Kellner, A., Correll, J. W. & Ladd, A. T. (1948). *Proc. Soc. exp. Biol., N.Y.*, **67**, 25.
Kellner, A., Correll, J. W. & Ladd, A. T. (1951*a*). *J. exp. Med.* **93**, 385.
Kellner, A., Correll, J. W. & Ladd, A. T. (1951*b*). *J. exp. Med.* **93**, 373.
Leopold, A. C. & Klein, W. H. (1951). *Science*, **114**, 9.
Metcalf, R. L., March, R. B., Fukuto, T. R. & Maxon, M. G. (1955). *J. econ. Ent.* **48**, 364.
Nelson, D., Szanto, P. B., Willheim, R. & Ivy, A. C. (1954). *Cancer Res.* **14**, 441.
Newell, G. W., Erickson, T. C., Gilson, W. E., Gershoff, S. M. & Elvehjem, C. A. (1949). *J. Lab. clin. Med.* **34**, 239.
Pace, J. & McDermott, E. E. (1952). *Nature, Lond.*, **169**, 415.
Reiner, L., Misani, F. & Weiss, P. (1950). *Arch. Biochem.* **25**, 447.
Roth, J. S., Wase, A. & Eichel, H. J. (1953). *J. biol. Chem.* **200**, 647.
Roth, J. S., Wase, A. & Reiner, L. (1952). *Science*, **115**, 236.
Stokinger, H. E. (1953). *Nucleonics*, **11**, 24.
Waggoner, P. E. & Dimond, A. E. (1953). *Science*, **117**, 13.
Williams, R. T. (1955). Unpublished report to the Medical Research Council's Toxicology Committee.
Winteringham, F. P. W., Harrison, A., Bridges, R. G. & Bridges, P. M. (1955). *J. Sci. Fd Agric.* **6**, 251.
Winteringham, F. P. W. (1955). *J. Sci. Fd Agric.* **6**, 269.

Unexploited technological possibilities of making food for man and animals

By N. W. PIRIE, *Rothamsted Experimental Station, Harpenden, Herts*

The three outstanding possibilities are: the synthesis of food, the more economical use of crops of the type we already grow, the exploitation of new primary sources of food. There is no need to discuss the first here. Experiments on fat synthesis are described by Williams (1953), and Cuthbertson (1953) has stressed the importance of synthetic vitamins and amino-acids in turning a nearly adequate diet into an adequate one. Both agree that synthesis of the bulk foods is not likely to become an important feature of food production soon. We will continue to rely mainly on photosynthesis.

When we eat a plant the digestible part is, by definition, used with 100% efficiency. Few people get less than half their energy from vegetable sources and most of the world's population gets nearly all its energy in this way. One solution to the food problem would therefore be to increase the amount grown. Even if this were done there would still be room for improvement because much of the crop, e.g. leaves, straw and peel, is wasted. Furthermore, the diets eaten in many parts of the world are inadequate. They have many faults but protein deficiency is a common one and the steps that could be taken to overcome it will serve as an example of what could be done to remedy the other deficiencies also.

The parts of a plant generally eaten are the starch depots such as grains and tubers. Some legume seeds contain adequate amounts of protein but many tubers contain very little; cassava with only 1–2% is an extreme example. As would be expected from their active metabolism, immature flowers and young leaves can be rich in protein, but they are inadequately exploited. In Britain brussels sprouts and cauliflower are the most valuable materials of this type eaten in significant quantity. This conservatism may now be unnecessary because refrigeration has solved the old problem of storing materials as perishable as leaves. In Table 1 a few

