prosopis pod | 90-93 | 9.0-17.0 | 1.2-4.3 | 16-34 | 47-61 | 5-7 | Shukla *et al*., 1986 |
| Prosopis pod | 90.13 | 13.64 | 0.72 | 14.62 | 53.77 | 7.38 | Yousif, 2012 |
| Corn meal | 88 | 10.2 | 4.8 | 2.8 | 68.6 | 1.6 | NRC, 2011 |
| Rice bran | 91 | 13 | 7.4 | 2.3 | 66.5 | 1.8 | NRC, 2011 |
| Wheat bran | 89 | 14.8 | 4 | 9.9 | 55 | 5.3 | NRC, 2011 |
| Soybean meal | 89 | 44 | 1.5 | 7.3 | 29.9 | 6.3 | NRC, 2011 |

The crude protein of Prosopis pod meal ranges from 7.1-18.5% on a dry matter basis (Sawal *et al*., 2004; Kingori *et al*., 2011). These notable variations in crude protein level could be due to the previously described explanation. The crude protein level of Prosopis pod is comparable to corn meal, rice bran and wheat bran (NRC, 2011). Prosopis pod contains an equitable amount of essential amino acids (Table 2). *P. juliflora* contains aspartic acid, threonine, cystine, valine, methionine, isoleucine, leucine, tyrosine, phenylalanine, alanine, histidine, lysine, arginine, serine, glutamic acid and glycine amino acids in the concentration of 0.99%, 0.28%, 0.14%, 0.43%, 0.10%, 0.27%, 0.52% 0.29%,

Table 2: Amino acids composition (concentration/ 100 g ingredients) of Prosopis pod meal as well as selected conventional ingredients

| Crude protein and amino acids | Prosopis pod[a] | Prosopis pod[b] | Prosopis pod[c] | Corn meal[d] | Rice bran[d] | Wheat bran[d] | Soybean meal[d] |
|---|---|---|---|---|---|---|---|
| Protein | 15.2 | 20.2 | 16.5 | 10.2 | 13 | 14.8 | 44 |
| Arginine | 0.67 | 2.687 | 0.56 | 0.4 | 1 | 0.64 | 3.23 |
| Aspartic acid | 1.76 | NR | 0.99 | NR | NR | NR | NR |
| Cysteine | 0.17 | 0.243 | 0.14 | 0.19 | 0.27 | 0.27 | 0.7 |
| Glutamic acid | 1.28 | NR | 1.4 | NR | NR | NR | NR |
| Glycine | 1.04 | 0.895 | 0.51 | NR | NR | NR | NR |
| Histidine | 0.2 | 0.545 | 0.19 | 0.25 | 0.34 | 0.3 | 1.17 |
| Isoleucine | 0.54 | 0.545 | 0.27 | 0.29 | 0.44 | 0.51 | 1.99 |
| Leucine | 1.03 | 1.333 | 0.52 | 1 | 0.92 | 0.89 | 3.42 |
| Lysine | 0.46 | 0.808 | 0.32 | 0.26 | 0.57 | 0.36 | 2.83 |
| Methionine | 0.12 | 0.201 | 0.1 | 0.18 | 0.26 | 0.21 | 0.61 |
| Phenylalanine | 0.4 | 0.465 | 0.33 | 0.42 | 0.56 | 0.63 | 2.18 |
| Proline | 1.11 | NR | NR | NR | NR | NR | NR |
| Thrionine | 0.47 | 0.485 | 0.28 | 0.3 | 0.48 | 0.37 | 1.73 |
| Tryptophan | 0.44 | 0.222 | NR | 0.07 | 0.14 | 0.17 | 0.61 |
| Tyrosine | 0.2 | 1.172 | 0.29 | NR | 0.4 | 0.43 | 1.69 |
| Valine | 0.67 | 0.707 | 0.43 | 0.42 | 0.68 | 0.59 | 2.4 |

NR: not reported. (Source: [a]Al-Harthi *et al*., 2018; [b]Heuze *et al*., 2015; [c]Shukla *et al*., 1986, [d]NRC, 2011)

