can oxidize methane — has been thoroughly investigated for the production of single-cell protein. These bacteria have not been isolated and clearly defined; usually called *Methanomonas methanica* Söhngen, they are probably not a single species. Methane-oxidizing bacteria need more oxygen for growth than yeast and algae, and this increases the cost of production. There are also problems in obtaining a concentration of bacteria in the medium that is high enough for profitable production. Methane is among the most inexpensive and abundant sources of energy to be found. It is the main component of the gas produced in the anaerobic treatment of sewage and of natural gas, which in some parts of the world is burned off for lack of demand.

The *Methanomonas* bacteria are the only ones that can utilize methane as a source of energy. The risk of contamination is minimal. The bacteria are cultivated as a submerged culture in a water solution of mineral salts and a source of nitrogen (ammonia or urea). Air and methane are bubbled through the liquid and dispersed with an impeller. A batch culture is harvested after three days and yields about 12 g of wet bacteria per litre. The dried biomass of bacteria is pinkish white, odourless, tasteless and non-toxic and consists of about 70-80% protein of balanced amino acid composition. For practical application it has been suggested that natural gas together with air (certain proportions of air and methane are explosive) can be bubbled through a lake or a pond. As a source of mineral and nitrogen, manure will do. As the bacteria produce acid it will probably be necessary to add limestone to maintain a constant pH. The bacterial biomass may either be collected and used for feed or allowed to remain in the water as a food for fish.

I19 Algae

Useful reference: 398

For growth, algae require carbon dioxide, sunlight, nitrogen and minerals. Carbon dioxide can come from the air or be supplied in pure form. Pure carbon dioxide is a waste product of many industries, including breweries. Three species of unicellular algae are important to the production of single-cell protein.

1. *Chlorella vulgaris*. This alga grows in an acid medium. The cells are small and must be separated by centrifugation. The cell walls are fairly rigid, and the digestibility of the dry matter of intact cells is 40-50% for monogastric animals.

2. *Spirulina maxima*. This species belongs to a group known as blue-green algae, which are closely related to bacteria. *Spirulina* grows in a saline and alkaline medium where carbon dioxide is assimilated through bicarbonate and carbonate. The pluricellular *Spirulina* is about one hundred times larger than *Chlorella* and can be separated from the growth medium by filtration. It grows naturally in ponds and lakes in Ethiopia and Chad, where sun-dried

Spirulina has long been used as human food. Under favourable climatic conditions the daily yield is about 14 g dried algae per square metre a day.

3. *Scenedesmus obliquus.* This species grows in a slightly acid medium and must therefore use carbon dioxide dissolved in the growth medium. It has, together with other *Scenedesmus* species, been artificially cultivated for feed. It grows naturally in some lakes in Mexico and was used by the Aztec Indians as human food. The yield is about 0.5 g per litre in shallow ponds. The cells have to be separated by centrifugation. The dry matter digestibility of untreated cells is very low, usually below 30% in monogastric animals.

Cultivation. The risk of infection in algae cultures is rather low if large inoculums are used and optimum conditions for rapid growth are ensured. The algae are often cultivated in open vessels in the form of circular shallow canals in which the liquid is kept in constant motion. The water is enriched with the required nutrients and carbon dioxide is bubbled through it. Often devices are used to prolong the contact between the gas and the liquid. An interesting development is the use of sewage water and waste water from industries (for instance, yeast plants) as the growth medium. For the production of algae from sewage water a mixture of *Scenedesmus* and *Chlorella* is used.

Use. Algae meal is nontoxic and can be used to supply all required protein without any ill effects. The dried material remains stable in storage for at least six months. Because of its high cost, it is not fed to ruminants. Up to 10% algae meal has been used in pig diets with no change in growth rate or feed conversion. It has been concluded that algae meal has at least the same protein value for pigs as meat-and-bone meal. Algae meal is rich in xanthophyll (2.2 g/kg) and gives egg yolks a good colour. It has also been used as a major source of protein in poultry. Algae meal is low in energy and reduces performance when included at high levels. It is readily accepted by both pigs and poultry.