Table 1. *Some protein-rich materials of vegetable origin, mainly leaves*

Common name	Latin name	Habitat	Total nitrogen (as a percentage of dry matter)	Reference
Mixed grasses		Temperate	5·0	Rothamsted Exp. Sta. (unpublished)
Nettles	*Urtica dioica*	Temperate	3·8	Rothamsted Exp. Sta. (unpublished)
Broad bean	*Vicia Faba*	Temperate	3·7	Rothamsted Exp. Sta. (unpublished)
Potato (leaves)	*Solanum tuberosum*	Temperate	4·6	Rothamsted Exp. Sta. (unpublished)
Cocksfoot grass	*Dactylis glomerata*	Temperate	6·8	Lugg (1938)
Oats	*Avena sativa*	Temperate	4·8	Reber & MacVicar (1953)
Cabbage	*Brassica oleracea*	Temperate	4·5	Crook & Holden (1948)
Bryony	*Bryonia dioica*	Temperate	6·2	Crook & Holden (1948)
Groundsel	*Senecio vulgaris*	Temperate	4·7	Crook & Holden (1948)
Cassava	*Manihot utilissima*	Tropical	4·4	Raymond, Jojo & Nicodemus (1941)
Spinach	*Talinum* sp.	Tropical	5·0	Kandiah & Koch (1938)
Groundnut	*Arachis hypogaea*	Tropical	5·6	Pal & Guha (1953)
Legume forages	*Indigofera subulata*	Tropical	5·2	Guyadeen (1951)
Oun-Tsai	*Ipomoea aquatica* (Forst)	Tropical	5·35	Teng-Yi Lo & Chih-Hua Wu (1942)
Colza	*Brassica chinensis* (Bailey)	Tropical	5·3	Teng-Yi Lo & Chih-Hua Wu (1942)
Sea lettuce	*Ulva pertusa*	Marine	5·05	Takagi (1950)

values for total nitrogen are assembled and they show that many leaves contain as much N as the legume seeds. A small part of it is not protein and would be lost in cooking but, in compensation, other components of the leaf are lost too, thus Raymond, Jojo & Nicodemus (1941) found 11·2% N in properly cooked cassava leaves. Some of the leaves, from the Solanaceae for example, contain toxic substances that, on cooking, are removed from only some of the species. Leaves from the same species often vary in composition. This is probably an important factor controlling the division of species into edible and inedible by primitive man; a leaf whose quality could only be assessed by Kjeldahl would not have been of much use.

Table 1 does, however, suggest that the investigation of systems of husbandry that would ensure large yields of protein-rich and fibre-poor leaves is a technological possibility that deserves fuller exploitation. Even the normally despised grasses would be useful if grown regularly with 25–30% protein. Obviously leaves could not supply the whole protein in a satisfactory diet but they could contribute much more than they do.

But top quality leaf is difficult to grow and it is always accompanied by leaf of lower quality. Traditionally, ruminants convert this into human food with varying loss. The amount of loss is in dispute (cf. Cooper, 1955; Wallace, 1955) perhaps because several different things are being measured. For example, we can study the efficiency of one animal at one time and measure the food intake and the manner in which food is converted into waste products and into useful products such as meat, milk or eggs. This would be primarily an academic study of metabolism and it would have limited practical value though it would shed some light on the problems of farmers who buy young pigs, lambs or calves for fattening, or pullets just coming into lay.

At the other extreme we can take an average section of the population of some animal and see what the food consumption and productivity of the group is. Thus we could consider a thousand cattle with cows, calves, heifers and bulls in the proportion in which they come in this country and assess the food requirement and the amount of meat and milk. The ratio of these two quantities is the conversion efficiency that is of importance in practice; it has not been measured but is very unlikely to exceed 10% for protein. There is little prospect of technological improvement here so long as preformed protein is the main source of the ruminant's nitrogen but an inadequately exploited possibility is the use of simpler nitrogen compounds such as urea which can, in the ruminant, replace dietary protein to a considerable extent.

In principle an animal converter is a device for destroying plant carbohydrate more rapidly than plant protein; by differential inefficiency it makes a protein concentrate. The same result could be achieved without destruction if the leaf were separated mechanically into a protein-rich and a carbohydrate-rich part. The protein is already there and valuable, it only needs separation from diluent carbohydrate and conversion is gratuitous. This process is obviously analogous to the familiar operations of shelling and threshing which separate a valuable component from one of less value, but it has not been adopted because of the technical difficulties. During the last 20 years these have been to a considerable extent overcome but work now proceeds on an entirely inadequate scale.

