THE NUTRITIVE VALUE OF SEAWEED MEAL FOR DOMESTIC ANIMALS[1]

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INTRODUCTION

The macroscopic, marine, and mainly benthic algae, which we denominated seaweeds, have been utilized more or less systematically by coastal dwellers for feeding purposes all over the world far back into history. Strangely enough, historical records on this use of seaweed in the Far East are very scarce. In the Mediterranean area the Romans made some use of seaweed for feeding horses. Along the coasts of France, Scotland, Iceland, and Norway seaweed formed a valuable supplement to the rations for sheep, cows, and pigs through centuries, and the animals were encouraged to stay browsing on the shore during both summer and winter. Regular feeding with seaweed was practised in Iceland, France, and Norway.

More recently, seaweeds were resorted to mainly in times of scarcity and feed shortage, for instance the critical spring period. However, in northern Norway, seaweeds, especially *Alaria esculenta*, were boiled together with fish heads and thrash fish to a soup which was regularly used as feed, especially for cows. This feed was said to help animals give much milk and stay healthy.

As the agricultural practices and techniques improved and modern feeding methods gained ground, the seaweeds were forced out. Today the only significant utilization of seaweeds in animal husbandry is the use of seaweed meal as a feed additive. For this purpose some 50,000 tons of meal are produced annually in Canada, France, Great Britain, Ireland, Norway, South Africa, and the United States. In the present treatise we shall look at the background for this use, and we shall try to establish the justification, if any, for the present and future role of seaweeds in animal husbandry.

Any critical evaluation of the worth of seaweeds for feeding purposes will have to be based on the chemical composition of the material. Although small quantities of *Fucus* meals and dried and milled *Macrocystis pyrifera* are on the market, today seaweed meal, for all practical purposes, means meal of *Ascophyllum nodosum*. We shall, therefore, regard seaweed meal as being processed from *Ascophyllum nodosum*, solely. This alga is a dominating plant of the intertidal zone of the North Atlantic coast of Canada and Europe, which possess large seaweed resources. It is easily harvested, and it is, as we shall see, better suited for feeding

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purposes than the more abundant *Laminariaceae*. These are some of the reasons for the special importance of *Ascophyllum nodosum* as a raw material for the seaweed meal industry.

Because of its special importance for feeding purposes, *Ascophyllum nodosum* has been investigated quite thoroughly for its chemical content. (Table 1) In the dried condition, i.e., with a moisture content of 12-15%, the plant is, as a typical brown alga, characterized by a high content of minerals, some 17-20% is normal, and the mineral is rich in sodium, potassium, zinc, iodine, and sulphur and contains a large number of trace metals. The content of chlorides is also high. The carbohydrate fraction of *Ascophyllum nodosum* is dominated by alginic acid, followed by fucoidan, cellulose, mannitol, and laminaran, giving the material a total content of N-free extracts of some 45-60%. The protein content is low, some 5-10%, as is the caloric value, which falls in between good hay and barley for ruminants and considerably lower for non-ruminants.

Table 1

Average composition of Norwegian seaweed meal (*Ascophyllum nodosum*)

Component	Content	Component	Content
Moisture	12 - 15%	Crude Fiber	<8%
Ash	17 - 20%	Crude protein	5-10%
Alginic acid	20 - 26%	Ether extract	2-4%
Mannitol	5 - 8%	Fucoidin	≈10%
Laminaran	2 - 8%	N-free extractives	45-60%
S	2.5 - 3.5%	Caloric value	0.56 SFU/kg*
K	2 - 3%	Ascorbic acid	500 -2000 mg/kg
Cl	3.1 - 4.4%	Carotene	30 - 60 mg/kg
Na	3 - 4%	Biotin	0.1 - 0.4 mg/kg
Mg	0.5 - 0.9%	Folic acid	0.1 - 0.5 mg/kg
Ca	1 - 3%	Folinic acid	0.1 - 0.5 mg/kg
P	0.1 - 0.15%	Niacin	10 - 30 mg/kg
B	40 - 100mg/kg	Riboflavin	5 - 10 mg/kg
Co	1 - 10mg/kg	Thiamin	1 - 5 mg/kg
Cu	1 - 10mg/kg	Tocopherols	150 - 300 mg/kg
Fe	150-1000mg/kg	Vit. B_{12}	0.004 mg/kg
Mn	10 - 50mg/kg	Vit. K	10 mg/kg
I	700-1200mg/kg	V	1.5 - 3 mg/kg
Zn	50 - 200mg/kg	Ni	2 - 5 mg/kg
Mo	0.3- 1mg/kg	Ba	15 - 50 mg/kg

* SFU - Scandinavian feed units

The quantitatively more important vitamins contained in *Ascophyllum nodosum* are: ß-carotene (provitamin A), the tocopherols (vitamin E), niacin, and thiamin (belonging to the vitamin B group). The ascorbic acid content is high, and a number of other vitamins are present.