0.33%, 0.37%, 0.19%, 0.32%, 0.56%, 0.41%, 1.4% and 0.51%, respectively (Gangal *et al*., 2009). Al-Harthi *et al*. (2018) also evaluated the essential amino acid composition of *P. juliflora* and detected arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine in the percentage of 0.67, 0.20, 0.54, 1.03, 0.46, 0.12, 0.40, 0.47, 0.44 and 0.67, respectively. The differences in Prosopis pod amino acid composition between studies are most likely attributable to differing origins, agricultural and environmental conditions and measurement tools or methodologies (Silvia *et al*., 2012). Moreover, the amino acid composition of Prosopis pod meal is comparable to those of conventional feedstuffs such as corn meal, rice bran and wheat bran (NRC, 2011).

Prosopis pods are rich in carbohydrates and can be used as a superior energy ingredient in aquafeed. The pod contains approximately 46-65% nitrogen-free extract (NFE) (Escober *et al*., 1987), with saccharose (20-25%) and reduced sugar (10-20%) being the major components (Silva, 1986). Prosopis pods have a high proportion of crude fiber levels (14-34%) (Choge *et al*., 2007; Kingori *et al*., 2011) and high differences in crude fiber content in pods may be due to variations in age of a tree, a season of pod collection and area of cultivation (Chopra and Hooda, 2001). The NFE level of Prosopis pod meal is compared to corn meal, rice bran, wheat bran and soybean meal, and it observed that the pod meal has a similar NFE content to wheat bran and slightly lesser NFE content than rice bran or corn meal (Table 1).

The ether extract content of pod meal ranges from 0.4 to 6.0%, which is comparable to corn meal and wheat bran (Kingori *et al*., 2011; Girma *et al*., 2011). Prosopis pods are concentrated in unsaturated fatty acids (67.21-73.97%), which comprised monounsaturated fatty acids (18.86-37.83%) and polyunsaturated fatty acids (29.37-50.92%). The saturated fatty acid content ranges from 20.14-26.42%, and the saturated fatty acid/ unsaturated fatty acid ratio ranges from 0.27 to 0.40. Palmitic acid (10.8%), oleic acid (35.5%) and linoleic acid (27.9%) are primary saturated, monounsaturated and polyunsaturated fatty acids, respectively (Choge *et al*., 2007). Prosopis pod meal contains a high amount of essential docosahexaenoic acid (1.17%), which is vital for fish growth, survival and immune development (Table 3) (Al-Harthi *et al*., 2018).

The total ash level of the pod meal ranges from 3.6 and 6.13%. Prosopis pods are an excellent source of macro- and micro-minerals (Table 4). Calcium, phosphorus, potassium, magnesium and sodium are found in concentrations ranging from 0.26 to 0.66%, 0.13 to 0.20%, 0.73 to 1.69%, 0.34 to 1.20% and 0.01 to 0.05%, respectively. The pod meal contains iron 764 ppm, zinc 69.4 ppm, manganese 33.9 ppm, copper 36.1 ppm, chromium 21.7 ppm, cadmium 7.4 ppm, nickel 9.8 ppm and lead 28.2 ppm. Prosopis pod mineral compositions are consistent with rice bran, wheat bran and soybean meal (NRC, 2011). Talpada *et al*. (1989) revealed that pods collected in winter have superior iron, zinc and copper level than in summer, whereas manganese is not changed by season. Similarly, pods collected from different areas have different mineral content (Chopra and Hooda, 2001).