Since the time of Rouelle (1773), protein has been extracted from leaves and coagulated; Ereky (1926) suggested that it was worth doing on a technological scale. These early publications seem to diminish the value of some recent patents on the process. The principle is simple (Pirie, 1952, 1955). Fresh, lush leaves are pulped to an extent sufficient to release from the cells most of the free protein and protein associated with the chloroplasts and other structures. The juice that is then pressed from the mass brings these various forms of protein with it. The protein is coagulated and separated from most of the highly flavoured or toxic components of the leaf by filtration. Three primary products are therefore made; their natures and probable uses are set out in the following scheme.

After milling and pressing, the leaf is separated into:

- Fibre containing
  - most of the: cellulose, hemicelluloses, lignins, pectin
  - some of the: proteins, starch, fats
  - → still a valuable fodder for ruminants
- Juice which, after coagulation, gives
  - fluid containing: sugars, amides, amino-acids, salts → culture medium for yeasts and other micro-organisms
  - coagulum containing: proteins, fats, starch → food for non-ruminants including man

Clearly, it is easy enough to see what we are trying to do; the technological problem is to do it.

Rollers and screw expellers have often been used to pulp leaves and separate the juice from them in one operation. They have been moderately successful but only when the material is passed through the machine several times. As soon as the scale of working is so large that some replication of machinery is necessary, this is no more economical than to pass the material through different machines each designed specifically for the very different jobs of pulping and pressing. This is our technique at Rothamsted (cf. Pirie, 1952). The pulper is the end-product of much experiment and is reasonably satisfactory. Its speed is variable and, by varying the ratio in which two types of hammer are used, the rate of movement of the charge through the machine can be controlled because one type moves the charge towards the outlet of the machine and the other does not. A setting that matches the texture of the crop can be found and it, as Table 2 shows, has a great effect on running efficiency.

Table 2. *Effect on efficiency of varying the speed and pitch of the pulper hammers*

Pulper speed (r.p.m.)	Hammer setting Pitch	Throughput (cwt./h)	Power used (kW/h/ton)	Total nitrogen in juice as percentage of that in crop	Protein nitrogen liberated from fibre (g N/ton pulp*)	Protein nitrogen liberated per kWh used on pulper (g)
523	Coarse	17·5	4·6	4·12	128	27·8
	Fine	17·5	7·0	4·69	138·5	19·8
653	Coarse	20	8·0	10·2	325	40
	Fine	17·5	5·8	16·6	541	93
760	Coarse	21·8	9·4	17·8	595	63
	Fine	15·6	7·8	24·3	829	106
950	Coarse	14·5	14·8	19·2	511	34·5
	Fine	12·0	16·0	21·5	565	35·4

Samples of the same batch of kale were pulped at four different speeds and at each speed the same two settings of the hammers were used. The coarse setting gives rapid movement through the pulper and the fine setting slower movement so that pulping is more complete (Byers, Fairclough & Pirie, 1955).

* 1 ton pulp contained 4·7 kg nitrogen.

This is important not only for economy but also to avoid heating the pulp and so coagulating the protein in it. In the experiment quoted less than one-quarter of the N is being extracted; a further equal amount is extracted when the residue is re-pulped with water and this process consumes little power. The exact arrangement, as well as the ratio, of the two types of hammer affects efficiency, so does the use of baffles inside the pulper and it is on the success with which these things can be managed that the ultimate practicability of this project will depend. From the various leaves used—kale, lucerne, grass, potato tops and others—it is always possible to get, in the first extract, 100 g protein N for each kW expended on pulping. By suitable choice of crops and by using fully the flexibility of the machine, extraction can be made still more economical.

