

18 Leaf Concentrate and Other Benefits of Leaf Fractionation*

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Abstract

Leaf concentrate is an extremely nutritious human food, containing approximately 50% (dry weight) high-quality protein, together with numerous micronutrients, principally β -carotene, vitamins B₆, B₉, E and K, plus iron, calcium and magnesium. Many studies have shown that those consuming it recover quickly from nutritional anaemia and have a significantly improved general state of health. Today, over 40,000 people receive a daily serving of 10g of dried lucerne leaf concentrate.

The fractionation of leaves was first reported over 200 years ago and has been the subject of extensive research and application since the 1940s. The process breaks down the original leaves into three products: residual fibre, 'whey' and leaf concentrate. The whey and the fibre are effective fertilizers, substrates for fermentation and/or animal feed. Through the use of all three products, leaf fractionation can be more productive, in terms of edible protein per hectare of land, than any other known agricultural method.

This chapter presents the history and nutritional qualities of leaf concentrate, provides technical details of leaf fractionation at domestic and intermediate (community/semi-industrial) scales of production, and reviews studies that provide evidence for the effectiveness of leaf concentrate in improving human nutritional status. It concludes by reviewing the factors that have hitherto hindered the widespread adoption of leaf concentrate and leaf fractionation. The authors suggest how these may be overcome, and discuss the potentially wider role of leaf concentrate in alleviating human malnutrition, including its use in a locally produced ready-to-use therapeutic food.

Key words: leaf concentrate, leaf fractionation, food security, nutrition, micronutrient deficiency, β -carotene, vitamin A, iron, anaemia, child and maternal health, HIV/AIDS

Introduction

Here is just one example of a subject that I believe deserves to be better known and

investigated, and whose benefits for undernourished children – and adults – are potentially immense. This is leaf concentrate. (John Waterlow, FRS,

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It is widely accepted that food security and maintaining the social fabric of communities help alleviate and prevent malnutrition (2). Also well recognized is the role of good nutrition in preventing infection and in aiding not only the physical but also the psychological and emotional recovery from illness (3).

Increasingly acknowledged, too, is the brake on economic development caused by malnutrition: almost everyone will know, from personal experience, how lack of food adversely affects strength and the ability to concentrate on a task.

However, still underestimated are the long-term effects of a deficient diet on a mother during her pregnancy and while breastfeeding, and also on the child, especially from weaning to the age of 6 years. The consequences for children's physical development and nervous system can be permanent and limit their ability to learn and later obtain skilled employment. This can significantly impede the evolution and economic progress of countries where nutritional deficiencies afflict a sizeable proportion of the population, particularly the young.

The production of leaf concentrate through the process of leaf fractionation offers a considerable contribution to the alleviation of the problems mentioned above.

All life depends, directly or indirectly, on the products of photosynthesis. Leaf fractionation produces not only a highly nutritious human food – leaf concentrate – that can be made in the home or mass-produced, but also offers a highly efficient way of using agricultural land.

When perennial forage crops are repeatedly harvested on the point of flowering and fractionated, their yield (per unit area) of protein and associated micronutrients is greater than from any other known method of farming (4–6). Because of this, land used for the production of protein-rich crops can be released for growing staple crops, thereby increasing the overall production (per unit area) of a balanced diet.

Such economy of land use, while desirable in any circumstances, is becoming more urgent

and important in the current context of increasing pressure on arable land and water resources from a growing global human population, combined with soil impoverishment and erosion and the erratic rain patterns and potentially rising sea levels associated with global warming. Leaf fractionation is a powerful tool to help manage this changing global situation.

Brief History and Current Status of Leaf Concentrate in Human Nutrition

The following summary is a brief overview of past and present work involving leaf concentrate in human nutrition. For comprehensive details of the biochemistry of leaf concentrate and the technicalities of its preparation, storage and use in human and animal nutrition, readers are directed to what are considered to be the standard texts on the subject (4,7). Details of projects are available through the organizations concerned or in cited references.

The nutritional value of leaf concentrate has been recognized for over 200 years. Its existence was first reported by Rouelle in 1773 (8), who described the curd that he obtained by heating leaf juice as an 'animal-vegetable' substance. Shortly afterwards, Beddoes suggested that it should be made into human food (9). Over the next 150 years there was occasional research, but it was not until the early 20th century that serious work began into the nature of the curd, the methods of separating it from the fibre and the nutritional value of both (10–12).

For over 50 years, from the early 1940s, the leading researcher in the UK was N.W. Pirie, FRS, based at Rothamsted Experimental Station. His team investigated many aspects of leaf concentrate, including biochemistry, toxicology and production. Much of this research, from the late 1960s to the early 1990s, was cross-fertilized by leaf concentrate projects run by 'Find Your Feet', a small British non-governmental organization (NGO), in partnership with local community organizations in Africa, Bangladesh, India and Sri Lanka. From the late 1980s, 'Leaf for Life', based in the USA, began

working with leaf concentrate in Latin America, principally in Bolivia, Mexico and Nicaragua.

