Algae in Animal Production

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Summary

- In the context of threats to fragile environments, there is a need in animal production to identify alternative feed resources, which are environmentally friendly, but at the same time utilize natural resources efficiently. Algae are autotrophic organisms, which have potentia as food and feed for man and animals. They are rich in protein (50-60%), lipids (2-22%), vitamins and minerals. Amino acid composition of algae is comparable to that of egg protein. In the Bangladesh Livestock Research Institute (BLRI), a method has been developed for culturing algae in a batch operating system, using locally available ingredients. With a mixed algal culture (Chlorella and Scenedesmus), grown in shallow polytene basins, daily yield of algal suspension was 95 tones or 247 kg dry substances per hectare. The estimated cost is about $ 1.25 per ton of algal suspension. The possibility of using this protein rich unicellular algae (Chlorella and Scenedesmus) as cattle feed has been studied. Heifers of indigenous breed consumed algal suspension @ 10% of their liveweight. In comparison to oilcake (0.5 kg/d), algal suspension supplemented to a basal straw diet increased fibre digestibilities (76 v. 81%), growth rate (399 v. 458 g/d) and feed conversion efficiency (10.3 v. 8.6 g DOMI/g LWt. gain). Algal suspension also increased the in sacco 48 h DM degradability (49 v. 53%) and rate of degradation (3.8 v. 4.18%) of rice straw. In another trial with bull calves fed urea-molassesed-straw, supplementation with algal suspension in comparison with pure drinking water improved ($p > 0.05$) the total microbial N yield (21.67 vs. 18.18 g/d), the efficiency of microbial N production (13.4 vs. 10.7 g/kg DOMR) and reduced the live weight loss (-3 vs. -10 kg in 60 d). It appears that as a supplement to a straw diet, algal suspension somehow created a more favorable environment in the rumen for efficient microbial growth and thus increased nutrients availability to the host.

Introduction

The philosophy of research activities in developing countries has been moving towards the attainment of sustainable rural development. This change in attitude arises from the threat to fragile environments due to population pressure and faulty official policies of Governments. Utilization of land for the production of food staples is and will continue to have the highest priority in areas with high population pressure. In this situation, for sustainable growth in animal production, new approaches are needed to identify alternative feed resources which are environmentally friendly and efficiently utilize natural resources (e.g., solar energy, land and water) at a minimum cost.

Traditionally, efforts have been directed to increase ruminant productivity by improving the quality and quantity of fibrous crop residues and also by-products of grain processing (Preston and Murgueitio, 1993). The idea of feeding algae for animal production is unique in the sense that they can uses nature's gifts of abundant solar energy and a high ambient temperature for their growth. Besides their use appears to be sustainable economically, ecologically, sociologically and etiologically.

Algae are autotrophic organisms with a high growth potential. For a long time they have been regarded as an important source of nutrients for humans, fish and animals (Halama, 1990; Phang, 1992). Cultivation conditions of algae are different from those required by most other microorganisms. They assimilate CO_2 and emit O_2 during photosynthesis in the presence of light. Light captured by the pigments in the thylakoid membranes of the chloroplast is converted into chemical energy through photosynthesis and electron transport chains. This chemical energy (NADPH and ATP) is then utilized in the photosynthetic carbon reduction cycle to convert CO_2 to carbohydrate. In the synthesis of glucose from CO_2, with the evolution of 6 molecules of O_2, 48 light quanta must be used (Stryer, 1989). During the process of synthesis of 1 g of algae on wastes, 1.6 g of O_2 is being produced (Phang, 1992).

Among the different algae species, *Chlorella* and *Scenedesmus* are the most widely studied and their biology is well understood. *Chlorella* is very resistant to changes in environmental conditions as well as against attacks by other organisms. Because of these properties they are distributed very widely in almost all areas of the World where conditions are such as to permit growth of green plants (Khatun et al. 1994).

Nutritional characteristics of algae

Of the different unconventional feed sources, algae appear to have the highest potential as an alternative to fish meal (Phang, 1992). Table 1 gives the gross chemical composition of some algae species.

Besides the high levels of protein (50-70%), lipids (2-22%) and carbohydrates (8-26%) they also contain appreciable amounts of valuable vitamins and minerals (Table 2).

The protein of *Chlorella vulgaris* contains most of the essential amino acids (Table 3). Besides, in suspension, living algae liberate simple sugars, alcohols, polysaccharide, glycolic acids, phenolic substances, hydrocarbon and aromatic compounds of unknown nutritional and ecological importance (Halama, 1990). The biological value of algal protein is lower than that of casein.