Table 3: Fatty acid profile (% of total fatty acids) of Prosopis pod meal

| Fatty acids | Prosopis pod[a] | Prosopis pod[b] | Prosopis pod[c] |
|---|---|---|---|
| C6:0 | 0.569 | NR | NR |
| C8:0 | 3.14 | NR | NR |
| C10:0 | 0.649 | NR | NR |
| C12:0 | 1.31 | NR | NR |
| C13:0 | 2.08 | NR | NR |
| C14:1 | 1.08 | NR | NR |
| C14:0 | 0.151 | NR | 0.16 |
| C15:1 | 0.944 | NR | NR |
| C15:0 | 0.777 | NR | NR |
| C16:1 | 0.308 | NR | NR |
| C16:0 | 10.8 | NR | 13.19 |
| C17:0 | 0.153 | NR | NR |
| C18:3 | 0.00 | NR | NR |
| C18:2 | 27.9 | NR | 50.92 |
| C18:1 | 35.5 | NR | 22.74 |
| C18:0 | 5.39 | NR | 4.75 |
| C20:2 | 0.304 | NR | NR |
| C20:0 | 0.281 | NR | NR |
| C22:0 | NR | NR | 1.26 |
| C22:1 | NR | NR | 0.31 |
| C24:0 | NR | NR | 0.75 |
| DHA C22:6 | 1.17 | NR | NR |
| THA | 92.54 | 92.45 | 94.11 |
| SFA | 25.55 | 26.42 | 20.14 |
| UFA | 67.21 | 66.03 | 73.97 |
| MUFA | 37.83 | 18.86 | 23.05 |
| PUFA | 29.37 | 47.17 | 50.92 |
| SFA/UFA ratio | 0.377 | 0.400 | 0.272 |

NR: not reported; DHA: docosahexaenoic acid; TFA: total fatty acids; SFA: saturated fatty acids; UFA: Unsaturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids. (Source: [a]Al-Harthi *et al*., 2018; [b]Choge *et al*., 2007; [c]Marangoni and Alli, 1988)

**Phytotherapeutic Compounds of Prosopis and Its Uses**

Plants and their byproducts have been shown to be classical sources of medicine and act as nutraceuticals when incorporated into aquafeed. Prosopis is well-known as "A Gift of Nature for Pharmacy" because it contains a variety of medicinally valuable bioactive substances or phytoconstituents (Pareek *et al*., 2015). Various phytoconstituents have been extracted from pods, such as tannins (gallic acid), alkaloids (prosophylline, spicigerine), flavonoids (patuletin, petulitrin, luteolin, rutin, prasogenin A, B, C, D and E), steroids (campestral, stigmasterol, sitosterol) *etc*. (Bhardwaj *et al*., 1981; Rani *et al*., 2013). These components have beneficial effects on animal growth, digestion and metabolism and immunity (Choge *et al*., 2007). The phytoconstituents of Prosopis act as antimicrobial, antifungal, antioxidant, anthelmintic, anticancer, antihyperlipidemic and antihyperglycemic (Garg and Mittal, 2013; Malik *et al*., 2013; Pareek *et al*., 2015).

**Antinutritional Factor and Its Amelioration**

The application of plant-based ingredients in aquafeed is advantageous by reason of its widespread availability and cheapness. Nevertheless, the occurrence of antinutritional factors and more fiber limited the inclusion of these ingredients in animal feed as this reduces feed intake or nutrient utilization and affects the health status of animals (Francis *et al*., 2001). Similarly, Prosopis pod meal also contains antinutrient elements, such as saponins, tannins, phenolic compounds, trypsin inhibitors, phytic acid, *etc*., which need to ameliorate before they can be used in aquafeed (Table 5). Tannins and total phenolic compounds are the principal antinutritional factors present in pods (Saxena and Venkateshwarlu, 1991). Since aquafeed must be made with more than one ingredient, incorporating Prosopis pod meal up to 30% of feed may reduce overall feed tannin levels within permissible limits. Becker and Makkar (1999) state that dietary tannin powder at 0.2% does not alter fish feed intake or growth performance. Similarly, Twibell and Wilson (2004) suggested that feeding pure saponins below 0.26% in aquafeed does not affect fish growth and feed intake. Therefore, incorporating up to 30% Prosopis pod meal into aquafeed has no saponin concerns because the overall feed saponin content reduces below the allowable limit. Prosopis pod meal contains phytic acid; nevertheless, Francis *et al.* (2001) recommended that the allowed level of phytic acid in aquafeed is less than 0.5%, and Prosopis pod meal contains lower than the tolerable limits.