Throughout the 1950s, 1960s and 1970s, Kohler and Bickoff, at the US Department of Agriculture in Albany, California, led work on leaf fractionation aimed primarily at reducing the energy costs of high-temperature crop drying. They developed the ProXan registered process, which was adopted by Batley-Janss Enterprises, whose leaf concentrate was shipped in bulk to Japan for incorporation in poultry feed. This operation shut down in 1973 when increases in oil prices rendered shipping costs prohibitive.

In parallel, at the University of Wisconsin, Bruhn, Koegel, Straub and Stahmann investigated the use of leaf concentrate as food in cooperation with F.H. Shah in Pakistan. Members of this group formed the NGO 'Leaf Nutrient, Inc.' to provide equipment and training for village-scale production of leaf concentrate in villages in the neighbourhood of the city of Saltillo, Mexico.

In 1982, a United Nations report concluded that leaf concentrate was safe and nutritious and that sites for its incorporation into traditional foods should be found (13).

Find Your Feet and Leaf for Life initiated over 30 projects, the majority of which were at the lower end of the intermediate scale of production described below. Some of these projects were set up solely to establish the nutritional benefits of consuming leaf concentrate; others had a wider aim of developing economically viable models of leaf concentrate production and consumption that could be adapted as needed for use in other locations with widespread malnutrition. Two projects in particular indicated the potential for local production of leaf concentrate to be self-sustaining; the relevant aspects of these are described below under 'Previous experience of intermediate-scale production' (pp. 351–352).

Since 1975, France-Luzerne, a group of French agricultural cooperatives, has been producing dried leaf concentrate from lucerne (alfalfa) on an industrial scale (currently 12,000 tonnes per annum) using a development of the Pro-Xan process. The leaf concentrate is mainly sold as poultry feed. In the early 1990s, France-Luzerne adapted its process to make

a human food-grade leaf concentrate; since 1994 it has supplied over 480 tonnes of this to local NGOs in over a dozen countries via the French NGO 'Association pour la Promotion des Extraits Foliaires en nutrition' (APEF). This makes it possible for researchers anywhere to obtain uniform samples of dried lucerne leaf concentrate for study, without needing to be involved in setting up and running their own small-scale production plant. In this way, the collection of robust data demonstrating the effects of leaf concentrate in human nutrition has been greatly facilitated. At the time of writing, the cost of food-grade leaf concentrate, ex-works in France, is 1€/kg; thus the cost ex-works of providing a daily 10 g serving of leaf concentrate for one year is less than 4€.

In October 2009, the Commission of the European Communities authorized the sale of dried lucerne leaf concentrate within the European Union (14). Currently over 40,000 people worldwide, mainly children, pregnant and breastfeeding women, the elderly and those affected by HIV/AIDS, receive a daily serving of 5 g (young children) to 10 g (older children and adults) of dried lucerne leaf concentrate.

For over 20 years, Michael Cole has been operating a small fractionation plant at Coombe Farm, Cove, Tiverton, Devon, UK (www.leafcycle.co.uk), developing processing technology and producing leaf concentrate from a wide variety of leaves for organoleptic appraisal and local marketing exercises, selling either direct to the public or through health-food stores. Among the principal findings of Cole's work are the following:

- Confirming Pirie's view that unconventional crops should be investigated (4), Cole's preferred crop is the stinging nettle (*Urtica dioica* L.), a hardy perennial weed, for its vigorous regrowth and yield and the taste of its leaf concentrate.
- The leaf concentrate is well accepted both alone (dried and granulated) and in a novel food, 'Leafu-Tofu', a co-precipitate of leaf and soybean curds (approximately 1:4, dry weight), which is sold vacuum-packed and refrigerated for cold-chain distribution. Leafu-Tofu is green, with the texture of tofu, and analysis indicates that the two curds are complementary as

sources of micronutrients. Funds are being sought for an *in vivo* trial.

- Comparison of the performance of small/intermediate-scale (up to 400 kg/h) pulper and press prototypes with that of one of France-Luzerne's industrial units, using the same raw material (lucerne leaves), indicated that the quality of the prototypes' leaf concentrate was even higher. Funds are being sought to develop these prototypes and increase capacity to 500 kg of leaf crop per hour.

Leaf Fractionation in a Food-based Approach to Combating Micronutrient Deficiencies

Almost all food is derived from the green leaves of plants. There are always losses when that food is translocated to other parts of the plant such as tubers, fruits and seed. The losses are far greater when the food formed in the green leaves is fed to animals. When animals digest the food created by plants, it is upgraded, resulting in new foods that are generally of a higher quality for the human diet, but in far smaller quantities. Thus, simple biology determines that plant-based foods will always be more plentiful than animal-based foods.

