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New sources of protein for pigs

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As the human population in the world expands one would wish to see animal production keeping pace with it, in order to supply it with products of high nutritive value which man needs and likes. Efficient animal production depends on the availability of feeding-stuffs of the right quality, and no component of feed is more important than protein. In the past the protein supplies for animal feeding came from agricultural production (cereals, grasses, legumes, oil cakes, etc.), the fish industry, or as industrial by-products (dairy or slaughterhouse by-products, etc.). Following an orthodox approach, all these sources of protein are capable of a further expansion, but their long-term limitations have been clearly exposed. In recent years, fears have been expressed that the supply of protein may not be adequate to support the expansion of animal production, or even maintain it at the current level. However, great efforts were made by scientists, technologists and industry to forestall shortages, and I believe that their endeavours were so successful that the supply of adequate and commercially viable sources of protein for animals is virtually assured for many decades.

In view of some of the developments in the last 2 years, it is of the utmost importance to reiterate the fact that the practical exploitation of new technical processes is strictly bound to economics. In Fig. 1, world production of soya bean and fish meal during the last 5 years is summarized. Accepting that the year 1974–5 was rather exceptional, there are clear trends indicating that the production of soya bean in the world has been rapidly increasing (due to increases in both the area under cultivation and the yield per ha), while production of fish meal remained virtually unchanged. I believe that the potential for increases in soya bean is still very great. On the same graph I have entered the retail prices of soya bean and fish meal in our area during the period in question. One is struck by the enormous increases during the summer of 1973. Without wishing to enter into the field of economics or politics and attempt to explain this rather transient situation, it is, I believe, important to warn against the impression created in some people's minds that such high prices can be used as a basis for developing new sources of protein. If one is realistic, one has to argue that, unless the new protein sources can be profitably produced at a price competitive with soya bean at, say £100±20/t, then their commercial future will, to say the least, be very doubtful. I do believe, however, that within these limitations the prospects are good.

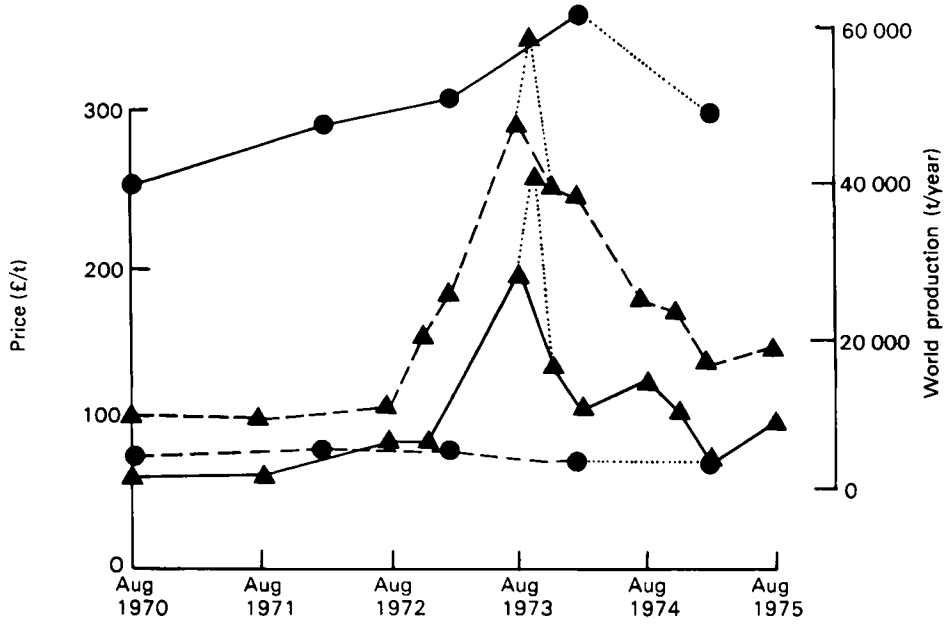

Fig. 1. World production of fish meal (●— — —●) and soya beans (●———●) during the last 5 years, and the retail price of each in the Reading area over the same period: ▲— — —▲, fish meal; ▲———▲, soya beans. ●.....●, Provisional world production; ▲.....▲, maximum price recorded.