Tannins, phenolic compounds, saponins and phytic acid are soluble in water and can be ameliorated through soaking, cooking, autoclaving and wet heat treatment (Kataria *et al*., 1989; Vijayakumari *et al*., 1996). Polyethylene glycol (tannin blocking agent) can also be used in Prosopis pod meal-based aquafeed to mitigate tannin detrimental effects (Makkar and Becker, 1996; Bhatta *et al*., 2002). Fermentation is another possible method for eliminating or removing tannins, saponins, and phytic acid from the Prosopis pod meal (Mukhopadhyay and Ray, 1999; Bhatt *et al*., 2011). The supplementation of phytase in fish feed can reduce phytic acid's negative effects (Gabriel *et al*., 2007). Prosopis pod meal contains trace quantities of trypsin inhibitors, which can be removed through moist thermal processing (Norton, 1991).

**Selected Studies on the Application of Prosopis Pods in Fish and Livestock Feed**

Several researchers have used Prosopis pods in fish and livestock feed and found that it is a viable alternative to the

Table 4: Minerals composition of Prosopis pod meal as well as selected conventional ingredients

| Minerals | Prosopis pod[a] | Prosopis pod[b] | Prosopis pod[c] | Prosopis pod[d] | Prosopis pod[e] | Rice bran[f] | Wheat bran[f] | Soybean meal[f] |
|---|---|---|---|---|---|---|---|---|
| Calcium % | 0.66 | 0.271 | 0.43 | 0.26 | 0.5 | 0.25 | 0.13 | 0.03 |
| Phosphorus % | 0.20 | NR | 0.17 | 0.13 | 0.2 | 0.66 | 1.16 | 0.28 |
| Potassium % | NR | 1.693 | 0.73 | 1.31 | 0.9 | 0.28 | 1.22 | 0.31 |
| Magnesium (ppm) | 0.034 | 0.119 | NR | 0.12 | 0.076 | 0.20 | 0.57 | 0.13 |
| Iron (ppm) | 764 | 289.9 | 400 | NR | 99 | 74.0 | 145.0 | 48.0 |
| Zinc (ppm) | 69.4 | NR | 300 | NR | 1279 | 68.0 | 95.0 | 17.0 |

NR: not reported. (Source: [a]Al-Harthi *et al*., 2018; [b]Chovatiya *et al*., 2016; [c]Manhique *et al*., 2017; [d]Girma *et al*., 2011; [e]Koech *et al*., 2010; [f]NRC, 2011)

Table 5: Antinutritional factors of Prosopis pod meal

| Antinutritional factors | Prosopis pod[a] | Prosopis pod[b] |
|---|---|---|
| Total phenol (%) | 0.582 | 0.640 |
| Tannin (%) | 0.973 | 0.860 |
| Phytic acids (%) | 0.188 | 0.181 |
| Saponin (%) | 0.393 | 0.317 |

(Source: [a]Chovatiya *et al*., 2016; [b]Sarasvati *et al*., 2014)

high-cost limited available conventional feedstuffs (Table 6). Most investigations on amalgamation of Prosopis pod meal as a fish feed ingredient were conducted on tilapia species. Prosopis pod meal can completely replace the conventional high-cost ingredients (corn meal, wheat flour, rice bran and cottonseed meal) in tilapia feed. The available literature suggests that it may include 6.0 to 38.67% of the feed of tilapia feed with positive impacts on growth and health (Mabrouk *et al*., 2008; Ramos *et al*., 2012; Sena *et al*., 2012; Nascimento *et al*., 2019). Fermented Prosopis pod