Contrary to the Laminariaceae, the Fucaceae show moderate seasonal variations in their chemical composition, and *Ascophyllum nodosum* is characterized by a rather constant composition throughout the year. Variations are found in ascorbic acid and some of the B-vitamins.

Very important questions to consider are whether the valuable components of the seaweed are preserved during drying and processing to the final product, and how the seaweed meal behaves during storage. The largest part of the seaweed meal produced today is processed in modern factories, which make use of rotary drum driers. These driers are successfully applied to the dehydration of many feed stuffs, such as fish, grass, and expeller cakes, and have been found to preserve most of the valuable components in a satisfactory way. The optimal conditions for seaweed meal drying have been worked out, and numerous analyses carried out in our laboratory have demonstrated that only small losses of vitamins occur during processing. We have also carried out comprehensive storage experiments with seaweed meal and shown that ß-carotene and tocopherols store considerably better in seaweed meal than they do in grass meal under identical conditions. We therefore feel quite confident that the valuable components of the alga can be well taken care of by modern processing methods.

The most important parameters for evaluation of the product are the moisture content (12-15% is optimal), the carotene content (>40-50 mg/kg meal), and the colour of the meal. A good seaweed meal should have a greenish colour and be free from any caramel-like odour.

The chemical data given in Table 1 make it quite clear that seaweed meal is a low-energy, low-protein feedstuff. It cannot compete with traditional fodder, such as hay, grain, and various fodder roots as a source of energy, because of the low cost of the conventional feed. Besides, the high contents of chlorides and of iodine set such low limits for its admixture to rations that the caloric value would be of minor importance. However, the caloric content make up for a considerable part of the cost of the meal, especially when it is fed to ruminants. The main value of seaweed meal must be seen in its content of minerals and vitamins and in its ability to give roughage to the rations. Because of its special composition, seaweed meal cannot be regarded as a complete source of minerals or vitamins. It has to be fortified and supplemented according to the requirements of the animals and the composition of the total ration.

FEEDING EXPERIMENTS

Having now established that seaweed meal contains fair amounts of several minerals and vitamins, feeding experiments are needed to demonstrate the availability of these components to the animals. A considerable number of such experiments has been carried out. However, little conclusive evidence is to be drawn from most of them, and the results reported in the literature are often contradictory. This is not surprising since the term "seaweed meal" has been used to cover a large variety of products. One can hardly expect harmonizing results from experiments based on *Ascophyllum nodosum, Fucus* species, *Laminara hyperborea*, and *Macrocystis pyrifera* collected at different times of the year, worked up in differing ways, and given at various levels of concentration to ruminants and non-ruminants in significantly differing rations. Many of the feeding trials have aimed at establishing the caloric value of seaweed meal. For this purpose very high concentrations of seaweed meal have to be given, and interfering substances like salts and tannins of the meal will influence the results markedly. These influences are probably negligible during practical feeding. It also seems impossible to determine the digestibility of the carbohydrate, fat, and protein of seaweed meal by feeding the whole meal to test animals, again because of interfering substances in the meal. A reliable determination of the biological value of the main components of seaweed meal would require isolation and testing of the purified component.

The feeding experiments which are relevant in the present context are those which have been carried out with modern seaweed meal of *Ascophyllum nodosum* in order to test its value as a source of vitamins and minerals. These experiments are few and include probably Burt, Bartlett, and Rowland's brief experiment with Ayrshire cows (3), Dunlop's trial with cows in West Scotland (5), the experiment carried out by Ørd and Homb with dairy cows (13), and our own work with twin cows in Norway (12). In addition to these experiments, we can also consider Cameron's test with bacon pigs (4), the studies referred to by Black (2), Homb's feeding experiments (8), and our own (9, 11), all with bacon pigs. In addition, our feeding trials with sheep (14, 15) and Høie's experiments with hens and chickens (6, 7) belong to this group of experiments. This literature should give the relevant information for evaluation of modern seaweed meal in animal nutrition.

Experiments with bacon pigs

The results of the relevant experiments with seaweed meal and bacon pigs are not in full agreement. While the results obtained by Cameron (4), British workers (2), and ourselves (9, 11), demonstrated that substitution of 3-5% of the ration by seaweed meal had no adverse effect on the rate of gain and food conversion ratio, Homb (8) found that this amount of seaweed meal caused a significant reduction in daily gain of the pigs. The latter author used relatively low concentrations of protein in the test ration, and it is likely that the negative effects obtained only reflected the well-known fact that dilution of a feed with a component low in calories and protein when not compensated for leads to relative reduction in weight gain. Especially the experiments of Jensen and Minsaas and Nebb and Jensen have clearly shown that moderate concentrations of seaweed meal (3-5%) in rations for pigs have no adverse effects on any of the parameters (9, 11). Two positive effects of the addition were observed, namely a reduction in back fat thickness and a remarkable drop in the number of livers that had to be discarded because of liver parasites. That seaweeds are effective against intestinal parasites, is, of course, a well-known fact in the Far East. In addition, seaweed meal could be substituted for expensive additives such as mineral and vitamin mixtures and thus increase the profit of the farmer.