In this brief review paper I will give a few relevant references from which up-to-date details can be obtained on some of the new sources of protein for pigs, and then summarize some of the investigations on this subject conducted in my department at the National Institute for Research in Dairying (NIRD), Shinfield, in recent years.

1. *Genetic improvement of plants*

There is a great potential for improving yield and quality of plant protein by genetic means. Consult the following: for maize, Cromwell, Pickett & Beeson (1967) and Klein, Beeson, Cline & Mertz (1971, 1972); for barley, Munck, Karlsson, Hagberg & Eggum (1970) and Schneider & Menke (1974); for wheat, Lougnon & Brette (1970); for oilseeds, (K. J.) Smith (1973); for leaf protein, Pirie (1971); for other plants, Maner (1973).

2. *'Single-cell' proteins*

This rather unspecific and certainly very inexact term embraces several products some of which have been recently developed. Interest in 'single-cell' proteins has been so great all over the world that a number of scientific symposia were held in order to discuss all relevant matters. Perusal of the proceedings of some of these meetings recently published may usefully act as an introduction to the subject (e.g. Division of Biology and Agriculture, National Academy of Sciences, 1973; FAO,

1973; Jones, 1973; Davis, 1974). The following general references may also be helpful: Mateles & Tannenbaum (1968), Enebo (1970), Snyder (1970), Tannenbaum & Wang (1975).

The 'single-cell' proteins will be discussed under four sub-headings.

(a) *Algae.* These are simple plants able to grow in purely inorganic culture media, and if assured of sunlight, CO_2 and ammonium ion in adequate quantities could produce considerable amounts of valuable protein. In fact, in some parts of the world, algae proliferate spontaneously in certain lakes, and the blue-green alga *Spirulina* is now commercially exploited in Mexico for production of a protein supplement. Other species of algae such as *Chlorella* and *Scenedesmus* have also been grown commercially and fed to pigs (Oswald & Golueke, 1968; Succi & Annoni, 1969; Hennig, Gruhn, Kleeman & Hahn, 1970; Tomme & Alekseev, 1970; Bourges, Sotomayor & Mendoza, 1972; Szentmihalyi, 1972; Sarycheva, 1973; Schröder, 1973; Wildheim & Schröder, 1975).

(b) *Yeasts.* Production of yeast as a source of nutrients for man and animal is not a new development. Already back in 1942 I have reviewed the animal aspect of the subject (Braude, 1942). Until recently, different carbohydrates were used as a source of energy in the fermentation containers in which a variety of micro-organisms were employed to convert the elements into protein. A great variety of substrates has been used, cereals, sugars, molasses, waste sulphite liquor, cheese whey and even sewage. The number of species and strains of yeast employed is also very considerable, with names like *Torula, Candida* and *Saccharomyces* being most familiar. There are many reports in the literature dealing with this subject, but only a few selected references concerning pigs and published within the last few years are mentioned here: Delic, Puaca, Mrvic, Vuckovic & Zdravkovic (1970), Bock, Wünsche, Herrmann & Kreienbring (1972), Fevrier, Colomer-Rocher & Seve (1973), Galic (1973) and Naess & Slagsvold (1973).

An interesting recent development was reported by Spicer (1970) of the Rank Hovis MacDougall Research Centre in England. They extracted protein from broad beans (*Vicia faba* L.) and used the carbohydrates of the broad beans as a source of nutrients for the fast-growing filamentous yeast cells in continuous culture. The combination of the bean protein and the yeast protein has resulted in a new protein source said to be equal in quality to good animal protein.

However, the recent exciting development in the production of yeast to be used as a source of protein for animal feeding is connected with the use of petroleum products as the basic raw material. Different sources of hydrocarbons can be used, and the following recent references will adequately introduce the subject: Takata (1969), Wilkinson (1971), Gounelle de Pontanel (1973), Walker (1973).

