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Leaf protein as a food source

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The mixture of proteins in the juice pressed out from pulped leaves may conveniently be called 'leaf protein' (LP) although, after coagulation and pressing, it also contains lipids, starch and nucleic acid. It is sometimes called 'leaf protein concentrate' (LPC): that term, if used, should be reserved for material that has undergone some further stage of refinement. The most obvious reason for including work on LP production in a program of research on solar energy is that, because it takes protein directly from the leaf – the site where protein is synthesized – the losses that are inseparable from translocation, or conversion in an animal, are avoided. LP production has, however, a bearing on other aspects of solar energy research and on the general problem of energy conservation.

If suitable crops were used, LP could be made from the leafy by-product of an 'energy plantation', the fibrous residue from which LP has been extracted would be a convenient substrate for methane fermentation, and various chemicals that are now made by partial or total synthesis (starting from coal or oil) could be separated from the juice after protein has been removed. Furthermore, less energy would be needed for managing an irrigation system if water weeds were being removed, and used as a source of LP, so that they no longer wasted water. And, in many situations, the fibrous residue from the extra growth resulting from irrigation would produce more energy, when used as a fuel, than would be produced by the same amount of water passing through a turbine.

The process

Simple pressure does not release LP from leaf cells: rubbing and partial disintegration of the leaf structure are essential preliminaries. Equipment ideally suited for extracting leaf juice on either an industrial or an 'Appropriate Technology' scale is not at present on the market. Because roller mills and screw expellers do not apply pressure as smoothly and efficiently as their makers intended, there is enough rubbing in them to release some juice. However, such inefficient extraction wastes energy. We have made some progress[1,2] in designing a unit in which thorough rubbing precedes pressing. This unit needs about 300 W to extract juice from about 100 kg of leaf per h; the actual quantities depend on the texture of the crop. This unit can make 5–10 kg (dry weight) of LP in a day. That is the scale of production for which, at present, there seems to be the most demand, but larger units working on the same principle could be made.

Leaf juice can be coagulated by acidification to about pH 4, but LP is easier to handle if it is coagulated by heating suddenly to 60–90 °C. Sterilization and enzyme inactivation are more complete at the higher temperature. The curd is collected on a filter and pressed until it contains 60%, or less, water. When made from species with little flavor, the LP is then ready for use; LP from most species should be resuspended in water, at pH 4, filtered off, and pressed again. It can be kept, like cheese, for a few days without refrigeration; for longer storage it can be canned, frozen or preserved with acetic acid, salt or sugar[3]. Drying should be avoided if possible; if it should be essential, it must be done carefully[4] or the LP will become gritty and less digestible.

Properties

When carefully made, LP consists of 60–70% true protein (on the dry matter), about 25% lipids including pigments derived from chlorophyll, and 0.1–0.2% β carotene. The lipids are highly unsaturated which, as in other foods, raises problems in storage. Some people find the green colour unattractive. For these reasons, solvent extraction is often suggested. This would be a mistake because the lipids are nutritionally useful and the β carotene (pro-vitamin A) is as valuable a component as the protein in those countries in which vitamin A deficiency is common. Furthermore, even partial decolorisation, by any process, would make LP much more expensive and would rob it of one of its main merits – that it is a good source of protein which can be made by unskilled people from local material for local use.

The nutritive value of LP has been well established by many experiments on animals and by trials with infants in India, Nigeria and Pakistan[5]. Unless LP is being made from a species not closely related to those already used, e.g. a conifer or fern, there is no need for further nutritional trials. Although LP has a less favorable amino acid composition and is less digestible than casein, if it has not been damaged by inept handling it is as good as, or better than, the protein in cereal or legume seeds. The poisonous substances present in some leaf species are removed when the LP is washed at pH 4.

Sources of leaf

By harvesting a succession of crops from the same piece of land, the annual yield of dry, 100% protein at Rothamsted was 2 t per ha; with irrigation the yield would be larger because there is here a summer water deficit in most years. In India the yield is 3 t. Yields from perennial grasses are a little smaller. These yields - 3 or 4 times as large as those of any other protein concentrate - are possible because crops that are harvested while still green maintain a photosynthetically active cover on the ground for longer than crops that need a period of ripening or drying. Therefore, LP is potentially the most abundant of all edible protein sources. Crops destined primarily for LP production will, however, replace seed crops to only a limited extent because the need for protein concentrates is limited. Seeds will remain the main source of dietary energy, and they are more easily stored than perishable LP.

The yield of dry matter from forage crops harvested several times during a year is larger than the yield from any other type of crop. They lose part of this advantage when they are put through the inefficient process of conversion in a ruminant animal, and they contain so much water that artificial drying is an expensive prelude to their use as fuel. That is why so much sunlight is used merely as a source of heat for maturing or drying crops in the field, rather than as a source of low-entropy energy for photosynthesis.

LP cannot be satisfactorily separated from leaves with a dry, fibrous, or mucilaginous texture, nor from leaves that are acid or contain a great deal of phenolic material. In spite of these limitations, more than 100 suitable species are known that grow well in the tropics or the temperate zone. No attempt has so far been made to select varieties specifically for LP production.

