Can waste re-cycling increase the sustainability of animal feeds?

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An annual production of over one billion tonnes, and an economic turnover in excess of $US400 billion; this is the animal feed industry. The vast majority of animal feed is given to terrestrial farm animals; those reared for meat, and those used to produce eggs and dairy products. Fish feeds make up about 5% of the total volume of animal feeds and have a 10% share of market sales.

It is easy to see that far more feed is needed to produce 70 million tonnes of beef cattle, 115 million tonnes of pigs and almost 120 million tonnes of poultry, than to produce 55-60 million tonnes of farmed fish. Farm animal production is predicted to increase to about 105 million tonnes of beef cattle, 150 million tonnes of pigs, 200 million tonnes of poultry and 115 million tonnes of farmed fish by 2050, and the amount of feed needed to double from the one billion tonnes used to-day to two billion tonnes in 2050.

To-day's animal feed ingredients

Feed manufacturers choose ingredients based on the nutrients they contain, for the absence of anti-nutritional factors (ANFs), for their palatability and their cost. The essential nutrients required by farmed animals are amino acids contained in proteins, essential fatty acids contained in fats and oils, vitamins and minerals. In terms of nutrient suppliers, the main feed ingredients are protein sources, fats and oils, and energy sources as carbohydrates (Figure 1).

Pig and poultry feeds contain 18-20% protein, whereas the feeds given to Atlantic salmon (Salmo salar) during on-growing in seawater have about double this amount of protein. The protein in animal feeds comes from both plant and animal sources, such as oilseed meals, legumes, and wastes from slaughterhouses and fish processing (Table 1). Far greater amounts of plant, than animal, protein sources are used in animal feeds. The main plant protein sources are produced from oilseed by-products after the oil has been removed. These are usually dried meals, but the by-products can also be processed to protein concentrates. The main oilseed crops are soybean, rapeseed (canola), sunflower, palm kernel, copra, linseed, peanut and sesame seed. Soybean products dominate current use, followed by canola. Animal protein sources are produced from the wastes and by-products of slaughterhouses and fish processing plants. Over 50% of the weight of cattle and sheep, and 30% of poultry, is waste not used for human consumption. Similarly, the processing of fish results in wastes in the form of viscera, heads, frames and off-cuts. These by-products are rendered to remove water and fat, dried and ground, and are then used as ingredients in animal feeds. The main rendered animal by-product meals are meat meal, meat-and-bone meal, fish meal, poultry by-product meal, blood meal and feather meal.

Figure 1. Dry feed ingredients provide the protein and carbohydrates in animal feeds.
(Photo credit: Skretting, Norway)

Table 1. Chemical compositions of examples of protein and oil sources with potential use as ingredients in animal feeds

Chemical components (%)	Soybean meal	Fish meal	Black soldier fly meal
Protein	44	63	64
Lysine	2.8	4.6	3.2
Methionine	0.6	1.7	1.0
Fat/oil	1.5	9.5	3.5
Mineral ash	6.5	16.0	10.5
Fatty acids (% total fatty acids)	**Soya oil**	**Fish oil**	**Black soldier fly oil**
Saturates	15.5	24.0	70
C12:0	0	0	45
C16:0	11.5	14.5	13.5
C18:0	3.5	1.0	2.0
Monounsaturates	25.5	51.0	15.0
C18:1	25.0	10.0	12.0
Polyunsaturates	59.0	21.0	12.5
18:2 n-6	52.0	1.5	10.0
18:3 n-3	7.0	1.5	0.5
20:5 n-3	0	5.0	0
22:6 n-3	0	6.5	0

Fats and oils are added to animal feeds to provide essential fatty acids, to act as an energy source, and they are carriers of fat-soluble vitamins (A, D, E, and K). Several fats and oils are used in animal feeds, including some of terrestrial animal origin, such as tallow, lard and poultry by-product oil, some vegetable oils, such as soya oil, rapeseed oil, sunflower oil, linseed oil, palm oil and cottonseed oil, and marine fish oils (Table 1). The amount of fat or oil added to an animal feed depends upon the species and life-stage to which the feed will be fed. For example, pig and poultry feeds usually contain 5-10% fats and oils, whereas an extruded feed used for on-growing Atlantic salmon in seawater may have over 30% added oil in the form of a mix of rapeseed oil, marine fish oil, algal oils and poultry by-product oil (Figure 2).