Experiments with chickens and laying hens

Older experiments with seaweed meal made from *Ascophyllum nodosum* had mainly shown that the admixture of 2-5% to the rations for chickens and hens had no significant effect on health conditions, growth, production, and feed conversion. Except for a marked increase in iodine content, no effect on egg quality was observed.

The most comprehensive experiments with seaweed meal to chickens and hens were carried out by Høie and his collaborators at the Norwegian Agricultural College (6, 7). Several thousand chickens and hundreds of hens have been tested, and the main conclusions to be drawn from the experiments are the following:

- Moderate quantities of seaweed meal (2-5%) added to fully balanced rations had no effect, positive or negative.
- Adding 3-7% seaweed meal to rations deficient in vitamins A or B_2 or both resulted in a significant increase in growth and production for both chickens and hens.
- A marked increase in the content of iodine in the eggs was again established a result of feeding with seaweed meal (16).

- Addition of 2-5% seaweed meal to hens' rations gave an agreeable colour to the egg yolks (7, 10).

There were indications in the results of effects of the tocopherols and the minerals of the seaweed meal, although the experiments were not designed to reveal such effects.

Experiments with sheep

Despite the fact that sheep seem to be the animals most frequently reported to graze on seaweed, very few scientific experiments have been carried out to establish the value of these plants as feed for sheep. Therefore, we conducted a large-scale feeding trial with sheep on 67 Norwegian farms to establish what effects could be obtained by giving a small quantity of seaweed meal (35g per day per animal) under practical conditions (14). About 3,500 animals were involved, and the most significant result obtained was an increase in winter wool production, corresponding to 3.3% for all test ewes. In flocks which received neither herring meal, nor mineral supplements, the addition of seaweed meal resulted in an increase of 20% in wool production. The main effect of the seaweed meal was due to its ability to prevent moulting. The seaweed supplement also reduced significantly the loss of lambs caused by white muscle disease. An increase in cases of pulpy kidney was observed in the test group and was regarded as an overfeeding symptom, since it attacked single lambs of fat ewes that produced much milk. The ewes of the test group lost less weight during barn feeding, compared with the control animals, and the growth rate of lambs was positively influenced by the seaweed meal addition. The seaweed meal supplement was more effective after a dry than after a wet summer. (The quality of the hay is usually better in wet summers.)

This feeding trial was carried out in a typical inland district and based on the rations normally given by local farmers. The experimental conditions therefore varied considerably between the farms, a fact that reduces the scientific value of the experiment. However, as it was conducted in a practical way under typical farm conditions, the results obtained can safely be applied directly to a normal agricultural situation.

Experiments with dairy cows

Again, few experiments relevant to the actual situation have been carried out. Burt, Bartlett, and Rowland compared two seaweed meals, one which consisted of *Ascophyllum nodosum* with an oatmeal-salt mixture in a feeding experiment with 18 high-yielding Ayrshire cows (3). On an average, 600g of seaweed meal were given daily to each test animal. The experimental periods lasted for 3 weeks only, and no significant effect of the treatment on milk yield or fat content of the milk was observed.

In a more practical trial, Dunlop obtained considerable increase in butterfat production upon substituting approximately 200g of *Ascophyllum nodosum* meal daily for a similar quantity of the normal concentrate ration given to cows on a number of farms in West Scotland (5). Ørud and Homb carried out a small-scale experiment with dairy cows in Norway (13). The slight increase in milk output shown by the test group animals was not statistically significant.

Feeding experiments with dairy cows tend to become large and expensive when their aim is to demonstrate the significance of relatively small effects, which is in principle what will result from comparisons of rather similar rations. And similar rations are necessarily involved in studies concerned with the substitution of one type of additive for another. When we wanted to compare seaweed meal with more traditional supplements as a mineral source for dairy cows, our intention was to feed nearly identical rations to the test and the control animals. In order to reduce the number of animals required to give statistically significant results, we made use of monozygotic twin cows; thus the genetic differences between the animals were reduced as far as possible.