The first commercial exploitation, using liquid *n*-paraffins, was based on the work by Champagnat, Vernet, Laine & Filosa (1963). It lead to the establishment by the British Petroleum Company (BP) of a plant at Grangemouth, Scotland, which since 1971 has been capable of producing 4000 t dried yeast/year. This was followed by a BP plant in Lavera, France, with a capacity of 16 000 t/year and using gas oil as a source of energy. Several plants with much larger capacities are now being built in different parts of the world.

The nutritive value for pigs of hydrocarbon-based yeasts has now been adequately established, first by the BP investigations carried out at the Institute of Agricultural Research in Biochemical Products, Wageningen, The Netherlands (van der Wal, Shacklady & van Weerden, 1969; van Weerden, Shacklady & van der Wal, 1969; Shacklady & Gatumel, 1972), and confirmed by the independent studies (Barber, Braude, Mitchell & Myres, 1971; Oslage & Petersen, 1973). Details of the composition of BP yeast used in our experiments are given in Table 1. Values given in Table 2 draw attention to very considerable differences in composition of yeasts available for feeding to livestock. The amino acid composition is generally good but relatively low amounts of the sulphur amino acids have been noted. It is therefore of interest that early indications that BP yeast, when fed to pigs, may have to be supplemented by methionine have recently been contradicted by our work at Shinfield (Barber, Braude, Esnaola & Mitchell,

Table 1. *Analysis of the protein supplements used in experiments with pigs*

	BP yeast*	Pruteen†	Pekilo-Protein‡	Lucerne juice (freeze-dried)
Nutrients (g/kg)				
Dry matter	942	955	934	914
Total nitrogen	99	124	76	55
Crude protein (N×6·25)	620	775	475	344
Nucleic acid	100§	147§	100§	nd
Total lipid	16	2·32	4	52
Crude fibre	nd	0·32	61	16
Ash	57	101	53	165
Calcium	0·7	0·4	0·7	25·4
Phosphorus	15·0	26·2	2·0	3·5
Amino acids (g/kg crude protein)				
Lysine	73	65	56	72
Histidine	23	20	18	27
Arginine	49	48	58	66
Aspartic acid	89	86	78	134
Threonine	47	43	42	52
Serine	43	32	43	49
Glutamic acid	120	95	105	110
Proline	42	32	50	63
Glycine	47	50	45	54
Alanine	76	70	57	63
Cystine	9	8	9	nd
Valine	55	50	43	57
Methionine	18	25	17	15
Isoleucine	49	46	39	52
Leucine	73	73	63	92
Tyrosine	37	29	31	47
Phenylalanine	45	37	36	66
Tryptophan	13	9§	13§	nd
(Ammonia)	nd	25	13	50

nd, Not determined.

*British Petroleum Company, Grangemouth, Scotland; grown on *n*-paraffins.
†ICI Agricultural Division, Billingham, Cleveland; grown on methanol.
‡Tempella AG, Tampere, Finland; grown on sulphite spent liquor.
§Values given by manufacturers.

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Table 2. *Composition (g/kg) of yeasts used in animal feeding*

	Brewers' yeast (*Saccharomyces*)	Fodder yeast (*Torula*)	BP yeasts* Grown on *n*-paraffins	BP yeasts* Grown on gas oil
Crude protein (nitrogen×6·25)	440–450	470–500	600–630	650–670
Lipids	10	25	70	15
Ash	60	80	60	80

*British Petroleum Company, Grangemouth, Scotland.

1972). In these tests in which BP yeast was fed as the sole protein supplement in cereal-based diets and compared with fish meal, no advantage accrued from the addition of DL-methionine. This may be because of the lower requirements of pigs for S amino acids than hitherto recommended (Braude & Esnaola, 1973).