The design of a press to get the juice out of material like leaf pulp is governed by two principles; pressure must be maintained for long enough to allow the juice to run clear of the fibre or it will be reabsorbed when the pressure is released; there should be no relative movement between the pressing or filtering surfaces and the charge while the pressure is applied or an unreasonable amount of power will be consumed in overcoming friction in this unlubricated system. The first principle rules out arrangements in which the material is passed through the nips of pairs of rollers with their convex surfaces touching; the second rules out screw expellers and machines derived from them. We feed the material on to a perforated conveyor that passes under a ram and only moves forward when the ram is lifted, 80% of the juice that can be expressed with prolonged high pressure comes out in 6 sec at 50 lb./sq. in. Only one machine of this type has so far been made and our work with it has shown that many aspects can be improved. Nevertheless it will handle three-quarters of a ton an hour and only takes 1·5 h.p. to run.

Protein can be precipitated from the juice by letting it age, by heating to 75°, by adjusting the pH to about 4, or by shaking it briefly with a variety of water-immiscible liquids such as the higher alcohols and halogenated hydrocarbons. The choice between these methods depends on the method that will be used to separate the protein curd from the liquor. Heating gives the most compact and easily filtered curd, the more rapid the heating the better. We found this in laboratory experiments in which heating took from 2 to 20 min, and so arranged to heat on a large scale in a fraction of a second with successful results. Steam is injected into a stream of leaf juice that is controlled by a thermostat valve set to open as the temperature, just beyond the point where the steam enters, approaches 75°. The juice is thus coagulated almost instantaneously and is only diluted about 10% by the condensed steam.

Conventional methods are applicable to the separation of the protein curd. It is pressed till it contains 50% water, resuspended in water and pressed again. This is as far as our detailed study of processing has gone, and the product has to be kept under refrigeration. It becomes stable when dried either directly or by extraction with solvents such as acetone or the alcohols; extraction removes, at the same time, 5–10% of lipids including chlorophyll. The product after extraction is pale green or fawn and contains 60–80% protein as well as some starch and fat.

Different preparations vary somewhat in digestibility but all have been less digestible than casein and some other proteins traditionally handled in the laboratory. Many other novel proteins are also relatively indigestible, which would appear to limit their technological use. We are therefore investigating the reasons for it and think it wise to postpone careful feeding trials until the phenomenon is more fully understood. After that there will be room for technological enterprise in making a palatable product; the use of the material we make now would be stoking rather than eating.

There is, however, every reason to think that useful protein could be made on a large scale without the loss inseparable from animal conversion or translocation to seeds or tubers in the plant. Many crops could be used which vary mainly in the

frequency with which they are harvested. Algae can be harvested daily or even continuously, leaves weekly or monthly, normal crops yearly and forests at much longer intervals. But, if other things are equal, all have similar photosynthetic efficiency. As a rule other things are not equal and this leads to the illusion that algae, such as *Chlorella*, are peculiarly efficient at trapping light and give a greater return per acre-year than other crops. High efficiency is only shown in very dim lights where yields are low and high yields are got by warming and manuring the system to an extent that would be looked on as unrealistically extravagant with normal crops. If pampered equally, leaves give as high a yield as algae and are as convenient to grow where soil and water are available. When these are restricted, higher plants can be grown in water culture with glasshouse cover as economically as algae. When only salt water is available, algae would probably have the advantage but this is a possibility that is not being exploited vigorously. Nitrogen-fixing marine algae would be particularly valuable. The sea is an underexploited environment and both the harvesting of marine microflora (cf. Jackson, 1954) and the use of the material harvested are ripe for technological investigation. There are also proposals for large-scale cultivation of micro-organisms such as yeasts which should be followed up, but this theme is not strictly relevant in this context. They will be a valuable means for recovering sugars and other substances from agricultural wastes such as molasses and the liquor that is a by-product from leaf protein. But these are not methods for bringing new carbon into circulation; they are complements to, rather than substitutes for, leaf protein.