Cereal grains and their by-products are important in animal feeds because of the binding properties of the starch they contain, and as a cheap source of energy. Maize (corn) is the most-used cereal grain in animal feeds, although other grains, such as wheat, barley and rye, are also used. The amounts of cereal grains added to animal feeds will vary according to species and life-stage for which the feed is intended. For example, pig and poultry feeds will usually have about half of the formulation as cereal grains that provide the main source of energy, whereas an extruded Atlantic salmon feed will usually contain 10-15% cereal grains that have pellet binding as their primary function.

It is estimated that about 500 million hectares of agricultural land are used for the production of crops to supply the animal feed industry, and there is increasing public concern about the way in which agricultural land is used. Should crops be grown for human consumption or to supply the animal feed industry? About one-third of the world's cereal grain production is fed to farm animals rather than being used directly for human consumption. This is a dubious practice. Oilseed meals and protein concentrates may also be consumed by humans, rather than being used to raise pigs, poultry, cattle and fish.

Substantial amounts of water are needed to produce the crop plants that are the main ingredients in animal feeds and water is a limited resource. Water use for cereal grain production is 1-2,000 m3 per tonne, and this increases to about 2,250 m3 per tonne for the production of oilseeds, such as soybeans and rapeseed. There are, therefore, questions relating to land and water use for the production of crop plants used as animal feed ingredients, along with the vexed question about the wisdom of feeding these crops to farm animals rather than humans.

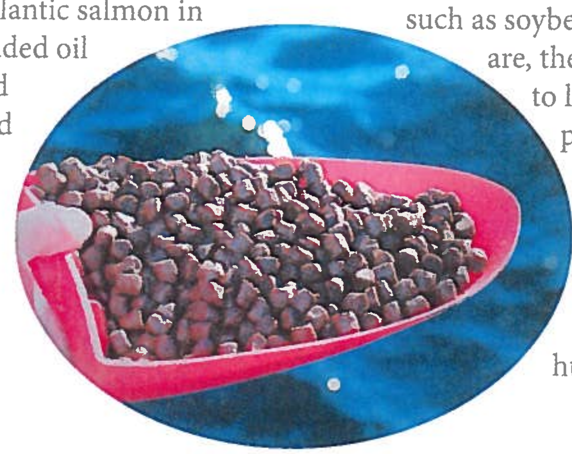


Figure 2. Extruded salmon feed used for on-growing fish in seawater.
(Photo credit: Skretting, Norway)

Looking to the future

Animal feed production is projected to increase from one billion tonnes to-day to about two billion tonnes in 2050. It seems unlikely that the increased demands for feed ingredients will be met via substantial increases in the use of cereal grains and plant by-products. There is, therefore, a pressing need to find alternative sources of nutrients that can supplement and replace these crop plant materials as feed ingredients.

The production of agricultural crops and farm animals gives large quantities of wastes that are neither eaten by humans nor used as ingredients in animal feeds. These wastes contain organic matter that is unsuitable as human food and animal feed because of low contents of bioavailable nutrients, and high concentrations of cellulose, hemicelluloses and fibre. Straw, green biomass in the form of leaves and stems, and animal manure are examples of organic wastes that result from crop and animal production. Most of these organic wastes are currently disposed of in land-fills, incinerated or composted, but increasing quantities are being converted into biogas, biodiesel and bioethanol. The latter represents a way to re-cycle the organic wastes using chemical and biological hydrolysis to give value-added products. It is also possible to convert these organic wastes into biomass that could be used as ingredients in animal feeds; heterotrophic micro-organisms, fungi, and insects.

Microbial biomass

Heterotrophic micro-organisms can grow effectively on the nutrients, such as glucose and fructose, inorganic and organic nitrogen sources and phosphate, present in organic wastes. Liquid waste streams, such as piggery waste and soybean processing wastewater, can be used directly as a nutrient source, but solid wastes, such as straw and green biomass, require liquefaction and hydrolysis for release of nutrients prior to use.

The liquefaction and hydrolysis of solid organic wastes using mechanical disintegration, chemical treatment with acids or bases, and addition of enzymes are cost factors to be considered in industrial-scale production of microbial biomass from organic wastes.