Seaweed meal is by no means a complete mineral supplement for dairy cattle, and it was fortified with 20% dicalcium phosphate, 1.2% magnesium oxide, and 0.06% copper sulphate. The fortified seaweed meal contained 50% minerals, and two parts of it were needed for every part of mineral mixture it replaced. The two supplements were compared in a practical feeding experiment carried out on two farms in central Norway (12). The experiment lasted for 7 years in all, involved 7 pairs of twin cows and covered 23 lactation periods in the test and control groups. The twins of each pair were fed identical rations, except for the mineral supplement. The test group, made up of 1 twin from each pair, received 200g each of fortified seaweed meal daily, while the control animals were given 100g each of a commercial mineral mixture per day. The main ration was composed of hay, dry concentrates, and small amounts of silage and potatoes during barn feeding. During grazing period, 0.5 kg of dry concentrate was given in addition to the mineral supplements.

During the 7 year period covered by the experiment, the animals in the seaweed group produced 78,172 kg of 4% fat corrected milk, compared to 73,175 kg obtained from the control group. The difference, 4,997 kg, corresponded to a total increase of 6.8%. The average milk production per lactation period was 3,399 kg per cow in the seaweed group and 3,182 kg in the control group. In 19 of the 23 lactation periods, the test animal produced more milk than its control twin did, the difference being significant at the 1% level. No systematic influence on the fat content of the milk was observed as a result of the seaweed meal feeding.

A marked increase in the iodine content of the milk was observed for the seaweed group. Milk from this group contained approximately 600 μg of iodine per liter, compared to ca. 100 μg per liter in the control milk.

There was no clear difference in reproductive performance between the 2 groups. However, a reduction in the number of services required per conception and an increase in "no returns" were indicated for the seaweed group. The supplement of seaweed meal had a considerable influence on the frequency of mastitis. Of a total of 10 cases, 9 occurred in the control group and only 1 among the seaweed animals.

General conclusions

One general conclusion that can be drawn from the feeding experiments is that the vitamins and minerals of seaweed meal seem to be available to domestic animals in the quantities indicated by the chemical composition of the material. Seaweed meal can therefore be regarded as an alternative source of these minerals and vitamins for chickens and pigs. It seems to be superior to normal mineral mixtures for milk production under inland conditions, and it can give agreeable colour to egg yolks when used to cover the requirement for minerals and vitamins of laying hens. It has shown good results in preventing wool shedding in sheep and has some effect against intestinal parasites in pigs. Whenever given, seaweed meal will result in a marked increase in the iodine content of eggs and milk.

DISCUSSION

Seaweed meal is obviously a good source of iodine in compound feeds and in rations for domestic animals generally. In the case of Laminariaceae, the high iodine content is seriously limiting their use, since admixture of a fraction of 1% will cover the iodine requirement, the result being that none of the other components of the meal will reach active concentrations. Meals of *Fucus* species and of *Ascophyllum nodosum* contain only one-tenth of the concentration of iodine found in most *Laminara* species and can safely be used in quantities up to 10% of the total rations.

The state of the iodine in seaweed meal has been investigated repeatedly, with little success. A small fraction is bound in amino acids, while the major part seems to occur in a form which cannot be differentiated from inorganic iodides. However, inorganic iodides are rapidly lost from mineral-rich feed additives, such as ordinary mineral mixtures, while the iodine in seaweed meal is stable for many years. This strongly indicates that the iodine is protected in some way in the seaweed meal. It is also likely that the heavy metal ions are bound in an organic matrix which will reduce their unwanted catalytic effect in the oxidation of certain vitamins and essential factors.

Concerning the importance of iodine in animal feed, it is a general trend, at least in Norther Europe today, that iodine deficiency is becoming more common with higher-yielding animals and as the yields of all crops are increased. An investigation carried out in 1963 in Great Britain by Alderman and Stranks showed that 15 out of 18 dairy herds at pasture were iodine deficient (1). Also in Scandinavia, signs of iodine deficiency have been observed in high-yielding herds. It seems unlikely that iodine is the only deficient factor in these and similar cases. A more reasonable attitude seems to be to regard iodine deficiency as a first sign of a more general deficiency caused by a lack of balance between input and output for high-yielding animals and crops. The results obtained in the feeding experiment with twin cows described above seem to support the idea that our best rations still are not complete, and it is to be expected that the effects of this type of deficiency will increase with increasing production per animal. In this situation, seaweed meal with its variety of minerals may have a fair chance of preventing or remedying the deficiency.

There is ample experimental data available to show that the supplementation of deficient rations with seaweed meal can considerably improve the feed in many cases.

Finally, there is a generally valid argument for the increased use of seaweed in both human households and for animals. For centuries rain and rivers have carried major and minor plant nutrients from the land into the ocean. All our efforts hitherto have been to increase the speed of this process. The minerals thus brought to the sea are accumulated by the algae and eaten by fish and other sea animals. We reclaim a small fraction through the fish and seafood which we consume. However, we would greatly increase the return of the valuable nutrients by systematically using the marine algae on a large scale. Feeding is one of the few possibilities we have in the western world for large-scale consumption of seaweeds, and it seems wise to make extensive use of this means of reversing the one-way flux from land to sea of valuable nutrients.

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