Green leaves, particularly those of legumes, are rich sources of many minerals and vitamins, and are an integral part of traditional diets in many parts of the world, including those where malnutrition and undernutrition are prevalent. Leaf fractionation is a means of improving year-round human access to most of the nutrients present in green leaves. At the same time, it removes most of the anti-nutritional components. In this way, it is analogous to separating grains from chaff or peeling a potato (4).

However, in leaf fractionation, all the products are utilized, whereas cereal chaff or potato peel is typically discarded. The process of fractionation creates three products from the original leaves and consists of mechanically separating the leaf juice from the leaf fibre, heating the juice to over 90°C and then separating the resulting green curd – the leaf concentrate – from the brown whey on which it floats.

The precise proportions of the three products will depend on the production method and on the leaf type, condition and volume but, as a rough guide, they are by weight:

- Leaf concentrate (moist) – 5% (~50–60% moisture content).
- Whey – 50% (~93–98% moisture content).
- Fibre – 45% (~50–60% moisture content).

Leaf concentrate is an extremely nutritious human food. It is approximately 50% (dry weight) high-quality protein, containing all essential amino acids, together with numerous micronutrients, principally β -carotene and iron. Various anti-nutritional components are largely removed by the fractionation process.

The fibre, either on its own or mixed with the whey, is a very effective animal feed: on a dry-weight basis, the fibre has a nutritional value roughly equal to, or sometimes better than, the original leaf crop (15,16). Both the whey and the fibre are effective fertilizers, while the whey can also be used as a substrate for fermentation.

Studies over many years have shown that a daily serving of 10 g of dried leaf concentrate has proved effective in alleviating deficiencies in vitamin A and iron (see 'Review of Evidence' below, pp. 357–361), while more recently, in Burkina Faso, communities have found that the incidence of noma (*Cancrum oris*, an oral gangrene) has been eliminated when leaf concentrate is consumed regularly (17,18). Observations of medical professionals are also consistent in noting, in those consuming leaf concentrate, the following effects (19–23):

- A reduction in the incidence of, and improvement in recovery from, diarrhoea and infections of the skin and upper respiratory tract, together with, in many cases, elimination of the need for associated medication.
- Improved post-operative recovery and healing of wounds.
- Rapid improvement in the general condition of various vulnerable groups, including
 - pregnant or nursing mothers (increase in breastmilk and rapid postnatal recovery);

- infants from the start of weaning;
- severely malnourished children, with anaemia and/or kwashiorkor and marasmus;
- sufferers of HIV/AIDS, malaria and tuberculosis, where the leaf concentrate is used as a nutritional adjunct to specific treatment; and
- the elderly.

Fresh, moist leaf concentrate has the consistency of a crumbly cheese and is bright to dark green in colour; it can be used fresh or may be preserved, usually by granulating and drying, after which it is ground to a flour for use.

Several decades of experience in many countries have demonstrated that leaf concentrate, fresh or dried, is highly acceptable and can be easily incorporated into local diets, in main meals, snack foods and drinks. Projects have varied significantly in their level of sophistication, from preparation at home, through distribution in social programmes to the marketing of retail products. The emphasis has always been on the importance of good nutrition for childhood and maternal health. Some examples now follow, together with aspects that were found to be important to their success.

As part of its wider programmes of building food security, nutritional education and child and maternal health, the Nicaraguan NGO 'Soynica' has been using leaf concentrate as a source of home fortification since 1989, initially with leaf concentrate made from local leaves and, since 1994, with dried lucerne leaf concentrate supplied by APEF. As well as providing powdered leaf concentrate for incorporation into families' normal diets and organizing 'community kitchens' to help mothers prepare meals with leaf concentrate, Soynica has developed a range of commercial products, including cereal mixes and teas enhanced with soy and leaf concentrate. Since the first Soynica/APEF study on 174 children and 15 pregnant women in 1995, Soynica's programme has grown to distribute leaf concentrate to over 22,000 children and 10,000 adults in urban and rural areas.

Since 2002, the French NGO 'Enfants du Monde' (EdM) has been distributing leaf

concentrate in Burkina Faso in a programme of home fortification. Initially, mothers were supplied with sachets on a weekly basis, each sachet containing 10 g of dried lucerne leaf concentrate, to be mixed into their children's normal diet at home, typically millet or sorghum balls. The programme has grown from a few tens of children in 2002 to over 7000 in 2009, including 5000 children in 52 schools. The leaf concentrate is delivered to the schools in bulk and given to children directly in its powdered form. The children receive 5 g/day for the first two weeks, after which they are given the full 10 g/day. As noted above, the programme has resulted in the elimination of noma (*C. oris*) when leaf concentrate is regularly consumed (17,18). Its success has been due to extensive awareness and education campaigns, the local populations' recognition of the health benefits of consuming leaf concentrate and the ease with which leaf concentrate can be eaten 'as is' or incorporated into traditional foods. EdM also distributes leaf concentrate to over 7000 children in Madagascar and to nearly 1000 children and pregnant and lactating women in Senegal.