Several crops, e.g. potatoes and sugar beet, are harvested while some of the leaf is still green and unwithered, and leafy material is a by-product from the cultivation of many vegetables. These leaves are at present unused or inadequately used: they are all good sources of LP. I calculate that 100,000 t of protein could be recovered annually in the UK from potato haulm (mainly from early and seed potatoes) and sugar beet tops.

Weeds growing on uncultivated ground are not likely to be useful, not because any defect characterizes all weed species, but because uncultivated ground is likely to be too rough or steep for convenient harvesting, and it is unmanured. The situation is different with water weeds. They would be easy to collect, they are often well fertilized, and much effort is already being expended on their control. LP has been extracted from a few species[5] but this potential source has been most inadequately studied.

Trees were not, in the past, thought of as probable sources of LP because it would not be easy to collect leaves from them in the conditions of conventional forestry. The recent increase in interest in coppiced trees as sources of paper pulp, and as components of 'energy plantations', changes the situation. Mechanical stripping of leaves from the uniform poles that grow in a coppice would be easy: machinery already exists in the USSR for stripping needles from conifers. Leaves collected in this way are being used as cattle fodder: I have reviewed that subject briefly elsewhere[6]. However, it would obviously be preferable to make LP from them for use as food by people and non-ruminant animals.

Few attempts have been made to extract LP from tree leaves. Casual experience at Rothamsted suggests that they tend to be dry and tough; elder *(Sambucus nigra)* is the only species from which extraction is satisfactory. It is unlikely that elder is unique. If, as seems likely, 'energy plantations' are used extensively for collecting solar energy, the possibility of extracting protein from the by-product leaves is a factor that should be borne in mind when selecting suitable species. Tree leaves could then become one of the more important sources of LP. Nitrogen-fixing leguminous trees, such as leucaena and the acacias, have obvious advantages, and there is no reason to expect poorer extraction from them than from other species.

Ethanol would be a more convenient end-product of trapped solar energy than wood. Sugar cane and cassava are the plants usually suggested as the raw materials for alcoholic fermentation. Sugar cane tops are so fibrous that it is difficult to extract what little LP they contain; LP does not extract readily from the varieties of cassava that have been studied, but other varieties may be more satisfactory[5]. Sweet sorghum and chicory have also been suggested as sources of fermentable carbohydrate. The appearance and texture of these leaves suggest that LP should extract readily from them, but experiments demonstrating this have not been published.

The by-products from LP production

By-product leaves from 'energy plantations' are important because their use will make this form of energy more economic. The same economic argument will make it essential that the pressed, fibrous, residue that remains when LP has been extracted from any type of leaf is efficiently used. Hitherto, most attention has been given to its value as ruminant fodder. Because juice has been pressed out of it, much less fuel is needed to dry it, compared with the original crop, for conserved winter feed. It is indeed possible, in most climatic conditions, to complete the drying by exposure to unheated air. Use of the fresh or conserved fiber as fodder is the most sensible course when LP is being made on a small scale for local use.

The disintegrated, fibrous residue from LP extraction has a texture that is well adapted to methane fermentation. It was primarily for use in a methane project that one of the early largescale pulpers (1 t of leaf per h), designed at Rothamsted, was sent to Uganda. So far as I know, this use of the fiber has not been exploited further.

Vegetable matter must obviously be as dry as possible before being used as a fuel. Therefore, straw gets the most attention and, when grasses are being considered as fuels, it is assumed that they will be harvested when mature in spite of the smaller yield of dry matter compared to what can be taken with repeated harvests of young growth. The fibrous residue from juice extractors of the present type, in which there is relative movement between fiber and metal, contains 65–75% of water. An extravagant amount of power would be wasted in friction if attempts were made to get drier fiber from them. The extra juice coming out with intense pressure contains little protein because that tends to be trapped by the tightly packed fiber. The hydrated fiber from young leaves, after intense pressing, contains about 50% of water. Fiber that is to be used as fuel, or conserved for ruminant feed by drying, should therefore be subjected to a 2nd pressing in a unit of the 'horn-angle' type in which there is no differential movement between fiber and metal. About 1000 times as much energy is needed to evaporate water as to press it out. I have discussed these points more fully elsewhere[7]. When comparing these 3 ways of using the fibrous residue, it should be borne in mind that the 1–2% of nitrogen in it can be recovered for use as fertilizer when the residue is eaten or fermented, but use as fuel wastes the nitrogen.

The protein curd that separates when leaf juice is heated is easily filtered from a 'whey' which contains most of the phosphorus and potassium, and much of the nitrogen, of the leaf. The simplest way to use the 'whey' is to put it back as fertilizer on the land from which the crop was taken. However, it also contains carbohydrate on which yeasts and other microorganisms grow readily. The 'whey' from many species of leaf contains drugs, dyes and substances which could be the starting points for various syntheses. These substances are now usually made be energetically extravagant processes starting with fossil fuels. If we are taking the use of solar energy seriously, the possibility of separating them as by-products from LP production is worth thinking about even if the thought seems a little old-fashioned.