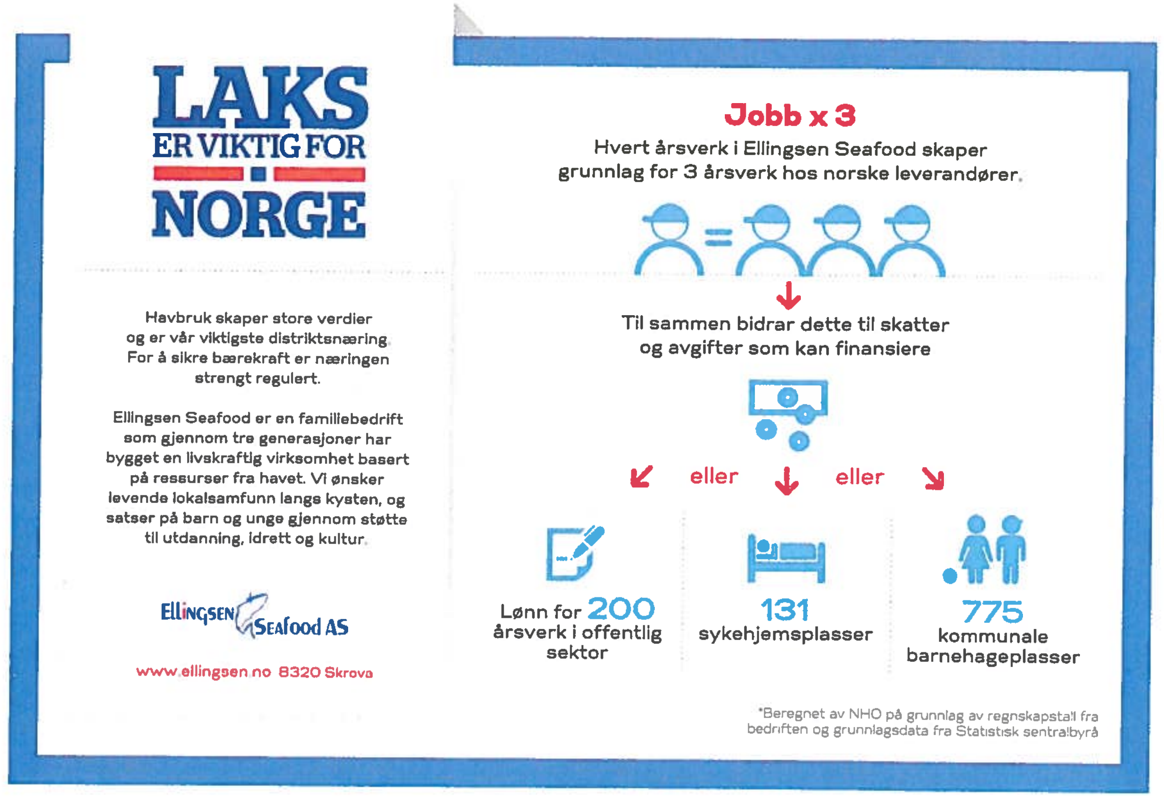
Cultivation of heterotrophic micro-organisms is carried out in stirred bioreactors under aerobic and sterile conditions. Aeration is energy-intensive, and in large bioreactors it can be challenging to ensure adequate distribution of both oxygen and nutrients, so stirring is essential. Cultivation also requires the temperature in the reactor to be maintained within a range that supports good growth of the microbes, and temperature-control may impose high energy demands and increased costs.

Microbial composition varies depending on species, the type of organic wastes used as culture media and the cultivation conditions. When grown under carbon-limitation, the carbohydrate and oil concentrations of the produced biomass decreases, but under nitrogen or phosphate limitation there is an increase in carbohydrate and oil concentrations and a reduction in protein. The dry biomass may contain over 30% protein, up to 40% carbohydrates and up to 50% oil. Species and cultivation conditions will also influence the fatty acid compositions of the oils; the oils are often rich in essential polyunsaturated fatty acids, and this makes them particularly valuable as a feed ingredient.