In hot climates, cold, sweetened drinks enriched with leaf concentrate are well received: *atole* (a thin, drinkable porridge common in much of Latin America) and lemonade have proved particularly popular. Drinks are normally easy to prepare, as they only require the leaf concentrate to be measured out and stirred in. Experience has shown that drinks tend not to be regarded by families as 'meals', which is often beneficial for the children receiving them: even a small amount of solid food, such as a biscuit given at school or in a day care centre, may mean that a child receives less food than usual at home.

In Mexico, the NGO 'Asociación Franco, Mexicana, Suiza y Belga de Beneficiencia' has worked with local food manufacturers to develop a range of products – candy bars, candy powder, *atole* mix and baby food – under the trademark 'Fortiplus', all containing dried lucerne leaf concentrate. The products are distributed by a variety of organizations to the children, aged 6 months to 6 years, in their care. The programme has been running for 8 years and, in 2009, comprised 79

institutions with 130 establishments in five states; over 6 million portions have been served. In 2009, the number of beneficiaries increased from 15,000 to 25,000.

In several countries in Latin America, small cooperatives of local women, usually with support from a government agency, church or civic organization, have made their own leaf concentrate, incorporating it into a range of retail products. The normal requirements of attractive presentation, packaging, good shelf-life and value for money apply to foods and drinks containing leaf concentrate as to most other products. In addition, the green colour imparted by the leaf concentrate to some products may be unfamiliar.

The most successful products have been pasta, lemonade syrup and *churritos* (a spicy, fried, maize-based snack). Snack foods are often better accepted than foods intended for primary meals, as people are more adventurous about trying them than integrating a new staple into the traditional diet at home. Snack foods also appeal more to the young, are identified with fun, and are usually sold in small units, all of which encourage people to try them. In addition, leaf concentrate-enriched pasta has been well received, particularly by those familiar with green pasta commonly found in developed countries.

One of the advantages of leaf fractionation is that it can be undertaken on a range of scales (domestic and intermediate, as described further below); some important differences between the scales are now highlighted, as they are fundamental to the understanding of the different ways in which leaf fractionation can play its part in a food-based approach to combating micronutrient deficiencies.

At the *domestic* or small group level, leaves can be fractionated using equipment commonly found in the kitchen and can be integrated with other activities. Domestic leaf concentrate is typically consumed fresh, which simplifies production and eases incorporation into local diets. The quantities of leaf used are small – 2 kg of leaves per day will provide enough leaf concentrate for a family of four – and hence they can often be obtained from a home garden or even collected from the wild. The fibre and the whey will normally be used within the family or

group setting to fertilize a home garden or provide fodder for domestic animals. In this way, domestic leaf fractionation may be undertaken almost entirely outside the cash economy, a feature that reinforces community resilience in times of hardship.

In certain circumstances, increasing the scale of leaf fractionation may be the preferred option. In this chapter we refer to this as *intermediate-scale production*, or ISP. ISP aims to realize the full economic value of all the products of leaf fractionation in order to provide sustainable production. ISP leaf concentrate is dried, which facilitates storage and transport from production sites to areas of need, which may include neighbouring communities. ISP's benefits of improved efficiency will outweigh the demands of increased complexity.

Where local conditions, be they climatic, agronomic, social or economic, do not permit the production of leaf concentrate, for example in emergency or disaster situations or in arid areas, imported leaf concentrate from the existing industrial units in France can provide an essential source of various micronutrients to a human population in need. It can also provide a source pending the establishment of a local leaf fractionation capability.

Nutritional Qualities of Leaf Concentrate

This section summarizes the most important nutritional constituents of leaf concentrate and describes some aspects that make it particularly effective in combating micronutrient deficiency malnutrition, including that of those affected by HIV/AIDS. Evidence for the effectiveness of leaf concentrate in combating micronutrient deficiencies is extensive (see 'Review of the Evidence' for more details, pp. 357–361).

The three deficiencies that are considered to be of greatest global public health significance are those of vitamin A, iron and iodine (24). As shown in Tables 18.1 to 18.4, leaf concentrate is rich in the first two of these – β -carotene (provitamin A) and iron – while also containing a high-quality protein and many other micronutrients. The iodination of

Table 18.1. Dried lucerne leaf concentrate: general composition and comparison with whole milk powder (Adapted from Bertin (25).)

| | Mean composition (%) | |
|------------------|----------------------|-------------------|
| | Leaf concentrate | Whole milk powder |
| Water | 8 | 3 |
| Protein | 50.8 | 26 |
| Lipids | 10.2 | 26 |
| PUFA | 4.7 | 0.9 |
| ω -3 PUFA | 3.5 | 0.2 |
| Minerals | 10.6 | 8 |
| Fibre | 2.5 | – |

PUFA, polyunsaturated fatty acids.

salt is a widely used, cheap and effective solution to the third.