Table 1. *Chemical composition (% of dry matter) of selected algae (Phang, 1992)*

Algae	Protein	Lipids	Carbo-hydrates	Minerals
Chlorella vulgaris	51-58	14-22	12-17	5-10
Chlorella pyrenoidsa	57	2	26	5-10
Scenedesmus obliqus	50-56	12-14	10-17	-
Scenedesmus quadricauda	47	2	-	-
Spirulina Platensis	46-50	4-9	8-14	-
Spirulina maxima	60-71	6-7	13-16	-

Table 2. *Some important minerals and vitamins in Chlorella (Milner, 1953)*

Chemical Composition	Content in DM ($g.kg^{-1}$)
Calcium	1.7 to 2.0
Phosphorus	15.0 to 21
Iron	1.7 to 2.0
Vitamin A	0.44 to 0.65
Vitamin B_1	0.001 to 0.018
Vitamin B_2	0.03 to 0.05
Vitamin C	0.20 to 0.35

Table 3. *Amino acids content (g amino acids per 100 g of protein) of Chlorella vulgaris and hens' egg (Khatun et al. 1994)*

Amino acids	*Chlorella vulgaris*	Hen egg
Alanine	7.8	-
Arginine	7.9	5.7
Cystine	0.27	10.5
Aspartic acid	9.70	2.3
Glutamic acid	13.1	12.6
Isoleucine	5.1	3.0
Leucine	2.0	8.8
Lysine	5.2	7.0
Methionine	9.1	9.2
Phenylalanine	8.4	7.4
Proline	2.4	3.0
Serine	5.2	5.1
Threonine	6.0	5.0
Tryptophane	4.0	8.4
Tyrosine	3.9	4.1
Valine	2.4	1.1
Glycine	5.8	4.2
Histidine	7.8	2.4

In a mixture of *Chlorella* and *Scenedesmus* (1:10), the digestibility of N in ruminants and pigs were found to be 73% and 54%, respectively (Halama, 1990).

Algae production

The productivity of algae depends on four major factors, e.g. nutrition, light, temperature and pH.

Nutrients: Nutrients required by algae may be classified as macro-nutrients which include carbon, nitrogen, hydrogen and phosphorus as well as calcium, magnesium, sulphur and potassium. The

source for the carbon for most photosynthetic algae is CO_2. In water CO_2 exists as H_2CO_3, HCO_3^- or CO_{3-}, depending on pH. Some algae may also use urea or amino acids. Oxygen comes from the air as well as from algal photosynthesis. Micronutrients include many of the minerals, vitamins and growth regulators. In addition to the elements needed by higher plants,

algae require vanadium, silicon, iodine and sodium for their growth. Unlike higher plants, many algae require external sources of vitamin B_{12}, thiamine and biotin. These vitamins are usually available in natural waters as products of metabolic activities of bacteria, but they may be depleted when phytoplanktons bloom (Phang, 1992).

Light: Generally light is not a limiting factor and many algae can grow in subdued light. However, intense light causes `photooxidative death' of algae. In general, the light conversion efficiency of algae is between 6 to 8% (Phang, 1992).

Temperature and pH : Algae can grow in a wide range of temperatures from 5 to 42°C with an optimum between 20 to 30°C (Khatun et al., 1994). Algal growth is inhibited at pH 11. However, *Chlorella* spp. can tolerate pH below 4. The optimum pH for algal growth is between 6.8 to 7.0.

Although algae grow naturally without any nutrient supply, the adequate supply of appropriate nutrients ensures `algae bloom' which is necessary for feeding algal suspension to ruminants at the desired concentrations.

Bangladesh Council for Scientific and Industrial Research (BCSIR) tried various chemical culture media for growing algae artificially (Khatun and Rahman, 1987). However, expensive harvesting techniques to separate cells from the chemical media made them unsuitable to be used by the farmer (Khatun et al., 1994). They then tried to culture algae in edible media so that the all may be fed directly to animals. They used pulse bran, pea shells, spinach stalks and cowpea and recommended the pulse brans for growing algae (Khatun and Kamal, 1993). This edible media, inexpensively available at farmers' level, supported a very good growth rate of algae (*Chlorella*/*Scenedesmus*) in batch operation systems.