Hydrocarbon-grown yeast other than the BP product has been fed to pigs in many countries, and the following are selected references to papers recently published on this subject: Kaspar & Prokop (1970), Taranenko & Bacikalo (1970), Yarov, Basargin & Shcherbak (1973).

(c) *Bacteria*. Recently petrochemicals produced from gaseous hydrocarbons or naphtha (e.g. acetic acid, methanol, ethanol) have been used as a source of energy for cultivation of bacteria. The continuous fermentation process involved in the production of Pruteen (ICI Agricultural Division, Billingham) from methanol using strains of *Pseudomonas* was first reported by MacLennan, Gow & Stringer (1973) and Stringer & Litchfield (1973). The nutritive value of the product was studied at NIRD, and the preliminary results (Braude, Mitchell & Rhodes, 1975) appear attractive and confirm the earlier findings of the manufacturers. Bacterial protein isolate may contain as much as 830 g crude protein (nitrogen×6·25)/kg. However, such a high value may be misleading as about one-quarter of it can consist of nucleic acids, which, on present evidence, cannot be utilized by single-stomached animals. In fact, the product used at NIRD, Pruteen, contained 740–750 g crude protein/kg, of which 140–150 g was nucleic acid. In our tests the nutritive value of the Pruteen was compared, on a crude protein minus nucleic acid content basis, with that of fish meal. In Table 1 details are given of the composition of Pruteen.

The high nucleic acid content of Pruteen was the subject of a special investigation. Nucleic acid ingested in the food of higher animals is broken down in the gut under the influence of nucleolytic enzymes from pancreatic and intestinal juices into various components including purines. After absorption purines are further metabolized to uric acid. In order to dispose of uric acid the action of the enzyme urate oxidase (*EC* 1.7.3.3) is essential to convert it to allantoin which can be excreted in urine. It is known that man lacks urate oxidase and cannot effectively eliminate large amounts of uric acid. Results of our tests clearly indicated that the pig has the necessary mechanism to dispose of purine-N as allantoin.

Bacteria can also be cultivated using methane as source of energy. Several investigations have been reported but none have reached commercial exploitation yet (Ribbons, 1967; Hamer & Norris, 1971).

(d) *Fungi.* A process has been developed recently in Finland which involves a continuous culture on sulphite spent liquor (waste from paper pulp manufacture) of the filamentous microfungus *Paecilomyces variotii.* The product, named Pekilo-Protein, has been described and its nutritive value for pigs assessed by Forss (1973). We evaluated the product in a comparative test with white fish meal. Table 1 gives the composition of the consignment of Pekilo-Protein used in our studies. Preliminary results indicate that Pekilo-Protein can satisfactorily replace fish meal as a protein supplement in the diets of growing pigs. Products of this type may acquire special importance if one takes into account that wood is the only renewable natural resource available.

Several attempts have been made to produce protein by fermentation of cereals using different fungi. For example, Reade, Smith & Palmer (1972) used barley as a substrate for cultivation of *Aspergillus oryzae* and *Rhizopus arrhizus.* The Tate & Lyle laboratories (Reading) have experimented with carob (*Ceratonia siliqua* L.) waste using a low-grade syrup obtained from carob pods and a strain of the fungus *Aspergillus niger.*

3. *Lucerne (*Medicago sativa *L.) and grass juice or protein concentrate*

Mechanical extraction of juice from lucerne and grass is now commercially feasible, and the proposition looks most attractive because not only can it provide a valuable source of protein for single-stomached animals, but also it cheapens considerably the preservation of these fodders for ruminants by drying (Connell & Davys, 1973). It appears that the protein removed by judicial juice extraction may be surplus to the requirement of the ruminants and that we may be witnessing the beginning of a very substantial source of home-produced protein for pigs.