The consumption of whole foods, such as fruit and vegetables, appears to have greater beneficial effects than taking dietary supplements containing isolated vitamins or minerals (27). Studies with leaf concentrate, a food that similarly combines a wide range of nutrients and micronutrients, support these observations, particularly with regard to the absorption of iron to alleviate iron-deficiency anaemia. For example, a recently published trial (28) found that 'daily

servings of leaf concentrate, containing 5 mg iron and 13 μ g folic acid, are as effective as daily supplements containing 60 mg iron and 500 μ g folic acid for treating anaemia in adolescent girls. Similar improvements in the blood parameters of the participants were seen in both arms of the trial, suggesting that the lower iron content of leaf concentrate may be offset by better bioavailability of iron in leaf concentrate and/or synergistic effects of other components of leaf concentrate'.

Infection with HIV increases a person's nutritional needs to fight infection, rebuild muscle tissue and gain or at least maintain weight. These needs increase as the HIV/AIDS symptoms develop. However, for various reasons, such as reduction in appetite, digestive system problems and lack of income, the food intake and absorption of nutrients of those affected with HIV declines. All these factors increase preference for a concentrated food containing proteins (for rebuilding muscle tissue), vitamins and minerals (to support the immune system) and carbohydrates and fats (for energy). Several small trials with lucerne leaf concentrate have shown favourable early results (e.g. in Burundi (29) and Cameroon (APEF, 2007, internal document)) and support field observations elsewhere (18,19).

Table 18.2. Dried lucerne leaf concentrate: essential amino acid composition and comparison with other foods. (Adapted from Bertin (25).)

| Essential amino acid (g/100 g food) | Leaf concentrate | Eggs | Whole milk | Beef (steak) | Chicken | Cooked rice |
|-------------------------------------|------------------|------|------------|--------------|---------|-------------|
| Valine | 3.1 | 0.8 | 0.2 | 1.6 | 1.3 | 0.2 |
| Leucine | 4.7 | 1.1 | 0.3 | 2.6 | 2.0 | 0.2 |
| Isoleucine | 2.6 | 0.7 | 0.2 | 1.5 | 1.4 | 0.1 |
| Methionine | 1.0 | 0.4 | 0.1 | 0.8 | 0.7 | 0.1 |
| Cysteine | 0.5 | 0.6 | 0.0 | 0.8 | 0.7 | 0.1 |
| Tryptophan | 1.2 | 0.2 | 0.1 | 0.2 | 0.3 | 0.0 |
| Threonine | 2.4 | 0.6 | 0.1 | 1.3 | 1.1 | 0.1 |
| Lysine | 3.1 | 0.9 | 0.1 | 2.7 | 2.3 | 0.1 |
| Histidine | 1.2 | 0.3 | 0.1 | 1.0 | 0.8 | 0.1 |
| Phenylalanine | 3.0 | 0.7 | 0.1 | 1.3 | 1.1 | 0.1 |
| Tyrosine | 2.2 | 0.5 | 0.2 | 1.0 | 0.9 | 0.1 |
| Methionine + cysteine | 1.5 | 0.7 | 0.1 | 1.3 | 1.1 | 0.1 |
| Phenylalanine + tyrosine | 5.2 | 1.2 | 0.3 | 2.3 | 2.0 | 0.2 |
| Total essential amino acid content | 25.0 | 6.8 | 1.5 | 14.8 | 12.6 | 1.2 |
| % Moisture | 8.0 | 74.0 | 88.0 | 56.0 | 65.0 | 23.0 |

Table 18.3. Dried lucerne leaf concentrate: principal vitamin content and contribution to children's Recommended Nutrient Intake (RNI). (Adapted from Bertin (25).)

| Vitamin | Mean content per 10 g | % of RNI for child aged 4–6 years (26) |
|--|-----------------------|--|
| A (β -carotene) ^{a,b} | 767 μ g RE | 170 |
| B ₁ (thiamin) ^b | 0.022 mg | 4 |
| B ₂ (riboflavin) ^b | 0.044 mg | 7 |
| B ₃ (niacin) ^b | 0.042 mg | 1 |
| B ₅ (pantothenate) | ~0 mg | 0 |
| B ₆ | 0.58 mg | 97 |
| B ₈ | 1.5 μ g | – |
| B ₉ (folate) ^b | 13.4 μ g | 7 |
| B ₁₂ ^b | 0.21 μ g | 18 |
| C ^{b,c} | 6 mg | 20 |
| D | ~0 μ g | 0 |
| E ^b | 9.9 mg | 198 |
| K | 0.08 mg | 400 |

^aBecause vitamin A is supplied in the form of β -carotene, there is no risk of an excess of vitamin A; 1000 μ g of β -carotene = 167 μ g retinol equivalents (RE).