Methodology of mass cultivation

A joint research program of Bangladesh Livestock Research Institute (BLRI) and BCSIR developed the following algae mass cultivation procedure. Artificial rectangular sinks were built with plastic sheets 3.5 m long, 1.8 m wide and 10-20 cm deep. The boundaries of the pond were brick made. The pond was filled with 200 liter fresh clean tap water, 20 liter inoculum and 1 liter of soaked pulse (*Vigna mungo*) bran extract. The pulse bran extract was prepared by overnight soaking of 100 g of pulse bran in 1 liter of water, followed by the straining through two layers of cheese cloths. Addition of 2 to 3 g of ammonium phosphate or urea was found to increase algal growth.

It is important to stir algal culture at least twice daily to prevent precipitation of algal cells and for even distribution of nutrients in the pond. Direct exposure to sun generally causes cell death, which is probably due to supersaturation of O_2 resulting from active photosynthesis (Phang, 1992). The pond should, therefore, be built in a shaded area but obviously not in absolute darkness. Excess supply of nutrients, especially the pulse bran extract, usually turns the algal culture into brown from its usual brilliant green color. For maintaining the volume of algal suspension , varying amounts of water need to be added depending on the evaporation rate.

After removing suspension for feeding, algal cultures may be reestablished just by adding the necessary water and nutrients, as enough algal cells are left in the pond to restart. Mixed algal culture grown in a shallow polytene sink yielded approximately 95 tons algal suspension (Packed Cell Volume, 5-10 ml/l) or 247 kg dry substances per hectare per day in our experiment at a cost of about $ 1.25 per ton of suspension.

Feeding algae

In BLRI, the possibility of using algae as protein for cattle has been studied (Chowdhury et al., 1994). In a 120 days' feeding trial with 8 heifers (mean initial body weight 146±9.3 kg), animals were given ad libitum urea-molassesed-straw with 2 kg wheat bran. On this basal diet one group of four animals received 0.5 kg/d sesame oilcake while another group received algal suspension ad libitum. Diets for the two groups of animals are shown in Table 4.

Unlike the other group, the algae fed animals were not given any drinking water, instead the algal suspension was supplied to drink ad libitum. There was no difficulty in introducing the suspension to the animals. Intake steadily increased from approximately 9 liters in the beginning to over 20 liters/d during the 8th fortnight. The relationship between the liveweight (X, kg) and the algal suspension intake (Y, liters/d) was found to be $Y = 0.222(\pm 0.26X) - 24.4$ ($r^2 = 0.927$; $p < 0.01$).

Table 4. *Composition of the experimental diet (Chowdhury et al. 1994)*

Ingredients	Diets	
	Oilcake	Algae
A. Urea-molassesed-straw (UMS)		
Composition of UMS ($g.kg^{-1}DM$)		
Straw	820	820
Molasses	150	150
Urea	30	30
B. Wheat bran ($kg.d^{-1}$/head)	2.0	2.0
C. Sesame oilcake ($kg.d^{-1}$ /head)	0.5	-
D. Algal suspension ($l.d^{-1}$)	-	ad libitum

The responses to the two diets are shown in Table 5. Despite a higher DM, total ME and digestible crude protein ($p < 0.01$) intake by the oilcake fed animals, growth rates and feed conversion efficiencies (g DOMI per g LW gain) were found higher in the algae fed animals.

There was no effect of the algae diet on the whole gut apparent digestibilities of DM and OM. However, crude protein digestibility was lower ($p < 0.01$) and crude fibre digestibility was higher ($p < 0.01$) in algae fed animals (Table 6).

Table 5. *Liveweights, daily gains, intake and feed conversion efficiencies of animals given urea-molassesed-straw either with oilcake or algae for 120 days (Chowdhury et al. 1994)*

Treatment	Oilcake	Algae	SED (with 6 df)	Significance
Initial Live Wt. (kg)[#]	149.9	139.8	6.61	NS
Final Live Wt. (kg)[#]	197.2	197.5	8.27	NS
Growth rate (g/d)[#]	399	458	31.15	NS
DM intake ($kg.d^{-1}$) :				
Urea-molassesed-straw	4.73	4.66	0.73	NS
Wheat bran	1.57	1.57	-	-
Sesame oilcake	0.44	-	-	-
Algae cell	-	0.03	-	-
Total ME intake ($MJ.d^{-1}$)	64.17	61.60	1.238	NS
ME intake ($MJ.kg^{-1}W^{0.75}.d^{-1}$)	1.38	1.36	0.41	NS
Digestible CP intake ($g.kg^{-1}W^{0.75}.d^{-1}$)	14	10	0.325	$p < 0.01$
Feed conversion efficiency (g DOM intake per g LW gain)	10.3	8.6	-	-

#Calculated from individual regression of live weight vs. time.