		As % of dry matter							
	DM	CP	CF	Ash	EE	NFE	Ca	P	Ref.
Chlorella vulgaris, dried	95.5	44.8	8.7	14.2	8.3	24.0			60
Spirulina maxima, dried	90.0	65.6			2.8				99
Scenedesmus obliquus, dried	94.0	56.4	6.9	8.5	13.8	14.4	0.17	1.87	458
Sewage-grown algae		53.1	4.7	14.2	6.8	21.2	1.90	2.20	337

		Digestibility (%)					
	Animal	CP	CF	EE	NFE	ME	Ref.
Sewage-grown algae	Pigs	72.1	0.0	28.7	0.0	2.09	217

Torulopsis utilis (Candida utilis)

Useful reference: 467

Whereas brewer's and distiller's yeasts are usually *Saccharomyces cerevisiae* (see 114), the yeast propagated specifically for animal feed is usually *Torulopsis utilis* (Torula yeast or fodder yeast). Torula yeast is used because it grows rapidly and can be cultivated on a variety of materials. Among the materials used as substrate for fodder yeast production are press liquor from the manufacture of dried citrus pulp, molasses, sulphite waste liquor from the paper industry, saccharified wood (both hexoses and pentoses can be used) and fruit wastes (coffee beans, apples, etc.). Torula yeast grows best at pH 4. Nitrogen and phosphorus must be added to the growth medium: about 0.4 kg of ammonium sulphate and 0.13 kg of trisodium phosphate for each kilogram of yeast to be produced. Air has to be supplied generously to promote rapid yeast growth and minimize the production of alcohol. The air is introduced at the bottom of the fermenter and dispersed by an impeller or by a porous ceramic disc.

Use. Dried yeast is valuable as a source of high-quality protein. It lacks the bitter taste of brewer's yeast (which has, however, on the average, a higher biological value). Fodder yeast is well supplied with minerals and B-vitamins, and if irradiated, supplies vitamin D as well. Dried yeast can be included in mixed feeds for all classes of livestock. Normally the high price limits its use, and its inclusion in diets is based chiefly on its value as a supplement to the amino acids and to compensate for the vitamin deficiency in cereal grains. Yeast is rich in purines (8%) and pyridines (4%), which have practically no nutritive value and are included in the crude protein fraction of the proximate analysis. When the cost of dried yeast is low, it may be fed to cattle as a source of protein in amounts of 1-2 kg per day. Cows with a high milk yield have been reported to show an additional increase from feeding with yeast, possibly because the animals' own production of B-vitamins is insufficient for a high milk yield. For calves the B-vitamins of yeast are of value; therefore, 3-5% is sometimes included in calf starters and feeds for growing calves. Pigs can well tolerate up to 5% yeast in the total ration. Sometimes, when other sources of vitamins and protein are cheaper, small amounts of yeast are added to supply unidentified growth factors. The feeding of yeast to sows during gestation and lactation (100-400 g per day) is reported to improve piglet growth and lower mortality. Yeast can be used as a substitute for soybean oil on a weight-for-weight basis in poultry diets up to 9% of the total ration for male chicks and at least 23% for female chicks. For optimum results much smaller amounts should be used — about 3 g daily per bird.

A distinction must be drawn between ordinary dried yeast and yeast which is the by-product of the production of yeast extract, as the latter contains only half the protein of the former and is low in vitamins.

Petroleum yeast

Useful reference: 439

The yeast *Candida lipolytica* can utilize the paraffin fraction of crude petroleum. Yeast grown on crude petroleum or paraffin extracted from it is now commercially produced at several plants close to refineries. The fermentation takes place in a petroleum-water emulsion supplied with ammonia and mineral salts and a generous amount of oxygen. Two different processes are used:

1. *Pure paraffins.* The paraffins extracted from petroleum are fermented under sterile conditions. The paraffins are almost completely consumed by the yeast, which is centrifuged off and dried without refining. The yield of dried yeast is about 1.6 g per litre.
2. *Crude petroleum (gas oil).* In this process the paraffin, which is about 10% of the petroleum, is consumed by the yeast, and the remaining 90% petroleum is used in the normal refining process. The yeast is centrifuged off after fermentation and then freed from the adhering crude petroleum by solvent extraction.