The future of leaf protein in the context of solar energy

If 'energy plantations' develop on the scale that is often envisaged, they will be an important, perhaps the most important, source of LP. Although my primary interest is in the LP, some general comments on photosynthetic methods for exploiting solar energy may be permissible. Most of them were made[8] at a UNESCO conference on 'Wind and solar energy' in 1954; they were then thought far-fetched, but have now become topical.

In 3 obvious ways photosynthesis is preferable to the use of photocells or 'solar towers'. The cost of covering an area with leaf is a tiny fraction of the cost of covering it with photocells or mirrors. Leaves keep themselves clean by continuous growth, whereas the labor involved in keeping other surfaces clean would be formidable; these methods for trapping solar energy might almost qualify as labor-intensive activities! The product of photosynthesis is there for use as and when it is needed, whereas the other methods supply energy only when the sun shines. The principal merit of photocells is that their efficiency is greater and they make electricity whereas plants merely make fuel. However, the argument that both the physical methods could be used in desert areas where plants would be incapable of growth is not quite as simple as it seems at first sight. Any process that changes the character of a large area of the earth's surface may affect the local climate.

There is general agreement that many deserts were created because of deforestation and overgrazing. A suggested mechanism for this desertification is that bare ground, when humus has been oxidised, has a greater albedo than ground covered with vegetation; convection leading to cumulous formation is therefore less over bare ground, and there is less nocturnal cooling. The matter is controversial, but it raises the possibility that, if water could be piped into a desert for a short time so as to reintroduce vegetation on an extensive area, rainfall would increase to such an extent that vegetation would survive without further attention. Although that suggested explanation is controversial, the issue may be pursued a little further. When a sandy area is covered with photocells, or mirrors angled so as to shine on a 'solar tower', there will be a diminution in albedo similar to that caused by vegetation. A hitherto cloudless area, could then become cloudy. If there is validity in this argument, the suitability of an area for photosynthesis is enhanced by using it for that purpose, whereas it is impaired if used for the physical methods. Obviously, this effect, if real, applies only to the exploitation of very large unbroken areas.

Undoubtedly, more water is consumed, in the transpiration stream, when plants rather than physical systems trap solar energy. In some circumstances the use of water by plants is more productive than the uses to which it is now put. Consider an ideal but not unrealistic set of conditions: if water passes through a turbine and is then lost because there is no irrigable land beneath a coastal cliff 100 m high, it produces only a tenth as much power as would have been produced if it had been used to increase plant growth in a semi-arid region at the top of the cliff, and if that extra crop had been burned in an engine with 20% efficiency[9].

In spite of much publicity, progress in exploiting biological methods for trapping solar energy is slow. This suggests that the economic and other advantages of using photosynthesis have not been widely accepted. The case for photosynthesis would be strengthened if LP and other by-products were fully exploited. There is already well financed research in Berkeley and Madison (USA) on large-scale equipment suitable for this job; the most pressing need is for research on the species most suitable for it.

The future of leaf protein in the context of appropriate technology

Research on the production of edible LP on a small-scale for local use is in an almost exactly inverse position. We know many suitable sources of LP, and there is good reason to think that its practical exploitation would have a more immediate effect on the welfare of more people than an increase in the energy supply would have. But there is no simple, robust, and economical unit on the market with which it can be made: nor is there properly financed work on the design of such a unit. Until this work is done, LP will be thought of as an interesting possibility rather than as a recognized food.

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Algae and water plants as energy converters

In H.A. Wilcox' paper the concept of raising seaweeds on huge structures ('ocean farms') is presented and the use of this biomass for food, fibers, fertilizers, methane and other products is described.
The basic problems of collecting energy from the sun through microalgae are discussed by S. Aaronson and Z. Dubinsky. Applications of this technique may be suited for sewage purification plants or in saline ponds in the tropics or subtropics. Many products, such as pharmaceutics and chemical raw materials can be gained from phototrophic microorganisms. Furthermore, the cells can be used to eliminate toxic or polluting compounds.
A similar study is made by C. Santillan as he presents the particular case of *Spirulina* in Mexico, a protein source depended upon the Aztecs already centuries ago.
The paper by T.G. Tornabene reviews the potential that microorganisms have for producing lipids and hydrocarbons and the use of these as fuels.
The special case of the oil alga *Botryococcus braunii* is examined by R. Bachofen. Considerable basic research is still required before it will be possible to induce the state, as is occasionally found in nature, wherein 85% of the dry weight of the algal cells is hydrocarbons.
In the alga *Dunaliella* the main product of photosynthesis is glycerol. A. Ben-Amotz et al. discuss the biological glycerol production from CO_2 with sunlight in ponds. As a raw material for the chemical industry this seems to be a promising alternative for the future.

The ocean as a supplier of food and energy

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Summary. This paper presents the concept of raising seaweeds and other valuable organisms with the aid of huge structures ('ocean farms') emplaced in the surface waters of the open oceans. Potential advantages from and difficulties to be expected in realizing the associated technologies are briefly set forth. Much of the published literature pertaining to the concept is referenced and summarized. Wave-powered upwelling of cool, nutrient-rich waters through vertical pipes extending to depths of 100–300 m is indicated as desirable. Technol-