Table 6. *Digestibilities (%) of dietary nutrients (Chowdhury et al., 1994)*

Treatments	Oilcake	Algae	SED (with 6 df)	Significance
Dry matter	68.5	69.6	0.841	NS
Organic matter	70.7	71.7	0.779	NS
Crude protein	76.1	70.7	0.694	$p < 0.01$
Crude fibre	76.2	81.1	1.286	$p < 0.01$

NS = Not significant

This is probably due to the enhanced cellulolytic activities in algae fed animals. Thus, in a subsequent trial, the effects of supplementing algal suspension or oilcake to a straw diet on the rumen cellulolytic activity have been studied (Huque et al., 1994).

Three rumen cannulated bulls (average body weight 353±3.0 kg) were fed three different diets in a 3x3 latin square design (see Table 7). The three diets were: a control diet with ad libitum urea-molassesed-straw and 4 kg wheat bran (SWB) and the experimental diets were SWB supplemented either with 1 kg sesame oilcake (SOC) or with ad libitum algal suspension (SAS).

Table 7. *Composition of the experimental diet (Huque et al., 1994)*

	Diets		
	SWB	SOC	SAS
A. Urea-molassesed-straw (UMS)	ad libitum	ad libitum	ad libitum
UMS composition ($g.kg^{-1}$.DM)			
• • Straw	820	820	820
• • Molasses	150	150	1501
• • Urea	30	30	30
B. Wheat bran	4.0	4.0	4.0
C. Sesame oilcake	-	1.0	-
D. Algal suspension	-	-	ad libitum

In each period, 2 to 3 g straw were incubated for 0, 8, 16, 24, 48, and 72 hours in the rumen to determine the DM degradabilities according to the method suggested by Ørskov et al.(1980). Besides intake, digestibility, pH and ammonia N concentration (at different hours of feeding) were also measured.

Intake and digestibilities of dietary nutrients are shown in Table 8.

Table 8. *Intake (DMI) and digestibilities (%) of dry matter (DMD), organic matter (DOM), crude protein (DCP) and acid detergent fibre (DADF) (Huque et al., 1994)*

	Diets			Significance	
	SWB	SOC	SAS	SED	Level
Total DMI(g/kgW$^{0.75}$/d^{-1})	116	125	116	6.51	NS
UMSDMI(g/kg^{-1}W$^{0.75}$/d^{-1})	74	72	73	3.02	NS
DMD	67	70	69	2.56	NS
DOM	70	73	72	1.49	NS
DCP	70	69	69	3.73	NS
DADF	66	68	69	1.87	NS

Supplementation of the SWB diet with oilcake or with algal suspension had no effect either on total or straw DM intake. Similarly, digestibilities of DM, OM and CP were also not affected by the oilcake or algal suspension. However, ADF digestibility improved moderately due to algal supplementation which supports the previous observation of higher fibre digestibility (table 6). Algal supplementation also increased the degradation rate and the 48 h DM degradability (Table 9). This increase in straw digestion in sacco or fibre digestion in the whole gut were probably due to the availability of degradable cell wall materials in the rumen which was observed in a separate trial where in sacco degradability of dried algae at 48 h was found to be 85 to 90% (Huque et al., 1994).

Table 9. *Rumen cellulolytic activities as indicated by degradation characteristics in response to three experimental diets (Huque et al., 1994)*

	Diets			Significance	
	SWB	SOC	SAS	SED	Level
48 h DM Digestibilities (%)	51	49	53	4.95	NS
Degradation rate constant c (%)	3.79	3.80	4.18	0.31	NS
Potential degradable fraction `B' (%)	59	62	55	12.6	NS
Extent of degradation `A + B' (%)	66	64	62	6.34	NS

Algae supplementation also tended to increase rumen NH_3N concentration (Huque et al., 1994) and this might also have contributed to improve rumen cellulolytic activities. However, the response observed in the algae fed heifers (Table 5) can not be explained by a small increase in the cellulolytic activity alone. Some other factor(s) might have been responsible, of which microbial protein production could be one.