During the last 4 years a research programme at NIRD has made considerable progress in this field. Preservation and storage of the juice and its nutritive value have been studied. During 1972 it was established that the true protein content of lucerne juice preserved with propionic acid declined very rapidly on storage. As a result of this, the nutritive value of the juice when added to replace fish meal on a crude protein basis in the diets of growing pigs was found to be low. When the replacement was made on a true-protein-N basis the value of the lucerne juice as a source of protein for pigs was marginally better (Barber, Braude, Florence, Mitchell & Newport, 1973). Next, attempts were made to prevent the changes in freshly produced lucerne juice by using hydrochloric acid and metabisulphite as preservatives. The decline in true-protein-N value was slowed down but not eliminated. However, using juice with these two preservatives added, and replacing the fish meal in the control diet on the basis of true protein content of the juice, satisfactory results were obtained with no differences in the performance of the lucerne-juice-fed and control pigs. The lucerne juice was also compared with grass juice replacing fish meal on a true-protein-N basis. There were no differences in performance of the pigs and this was taken as evidence that under conditions prevailing at NIRD we need not worry about some of the adverse factors which, according to reports from Australia and elsewhere, may be associated with lucerne juice (e.g. saponins). During 1973 it was confirmed that the rapid changes in the

protein component of the lucerne juice were largely due to enzymic action, and could be nearly prevented by mild heat-treatment of the juice within 1 h after production (Braude, 1974). The heat-treated lucerne juice (steam injection at approx. 85° for 10 s), preserved by addition of HCl (to reduce pH to approx. 3·0) and metabisulphite, was used to replace (on a true-protein-N basis) all the fish meal in either a 'standard 7% fish-meal diet' (70 g fish meal/kg) or in a diet with 35 g fish meal/kg, supplying a 'marginal' level of protein. The results indicated that lucerne juice processed and preserved in the way described can replace satisfactorily fish meal as the protein supplement in diets for growing pigs (Barber, Braude, Florence & Mitchell, 1974).

If an efficient lucerne-harvesting and juice-pressing equipment could be operated on individual farms, one could envisage a 'zero grazing' operation which could be economically very attractive. It could mean a single routine farm operation which would save on processing equipment and on over-all labour and transport costs: harvesting the lucerne and squeezing out the juice followed by feeding the fresh juice to pigs and the fibrous residue to cattle. It would possibly dispense with juice preservation and storage problems and with drying or ensiling, or both, of the fibrous residue.

It appears that the liquid form could be the economically most attractive way of feeding lucerne juice to pigs, though drying can under some circumstances be an alternative.

In order to produce a dried protein concentrate a routine developed by Pirie (1971) will have to be followed. In the USA commercial exploitation has already started using a technique described by Kohler, Chrisman & Bickoff (1973) from the Western Regional Research Laboratory of the US Department of Agriculture in Albany, California. The material produced by them is called Pro-Xan (protein-xanthophyll concentrate). This product contains (g/kg): crude protein (N×6·25) 390, diethyl ether extract 60, fibre 25 and ash 192. Apparently it is well utilized by various classes of pigs (Cheeke & Myer, 1973), but the economics of production have recently been questioned.

It is interesting that the residual matter ('brown liquor') left after extractions of protein from the lucerne juice has been used as a source of energy for cultivation of yeast (Paradez-Lopez & Fernandez-Arias, 1972). However, I cannot envisage such a process ever being technically viable on a commercial scale.

4. *Use of waste products*

The disposal of organic waste from agriculture and industry and of urban waste by processing into animal feeding-stuffs has been attempted from time to time. Some recent claims appear attractive, but I am rather doubtful about the contribution that these products can make to the future supply of protein for animals. A few selected references are given: Hintz & Heitman (1967), Janardhanan, Kaul & Husain (1970), Tscheschmedshiev, Dzarova, Angelova & Paliev (1970), Bringmann (1971), Vogt (1973), (L. W.) Smith (1973). Recently, even pig manure came under scrutiny and its nutritive value was reported on (Harmon, Day, Jensen & Baker, 1971*a*, *b*; Orr, 1971). The use of pig manure as a medium for

growth of algae has been suggested (Wilson & Houghton, 1974). The proceedings of a symposium on *'Nutritional potential of recycling waste'* (Young, 1974) makes interesting reading in this context.

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