Fungal biomass

Filamentous fungi can grow on many organic-rich materials, and fungal fermentation has a long tradition in south-east Asia for production of foods, such as miso, tofu, and tempeh. Although filamentous fungi have a long history of use in food production, several species produce mycotoxins, such as aflatoxin and fusarin. It is important to avoid inclusion of mycotoxins in animal feeds because they can reduce growth, impair immune function and sometimes cause death of the animal. Care must, therefore, be exercised when choosing the fungi to culture as feed ingredients. Organic-rich waste streams from the dairy and wood-pulp and paper industries can be used as nutrient sources for fungi. By-products from the processing of agricultural crops, such as soybeans and other oilseeds, and rice, wheat and other cereals, can also be used as substrates. In addition to forming a biomass with potential for use in animal feeds, filamentous fungi can also produce a range of value-added products, such as enzymes, pigments, organic acids and other metabolites with industrial applications.
Species of filamentous fungi within the genera Rhizopus, Neurospora, Aspergillus and Mucor have received the most attention with regard to large-scale production and industrial application. The filamentous fungi are cultivated using either submerged or solid-state fermentation, followed by harvesting that includes separation from the rearing medium and de-watering. Filamentous fungi have a high water content, and drying is necessary to reduce water to under 8% for prevention of deterioration and to extend the shelf-life of the final product.

The dry biomass contains 40-60% protein, depending upon species and cultivation conditions, but is generally 40-50%. The balance of essential amino acids is often variable, with deficiencies in methionine, lysine and tryptophan sometimes being reported. This means that if fungal biomass is used as a major source of protein in animal feeds amino acid supplementation will sometimes be needed. In addition to protein, dry fungal biomass contains 20-25% oil. The fatty acids are dominated by C16-18 saturates, monounsaturates and polyunsaturates of the n-6 series, with little or no fatty acids of the n-3 series. This limits the value of the oil as an ingredient in animal feeds.