In the next trial, 6 bull calves (approximately 1.5 years old and 180±13.9 liveweight) were fed urea-molassesed-straw for 60 d. Three of them were given ad libitum algal suspension and the other three clean water. Daily food intake, weekly liveweight change, digestibility of feed nutrients and microbial N yield (estimated from the urinary purine excretion, after Chen and Gomes, 1992) were measured. Since, there were only 3 animals on each treatment, data of the individual animal's response along with their group averages are presented in Table 10.

Table 10. *Performance of calves fed urea-molassesed-straw (UMS) along with ad libitum algae water or plane water*

Parameters	Animals in the Algae Group			Mean	Animals in the Water Group			Mean	SED (4 df)	Significance
	219	220	215		209	225	218			
Initial Wt. (kg)	189.5	154.0	189.0	177	180.0	190.0	176.5	182.2	12.42	NS
Wt. After 60 d (kg)	185.5	151.0	187.0	174.5	164.5	179.0	173.0	172.2	12.49	NS
Wt.Change in 60 d (kg)	-4	-3	-2	-3	-15.5	-11	-3.5	-10	3.55	NS
Dig. OMI (kg/d)	2.33	2.51	2.71	2.51	2.77	3.02	2.28	2.69	0.24	NS
Dig. ADFI (kg/d)	1.37	1.56	1.58	1.50	1.50	1.76	1.05	1.44	0.218	NS
Dig. NI (g/d)	53	57	54	54.7	60	61	50	57.3	3.71	NS
Microbial N (g/d)	23.4	22.0	20.0	21.8	16.2	17.2	21.2	18.2	1.81	p<0.05
Microbial N g/kg DOMR[a]	15.2	13.5	11.4	13.4	9.0	8.7	14.3	10.7	2.13	p<0.05

[a] Digestible organic matter intake x 0.65 (ARC 1984).

There were no differences ($p > 0.05$) in the daily intake of straw DM (4.9 vs. 4.8 kg), digestible OM (2.5 vs. 2.7 kg), digestible N (54.7 vs. 57.3 g) and digestible ADF (1.5 vs. 1.4 kg) between the animals fed algal suspension or clean water. The total microbial N yield (21.67 vs. 18.18 g/d) and the efficiency of microbial N production (13.4 vs. 10.7 g/kg DOMR) were higher ($p > 0.05$) in the

algal suspension fed animals. Thus, lower liveweight losses by the algae fed animals (-3±1kg) compared to that of the water fed animals (-10±6kg) during the experimental period, were probably due to the increased supply of microbial N to the former. However, how algal suspension has improved the efficiency of microbial N production is yet to be understood. Judged by visual appearance (shining coat) the condition of the algae feed group was much better.

Practical implication

Although the mechanism has not yet been understood properly, an algal suspension somehow improves the balance of nutrients, when supplemented to a straw based diet by increasing the efficiency of conversion of feed to products. Straw comprises a major part of the ruminant diets (over 70% in Bangladesh) in many parts of the world. It is typically deficient in readily fermentable energy, protein, macro-, and micro-minerals and vitamins, which need to be corrected by appropriate supplementation. But these supplements, particularly protein are relatively expensive for poor farmers and may not be available under many circumstances. Introducing algal suspension in the feeding system may help in correcting some of the nutritional imbalances imposed by straw at an affordable price. For example, during the 120 d growth trial mentioned earlier (Table 5), the cost effectiveness of feeding two groups of animals are shown in Table 11.

Table 11. *Economic analysis of two diets when animals were given urea-molassesed-straw and wheat bran either with sesame oilcake or with algae for 120 days (assuming $ 1 = Tk. 40; adopted from Chowdhury et al., 1994)*

	Oilcake group	Algae group
Daily feed cost per animal	0.54	0.45
Feed cost in 120 days per animal	64.86	54.30
Price of Wt. gain in 120 d @ $ 1.25 per kg.	59.85	68.70
Net gain	-5.01	14.40

The feed costs were $ 64.9 and $ 54.3, respectively for the oilcake and the algae fed animals. Assuming the price of each kg gain to be $ 1.25, the oilcake group encountered a loss of $ 5.0, while the algal group earned $ 14.4 per animal.

Besides, algae is a very rich source of carotene and many other vitamins and minerals (tables 2 and 3). A supplement of algae can therefore help to prevent infertility, night - or total blindness and many other deficiency diseases.

With the increasing demand for food grain production, it is becoming more difficult to spare land for fodder production in the developing countries. However, growing algae, which can be produced in the homesteads throughout the year without using crop land, may be a help to a certain extent in this situation.

However, to understand how algal suspension improves the feed utilization and microbial N yield deserves further investigation.

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