^bIdentified as important vitamins and minerals for people living with HIV/AIDS (3).

^cVitamin C is added by France-Luzerne during the production of leaf concentrate at a concentration of 60 mg/100 g leaf concentrate.

Table 18.4. Dried lucerne leaf concentrate: principal mineral and trace element content and contribution to children's Recommended Nutrient Intake (RNI). (Adapted from Bertin (25).)

| Mineral/trace element | Mean content per 10 g (25) | % of RNI for child aged 4–6 years (26) |
|------------------------|----------------------------|--|
| Calcium ^a | 338 mg | 56 |
| Magnesium ^a | 14.8 mg | 20 |
| Phosphorus | 79.1 mg | – |
| Potassium | 80.1 mg | – |
| Sodium | 1 mg | – |
| Copper | 0.076 mg | – |
| Selenium ^a | 0.5 μ g | 2 |
| Iodine ^a | 3 μ g | 3 |
| Iron ^a | 5.4 mg | 135 ^b |
| Zinc ^a | 0.2 mg | 6 ^c |

^aIdentified as important vitamins and minerals for people living with HIV/AIDS (3).

^bAt 15% bioavailability.

^cHigh bioavailability.

While retaining the greater part of many of the nutritional components of the original leaf, the process of making leaf concentrate also largely removes many anti-nutritional elements. Their residues in leaf concentrates, such as phytates, saponins, L-canavanine and phyto-oestrogens, including coumestrol, are present in concentrations that are insignificant owing to the small quantities of leaf concentrate consumed (25).

Tables 18.1 to 18.4 summarize the principal nutritional components of leaf concentrate, based on routine analyses of lucerne leaf concentrate produced industrially in France. In Tables 18.3 and 18.4, values for selected nutrients are compared with recommended daily intakes for children (26) as indicated and those vitamins and minerals identified as important for people living with HIV/AIDS are highlighted (3).

Domestic-scale Leaf Concentrate Production

This section describes the production and use of leaf concentrate within a family, a small group of families or a small institution such as a school. Although at the upper end (in quantity of leaf crop processed per day) there may be some overlap in machinery with the intermediate-scale production described in the next section (pp. 349–357), it should be noted that small group production in this context is quite separate: in general, all of the products – the leaf concentrate, fibre and whey – would be utilized by the group of families, or organization, producing them; if any income could be generated through the sale of any of the products, this would be a bonus, rather than a primary objective.

Long-term solutions to malnutrition require local control of a diverse food supply. While it may be reasonable to import some occasional luxury items, dependence on importing basic daily foods makes a community inherently vulnerable.

The production of leaf concentrate through domestic-scale leaf fractionation offers a simple and inexpensive means of upgrading the nutrient availability from green leaves for individual families or small groups of families, thereby improving their ability to control their own nutrition. It improves self-reliance for those on a low income and, in situations of unemployment and underemployment, enables a family to make economic use of available labour outside the cash economy as it can be easily integrated with other activities. In addition, the cultivation of leaf crops for fractionation, particularly leguminous crops, can enhance the productivity of available land, while reducing the need for, and therefore the cost of, chemical fertilizers, herbicides and pesticides.

Production can be scaled according to need, so that there is no need to store excess leaf concentrate that is not to be consumed the same day, although leaf concentrate can be readily incorporated into a wide variety of dishes for later use. In addition, the quantities of fibre and whey are small and can generally be used (for feeding and watering

domestic animals) by the family producing the leaf concentrate.

Crop selection, management and harvesting

Two kilograms of leaf will produce about 100 g of fresh, moist leaf concentrate, which is sufficient to provide significant insurance against most micronutrient shortfalls for a family of four. This quantity of leaf can be obtained in various ways, for example from a home-garden, by children weeding a corn-field (e.g. pigweed (*Amaranthus retroflexus*) or lambsquarters/Fat Hen (*Chenopodium album*)), or it can be acquired from a market as fresh forage crop (e.g. lucerne).

To have fresh leaf concentrate daily over the course of an eight-month growing season, a family of four would therefore need to obtain a total of about 500 kg of fresh leaves. Although the yields of leaf crops vary greatly with climate, soil, variety, planting density and cultivation techniques, there are several crops that can produce over 50 tonnes of fresh leaf per hectare, and some that can produce more than double that (e.g. amaranth or lucerne). This means the entire leaf crop needed for the year could be raised on less than 100 m² of land. Some of the best crops for leaf concentrate production are listed in Box 18.1.

The first five plants listed in Box 18.1 are legumes capable of both high leaf yields and

Box 18.1. Preferred crops for leaf fractionation.