Table 6: Selected study on the use of Prosopis pod meal in fish feed

| Sl. No. | Species | Replacement | Results | References |
|---|---|---|---|---|
| 1 | *Oreochromis niloticus* juveniles | Corn meal | Corn meal can be replaced by *P. juliflora* pods meal entirely, without hostile health consequences. | Souza *et al*., 2019 |
| 2 | *Oreochromis niloticus* juveniles | Corn meal & wheat flour | *P. juliflora* pod meal could be incorporated in juvenile tilapia diet up to 38.67%, with encouraging effects on growth and health. | Nascimento *et al*., 2019 |
| 3 | *Labeo rohita* fingerlings | Rice bran | Rice bran can completely replace by fermented *P. juliflora* pod meal (33.4% of diet), and addition of probiotics significantly improve growth performances. | Chovatiya *et al*., 2016 |
| 4 | *Oreochromis niloticus* juveniles | Corn meal | *P. juliflora* pod meal can totally replace corn meal or incorporated 20% of the diet for Nile tilapia. | Silva *et al*., 2015 |
| 5 | *Oreochromis niloticus* juveniles | Cottonseed & corn meal | Inclusion of *P. juliflora* pod meal at the level of 15% of feed improves growth performance of tilapia. | Carvalho *et al*., 2012 |
| 6 | *Oreochromis niloticus* juveniles | Cottonseed meal | *P. juliflora* pod meal can be incorporated in tilapia diet of up to 20% level without compromising growth performances. | Sena *et al*., 2012 |
| 7 | *Valamugil seheli* fry | Wheat flour | *P. cineraria* can be incorporated in Mullet diet up to 20% level without affecting growth performances. | Yousif, 2012 |
| 8 | *Oreochromis niloticus* adults | Conventional feedstuffs | The equivalent apparent dry matter and crude protein digestibility coefficients were observed in tilapia fed with 30% cassava leaf meal, cocoa meal and Prosopis pod meal. | Ramos *et al*., 2012 |
| 9 | *Colossoma macropomum* fingerlings | Corn meal | *P. juliflora* pod meal could completely replace corn meal in feed without affecting growth performances of Tambaqui, when included in feed at 33.8% levels. | Miranda *et al*., 2009 |
| 10 | *Oreochromis niloticus* fry | Corn meal | *P. juliflora* pod meal at 6% dietary level can significantly increase growth compare to non-inclusion groups. | Mabrouk *et al*., 2008 |

can wholly substitute rice bran in the feed of *Labeo rohita* without impacting growth performance and feed intake (Chovatiya *et al*., 2016). Miranda *et al*. (2009) observed that *P. juliflora* pod meal (33.8%) could be substituted for corn meal in the diet of *Colossoma macroporum* fingerlings. *P. cineraria* can be incorporated up to 20% of the diet for *Valamugil seheli* fry without impairing growth performance (Yousif, 2012).

Prosopis pod meal as a substitute for conventional feedstuffs in terrestrial animals is well established (Table 7) (Sawal *et al*., 2004). Prosopis pod meal was added to chicken feed to replace maize meal and wheat flour, and shown that it could be blended up to 20% without compromising growth or egg production (Silva, 1986; Al-Beitawi *et al*., 2010; Girma *et al*., 2011; Al-Marzooqi *et al*., 2015; Al-Harthi *et al*., 2018). Both *P. cinerea* and *P. juliflora* species pods have been added to goat and sheep feed, and it has been observed that the pod meal can substitute conventional feed ingredients (Mahgoub *et al*., 2004; Koech *et al*., 2010). Incorporating up to 30% Prosopis pod meal into the diet did not alter the growth performance of lamb and pig finishers (Pinheira *et al*., 1993; Ravikala *et al*., 1993).