Use. The yeast cream from the separator is spray-dried into a powder, which is used in calf, poultry and pig rations. If supplemented with methionine, up to 25% can be included with excellent results in calf milk replacers and at least 20% can be included in poultry rations to replace soybean oil meal and fish meal. Up to 10% has been used for sows and 15% for piglets to replace all fish meal and a portion of the soybean meal without significant adverse effects. Petroleum yeast is palatable, and toxic symptoms have not been recorded.

Yeast surface culture

Plant residues can be partly covered with a solution containing sugar. After adding a small quantity of dried yeast, together with nitrogen salts and phosphate, the whole is aerated and allowed to ferment. It is then dried and used as fodder. This method is in most cases uneconomical.

Symba yeast

Useful reference: 241

This yeast is the product of a symbiotic process employing two microorganisms: *Endomycopsis fibuliger,* a yeast that converts starch into simple sugars, and *Torulopsis utilis,* a yeast that grows on the sugars produced from the starch. The method has its greatest value in utilizing starch containing waste water and starchy wastes from primary industries. Symba yeast is a mixture of about 95% Torula and 5% *Endomycopsis.*

Symba yeast has been used successfully in a milk replacer for calves with the following composition: 24.5% yeast, 35% dried skim milk, 20% dried whey, 19% fat, 1% minerals and vitamins and 0.5% methionine.

MOULD

Many species of mycelium-forming fungus produce extracellular enzymes that can degrade complex substrates such as lignocellulose. There has been much research on the possibility of using sawdust and other highly lignified by-products for the production of mycelial protein; however, the growth of these organisms is usually slow. Moulds are also used in submerged cultures on more conventional substrates. *Aspergillus niger* is used to produce microbial protein from carob beans. *Pekilomyces varioti* is cultivated on sulphite waste liquor on a commercial scale in Finland for use in pig and poultry feeds. One of the advantages of using a mycelial fungus is the very simple separation process. The mycelium is easily filtered off and washed directly on the filter, after which most of the water can be removed by pressing.

		As % of dry matter							
	DM	CP	CF	Ash	EE	NFE	Ca	P	Ref.
Torula yeast	93.0	50.0	0.5	8.6	6.5	34.4	0.40	1.30	519
Molasses-grown yeast	85.7	50.9	1.0	9.9	4.8	33.4			191
Wood sugar-grown yeast	89.9	51.9	1.6	8.0	1.6	36.9			191
Sulphite-grown yeast	91.7	47.9	1.2	8.5	3.6	38.8			191
Crude petroleum yeast	94.0	70.2	—	7.8	1.0	21.0			537
Scenedesmus obliquus	91.0	68.7	7.4	7.4	7.2	17.3			537
Aspergillus niger, mould	95.2	30.9	7.6	2.3	1.0	58.2			495
Pekilomyces varioti, mould	95.0	65.0	8.0	6.0	2.2	23.0			

		Digestibility (%)					
	Animal	CP	CF	EE	NFE	ME	Ref.
Torula yeast	Cattle	90.0	90.0	80.0	90.0	3.49	519
Torula yeast	Sheep	89.0	99.0	78.0	95.0	4.03	519

121 Manure

Useful references: 25, 184

Coprophagy, or feeding on manure, is not new in animal nutrition. For example, livestock feeding on a farm has frequently involved a system of beef cattle followed by hogs and subsequently chickens. Under such a programme the nutrition of the hogs and chickens is based on manure. The current interest in manure as a feedstuff is mostly due to the problem of waste disposal from intensive livestock and poultry operations. Apart from this problem it has been recognized that large amounts of nutrients are wasted. The re-use of manure is one way of creating edible protein from