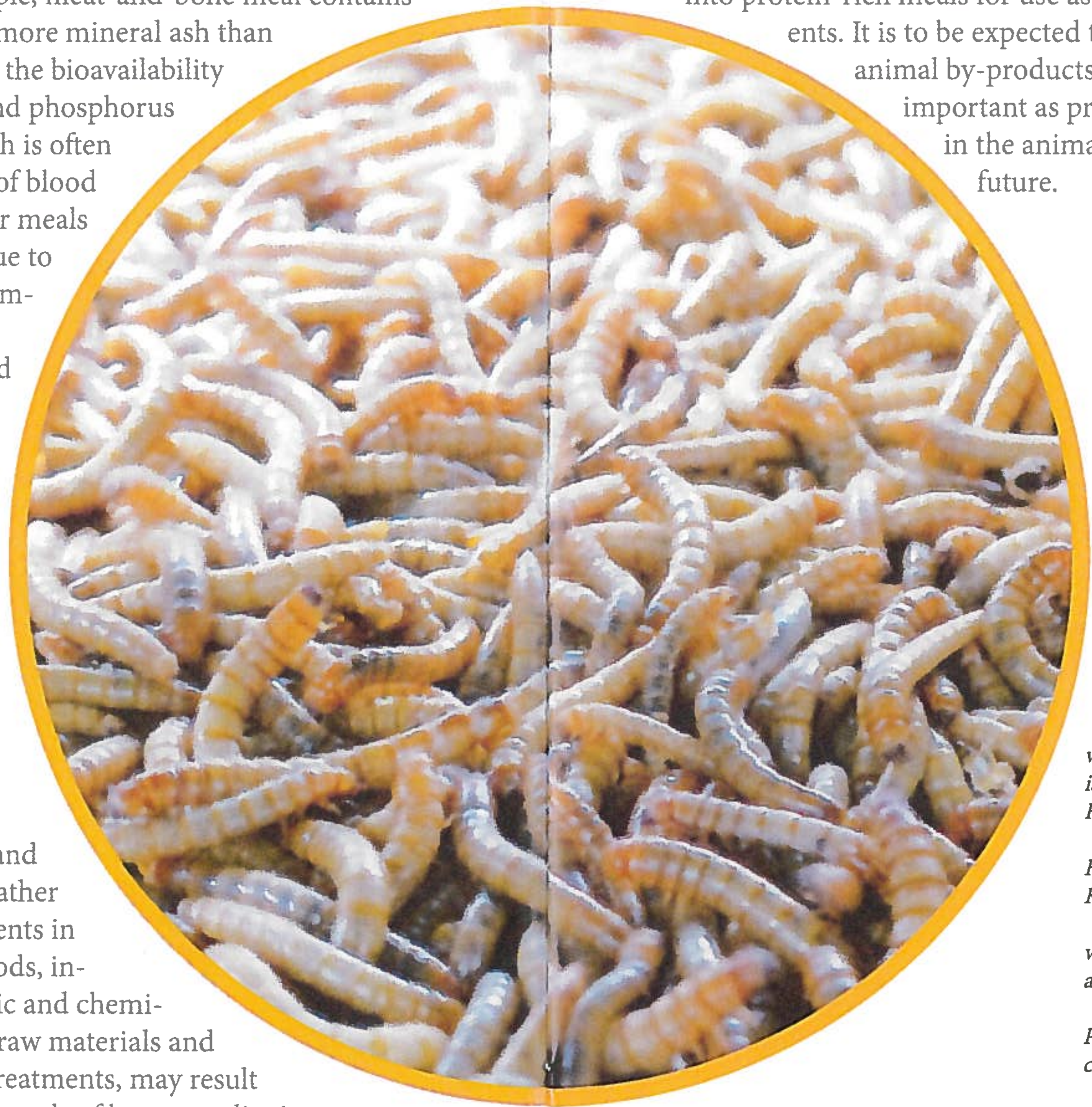
Insects

The processing of agricultural crops results in the production of large quantities of organic waste, and one way to re-cycle the nutrients it contains is to use the waste to grow insects. Several insects have been grown on wastes and tested in fish feeds, including mealworms (Tenebrio molitor) (Figure 3), house-fly maggots (Musca domesticus) and black soldier fly larvae (Hermetia illucens). Of these, the most promising is probably the black soldier fly. It is neither a pest nor a disease vector and its larvae are saprophagous and omnivorous, robust and easy to cultivate. The fly larvae are able to extract nutrients from the complex biomolecules, such as cellulose, hemicelluloses and lignin, present in crop wastes without any need for hydrolytic pretreatment using acid or enzymes. This saves on waste processing costs, so is advantageous in comparison with other re-cycling methods. The black soldier fly is a native of the Neotropics, and the larvae need temperatures of 25-35oC for rapid growth and production.

The larvae contain 40-45% protein on a dry matter basis, and the essential amino acid profile is well-balanced in relation to the requirements of farm animals. These attributes mean that the larvae have potential as a high-value ingredient for inclusion in animal feeds as a source of protein (Table 1). The larvae are also relatively rich in fat, having about 30% fat in the dry matter. Fatty acid compositions are influenced by the type of waste materials the larvae are fed. When larvae are reared on organic wastes from agricultural plant crops the fatty acid profile is dominated by saturated fatty acids and this is sub-optimal for animal feed purposes (Table 1). The fats do, however, meet the criteria for use in the production of biodiesel.

Rendered animal by-products

Rendered by-products are used as ingredients in animal feeds produced to-day, and there are specifications and regulations in place that govern processing, quality criteria and use. There are practical issues relating to variable composition and nutrient bioavailability of some animal by-product meals. For example, meat-and-bone meal contains less protein and more mineral ash than other meals, and the bioavailability of the calcium and phosphorus in the mineral ash is often low. The quality of blood meals and feather meals is inconsistent due to unpredictable compositions of the raw materials and their responses to processing. In addition, both blood and feather meals contain proteins that are deficient in some essential amino acids; methionine in blood meal, and histidine, lysine and methionine in feather meal. Improvements in processing methods, including enzymatic and chemical hydrolysis of raw materials and milder thermal treatments, may result in production of meals of better quality in the future.



Farm animal production is predicted to increase towards the year 2050, driven by increased consumer demand for meat, eggs and dairy products. The increase in farm animal production will generate large amounts of slaughterhouse waste and processing by-products that can be rendered into protein-rich meals for use as feed ingredients. It is to be expected that rendered animal by-products will be important as protein sources in the animal feeds of the future.

Figure 3. Insect larvae; a feed ingredient with potential?
(Photograph shows mealworms (Tenebrio molitor))
(Photo credit: Skretting, Norway)

Concluding remarks

Most of you who have read this article will be in your 50ies, 60ies or 70ies in 2050, and many of you will have worked on problems relating to food supply and security at some time during your career. Some of you will have been employed by animal feed companies and will have faced the challenges outlined in this article head-on.

There is no doubt that the demand for meat and other animal proteins, such as dairy products and eggs, will increase due to the growth of the human population, and increasing incomes and standards of living. Predictions about farm animal production and needs for animal feeds in the year 2050 have been made. Are the prognoses realistic, and will the animal feeds produced in 2050 be based on the re-cycling of organic wastes? You will be able to answer these questions in just over thirty years from now, but I will not; I will have been re-cycled.

Further reading

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