- *Medicago sativa* (lucerne or alfalfa)
- *Vigna unguiculata* (cowpea)
- *Trifolium alexandrinum* (berseem clover)
- *Lablab purpureus* (lablab or hyacinth bean)
- *Clitoria ternatea* (butterfly or Kordofan pea)
- *Brassica oleracea* (collards or kale)
- *Brassica juncea* (mustard)
- *Beta vulgaris* var. *cisla* (Swiss chard)
- *Atriplex hortensis* (orach, mountain spinach)
- *Triticum aestivum* (wheat)
- *Hordeum vulgare* L. (barley)
- *Amaranthus tricolor* (amaranth)

good fixation of atmospheric nitrogen; the latter helps to reduce the need for artificial fertilizer.

Leguminous leaf crops also lend themselves to intercropping. For example, cowpeas or lablab beans can be grown in between rows of maize, sorghum, millet, cassava, yams or bananas, helping to reduce the growth of weeds.

Intercropping is, moreover, mutually beneficial: two hectares of maize and cowpeas intercropped will usually produce about 30% more than one hectare of maize and one hectare of cowpeas. Three hundred square metres of maize, cassava or bananas intercropped with cowpeas could reasonably produce enough cowpea foliage for a family's leaf concentrate, without competing with the other crops. Furthermore, cowpea leaves can be harvested at least once without significantly affecting the yield of beans.

In addition to intercropping, fast-growing crops for leaf concentrate can be grown before or after a grain crop. Cowpeas, lablabs, bell beans, field peas and butterfly peas are well suited because they fix enough nitrogen to benefit the crop that follows or to replace the nitrogen used by the grain crop. In this way, the entire growing season can be economically utilized. Some non-leguminous leaf crops such as amaranth are enormously productive (up to 170 tonnes of leaf per hectare per annum under intensive cultivation) and ready for a first harvest in less than 30 days. Lucerne and perennial clovers do well as an undercrop in fruit or nut orchards. The multiple uses for many of the best leaf concentrate crops provide the small grower or part-time farmer with much flexibility.

Preparation of fresh leaf concentrate

The preparation of leaf concentrate in the home is straightforward. Domestic production can be integrated with other activities: for example, a mother grinding leaves for her family can simultaneously watch over her children and can cook beans with the same fire that heats the leaf juice.

The steps are described in Box 18.2, based on information taken from 'The Domestic

Method of Making Leaf Concentrate', a guide produced by the Nicaraguan NGO Soynica (30). As with most food processing, quality control throughout is critical to acceptance – burning of the curd, spoilage of leaves or curd, and inadequate pressing of the whey can all lead to leaf concentrate with unacceptable flavour.

Consumption and storage of leaf concentrate

Although dried leaf concentrate can be stored for 6 months or more if it is kept in an airtight container and out of the light, a significant advantage of domestic-scale production is that all of the product can be used fresh. This greatly simplifies packaging and storage, as well as eliminating the steps involved in preserving the leaf concentrate.

Food and drink preferences vary enormously between and within cultures, countries and communities. In many parts of the world, the consumption of leaves that are suitable for fractionation is already part of the traditional diet. For example, cowpea leaves are used as a potherb vegetable in many parts of Africa and southern Asia, while the Sri Lankan dish *kola kanda* is made by pounding leaves and coconut in a mortar, squeezing out the juice and adding it to boiled rice.

Fresh leaf concentrate is best used the same day it is made or the next day, unless it can be refrigerated, in which case it may last up to a week. It disperses more readily in liquids than its dried alternative and can be easily added to soups, stews and porridges or be incorporated into a variety of sweets and other dishes. One of the most popular options, which is also a good method of preserving the fresh leaf concentrate, is to add it to a syrup of lemon juice and sugar. This has the advantage for those suffering from anaemia of supplying vitamin C, which significantly improves absorption of the iron from the leaf concentrate. Also easy to make and with a good shelf-life is pasta: at flour to leaf concentrate ratios of 10:1 (dried) or 4:1 (fresh), a 100 g serving of pasta will provide the recommended daily portion of leaf concentrate. Box 18.3 contains a list of

Box 18.2. Domestic-scale leaf fractionation: production steps. (Adapted from Soynica (30).)