Various reactions are possible to proposals like these. We can say we prefer existing foods and do not welcome any changes. But change is inevitable; we have hitherto been in a particularly favoured nutritional position; a wealthy nation buying its food from the rest of the world. If this situation does not last it will be possible for us to live off our own acres but only by changing our style of eating. We can say that technology must be used to better effect but that choosing among the possibilities is the business of various government departments. This reaction overlooks the official capacity for procrastination and evasion. It is often easy enough to do the research; the difficulty lies in getting it sanctioned. Finally, we can accept both the inevitability of change and our responsibility for planning it. We must remember the sceptical or even hostile attitude of the public towards many of the incursions of science into daily life. A change should only be made after exhaustive pilot-scale experiment; we cannot afford another 'Groundnut Scheme'. The project should interfere with amenities as little as possible. On this score intensive farming has probably an aesthetic advantage over acres of algal culture tubes. The guiding principle can perhaps be epitomized: technology, like the Sabbath, was made for man and not man for technology.

REFERENCES

Byers, M., Fairclough, D. & Pirie, N. W. (1955). *Rep. Rothamst. exp. Sta.* p. 80.
Cooper, M. McG. (1955). *Proc. Nutr. Soc.* **14**, 1.
Cuthbertson, W. F. J. (1953). *Chem. & Ind.* p. 553.
Crook, E. M. & Holden, M. (1948). *Biochem. J.* **43**, 181.

Ereky, K. (1926). *British Patent* no. 270,629.
Guyadeen, K. D. (1951). *Trop. Agriculture, Trin.*, **28**, 231.
Jackson, P. (1954). *J. Cons. int. Explor. Mer*, **20**, 167.
Kandiah, S. & Koch, D. E. V. (1938). *Agriculturalist*, **90**, 3.
Lugg, J. W. H. (1938). *Biochem. J.* **32**, 2114.
Pal, P. R. & Guha, B. C. (1953). *Sci. & Cult.* **18**, 597.
Pirie, N. W. (1952). *Rep. Rothamst. exp. Sta.* p. 173.
Pirie, N. W. (1955). In *Modern Methods of Plant Analysis*. Vol. 4, p. 23. [K. Paech & M. V. Tracey, editors.] Heidelberg: Springer.
Raymond, W. D., Jojo, W. & Nicodemus, Z. (1941). *E. Afr. agric. J.* **6**, 154.
Reber, E. & MacVicar, R. (1953). *Agron. J.* **45**, 17.
Rouelle, H. M. (1773). *J. Med. Chir. Pharm.* **40**, 59.
Takagi, M. (1950). *Bull. Fac. Fish. Hokkaido*, **1**, 35.
Teng-Yi Lo & Chih-Hua Wu (1942). *J. Chin. chem. Soc.* **9**, 108.
Wallace, L. R. (1955). *Proc. Nutr. Soc.* **14**, 7.
Williams, P. N. (1953). *Chem. & Ind.* p. 582.

Some technological developments of importance in animal nutrition

By J. DUCKWORTH, *Rowett Research Institute, Bucksburn, Aberdeenshire*

Adequately to review the technological translation of nutritional science into commercial practice is beyond the scope of a single communication. Attention must be restricted to a narrow field and the relationship between technology and protein provision has been selected.

This is no arbitrary choice. Most common energy sources are often too low in protein for productive purposes and must be supplemented to secure appropriate ratios of metabolizable energy to digestible protein. All protein-rich supplements are expensive, relative to the basic energy sources, and thus minimum feeding costs are realized only when supplements are added at the level that just satisfies the animal's needs. In practice, an excess must be added to provide a margin of safety and the greater the uncertainty about dietary protein the greater this margin must be.

This uncertainty has four major origins: variation in protein content among different batches of individual feeding-stuffs, variation in amino-acid composition within the total protein content, natural variation in protein digestibility, and variable effects of processing on protein quality, defined in terms of digestibility and of metabolic availability of certain important amino-acids of the digested protein. An independent source of uncertainty is variation in the metabolizable energy of feeding-stuffs, disturbing the nutritive ratio. Organizations sufficiently large to afford chemical analysis can eliminate uncertainties about the content of protein and metabolizable energy. The other uncertainties remain, except for those who, by animal trials, can identify sources of feeding-stuffs that are consistently or erratically inferior in protein quality, and thereafter avoid them. This does not necessarily remove them from the market but rather deflects them into hands that lack testing facilities.