## Fermentation Process Improves Nutritional Quality of Prosopis Pod Meal

Fermentation can improve the nutritional quality of plant-based ingredients. Solid-state fermentation of Prosopis pod meal with *Bacillus subtilis* improves nutritional quality by enhancing essential nutrients and reducing antinutritional factors (Yusuf *et al*., 2008). The Prosopis pod crude protein can be increased 1.4-fold after 48 hours of fermentation with *B. subtilis*. Prosopis pod meal contains 40 to 52% soluble sugar (sucrose), and fermentation with *B. subtilis* increased the total soluble sugar of pod meal by 28.66% after 24 hours (Cardozo *et al*., 2010). The pod meal's crude fiber content is as high as 24.64%, which may be lowered to 17.37% after 48 hours by *B. subtilis* fermentation. Prosopis pod meal's antinutritional factors can be decreased or eliminated through fermentation. Phytic acid can be eliminated or reduced to undetectable levels through fermentation, while tannins of pod meal can be reduced by 16% after 96 hours of fermentation with *B. subtilis* (Sarasvati *et al*., 2014). Chovatiya *et al*. (2016) also found that fermentation of Prosopis pod meal with *Lactobacillus acidophilus* enhanced crude protein levels from 12.05 to 15.08% and eliminated phytic acid entirely.

Table 7: Selected studies on the use of Prosopis pod meal in livestock feed

| Sl. No. | Species | Replacement | Results | References |
|---|---|---|---|---|
| 1 | Chicken | Corn meal | Prosopis pod meal could be used in the chicken feed as an unconventional feedstuff. | Al-Harthi *et al*., 2018 |
| 2 | Chicken | Maize meal | Dietary Prosopis pod meal at 10% level improves growth and egg production. | Manhique *et al*., 2017 |
| 3 | Chicken | Crushed corn | Prosopis pod meal can be added at level of 5% in chicken feed without affecting growth performance. | Al-Marzooqi *et al*., 2015 |
| 4 | Chicken | Wheat short | In broilers feed ground Prosopis pod meal can be incorporated up to 20% of diet to reduce feed cost. | Girma *et al*., 2011 |
| 5 | Chicken | Maize meal | Prosopis pods meal at 20% levels could be incorporated in diets of chickens with no loss of growth and egg production. | Al-Beitawi *et al*., 2010 |
| 6 | Goat | Conventional feedstuffs | Feeding 200g Prosopis pods per day to individual goat improve weight gain without affecting feed intake and digestibility. | Koech *et al*., 2010 |
| 7 | Sheep and Goat | Conventional feedstuffs | *P. cineraria* and *P. juliflora* pod meal can be incorporated up to 15 and 20% in diets of sheep and goats, respectively, without affecting body weight gain and feed conversion ratio. | Mahgoub *et al*., 2004 |
| 8 | Lamb | Wheat bran | The inclusion of less than 30% Prosopis pod meal in diet did not affect growth performance. | Ravikala *et al*., 1993 |
| 9 | Pig finisher | Maize and soybean meal | The pod meal can be included in finisher pigs diet up to 30% level. | Pinheira *et al*., 1993 |
| 10 | Rabbit | Conventional feedstuffs | Nutrient intake and digestibility do not affect by the inclusion of Prosopis pod meal up to 30% of diet. | Silva *et al*., 1990 |
| 11 | Sheep | Cassava | The 100% cassava leaf meal can replace by Prosopis pod meal without effecting feed intake and nutrient digestibility. | Barros *et al*., 1986 |
| 12 | Laying hen | Wheat bran | The wheat bran can completely replace by Prosopis pod meal without affecting feed intake, FCR and egg production. | Silva, 1986 |

## Conclusion

Aquaculture is gaining popularity due to its rapid growth rate among the animal-based protein sector. Nowadays, feed manufacturers are employing a higher proportion of conventional feed ingredients in aquafeed, raising the feed cost. To lower feed costs, shifting from conventional ingredients to readily available and low-cost unconventional ingredients is necessary. Prosopis pod meal can be used as an alternative ingredient in aquafeed. Prosopis pod meal has an excellent nutritional profile and can be used instead of regular ingredients such as corn meal, wheat flour, rice bran, *etc*. It also contains some antinutritional factors as other plant-based ingredients, although these can be reduced or removed through various processing methods. Fermentation improves the nutritional profile and antinutritional factor of the Prosopis pod meal. Hence, Prosopis pod meal can be incorporated into aquafeed as an alternate feed ingredient to reduce feed costs and reliance on conventional ingredients.

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