1. *Gather the leaves:* use very young leaves, before, or just after, the plant starts flowering. Choose tender leaves, rejecting any that are tough or dry. Immediately after harvest start the following steps.
2. *Wash the leaves* in clean water to remove mud or dust and foreign objects.
3. *Sorting:* strip away any tough stalks by hand or with a knife. Shred the leaf blades to make pulping easier.
4. *Pulping:* this is the most difficult part but very important to ensure a good yield of leaf concentrate; if the leaf cells are not thoroughly ruptured, yields of leaf juice and consequently leaf concentrate will be adversely affected. A manual meat mincer is suitable, as is a pestle and mortar. If electricity is available, a kitchen mixer or an electric grinder makes the process easier. A little extra water may be needed to help leach out the protein, but often the residual water left on the leaves after washing is enough. Added water increases the cooking fuel required to bring the juice to boiling point.
5. *Pressing:* wrap the pulped leaves in a previously moistened, open-weave cloth and use convenient objects – stones or boards – to press the pouch as well as possible, catching the green leaf juice in a suitable vessel. It is important to keep the layer of pulp thin: if the initial layer of pulp is more than 2–3 cm thick, some of the protein molecules will be trapped in the tightly compacted fibre, thus reducing the yield and quality of the leaf concentrate. Pressing the fibre should take no more than 5 min.
6. *Heating:* heat the green juice quickly while stirring to prevent it from sticking; slow heating can damage the nutritive value, but burning the curd may adversely affect its taste. Coagulation occurs from 45 to 75°C but it is essential to go on heating just to boiling point to achieve:
 - the virtual elimination of bacteria;
 - the minimization of undesirable components, and
 - improvement of the texture of the curd, facilitating filtration.
7. *Filtration:* filter the hot juice through a previously wetted, tightly woven cloth, such as denim or twill, to separate the green curd from the whey.
8. *Pressing:* when pressing the curd, pressure should be applied more gradually than when pressing the fibre, and for longer, if necessary overnight. Remove as much whey as possible: what stays in the cloth is moist green leaf concentrate, ready to eat. When it has been adequately squeezed it will peel cleanly from the cloth and will have the consistency of a crumbly cake.

25 recipes tested for their acceptability in several countries. Full details are given elsewhere (6).

Fresh leaf concentrate can also be preserved by pickling or drying, for example with a simple solar dryer with good airflow. It dries faster and more evenly if it is granulated first, for example by rubbing it through a screen. The leaf concentrate must be kept out of direct sunlight and the maximum drying temperature is about 55°C.

Use of fibre and whey

One of the advantages of leaf concentrate production is that there should be no waste: the whole above-ground plant is used. As a general guide, taking into account some water added for cleaning and processing, 2 kg of leaf will produce:

- Leaf concentrate (moist) – 0.1 kg (~50–60% water content).
- Whey – 1 litre (~93–98% water content).
- Fibre – 1 kg (~50–60% water content).

The fibre has two principal uses: as animal feed and as green manure.

- Cattle, horses, sheep, goats, rabbits and guinea pigs have all been successfully raised using the fibre as a primary or secondary feed. Some care must be exercised, however. For example, residual fibre from lucerne is likely to have too much calcium to be a good choice for feeding rabbits more than 6 months old. The manure that is produced by animals eating the fibre can also be used to enrich soil.
- Research in India has shown that yields of wheat were greatly increased when it was sown 30–40 days after a

Box 18.3. Recipes for foods containing leaf concentrate.

| Recipe | Main country/area of consumption (if applicable) |
|---|--|
| Leaf concentrate syrup | |
| Lemonade concentrate syrup | |
| Pasta | |
| Soup nuggets | |
| <i>Atole</i> | Latin America |
| Porridge | |
| Soymilk shake | |
| Frozen banana/milk snack | |
| <i>Laddu</i> | India |
| <i>Tortillas</i> (corn/wheat flatbread) | Latin America |
| <i>Tamales</i> | Latin America |
| <i>Uchepos</i> | Mexico |
| <i>Kola kanda</i> | Sri Lanka |
| Curried potato soup | |
| Lemon trail bars | |
| <i>Barfi</i> | India |
| Leaf concentrate rice | India |
| <i>Tikki</i> | India |
| Tamarind jelly | Nicaragua |
| Green salsa | Mexico |
| <i>Churritos</i> | Latin America |
| Potato/carrot pancakes | Mexico |
| Swedish vegetarian meatballs | |
| Leaf burger | |
| Vegan leaf burger | |

green manure crop of *Sesbania sesban* or *Crotalaria juncea* had been fractionated before its fibre was tilled in (31).

Other potential uses for leaf concentrate fibre include making biogas for cooking (the slurry remaining from making biogas also improves soil fertility) and enriching the soil through improving soil structure and the availability of soil minerals.

The whey is also a very useful by-product. It can be re-mixed with the fibre prior to use as animal feed, or used diluted with water as a garden fertilizer, as it contains enough nitrogen and potassium to be effective in this capacity.

From domestic to small group production

Single-family production can readily be extended to a small group of families: for example, five or six families could rotate responsibility for making the leaf concentrate. On the next

level, a school, church, orphanage or social club could make leaf concentrate for up to 100 children with a modest investment in equipment. This would require processing about 40 kg of fresh leaf daily, for which a manual meat grinder driven by a small geared-down electric motor would be suitable. Box 18.4 contains a sample of small-scale leaf processing equipment, together with country of use.

It is important to note that processing more than 10–20 kg of leaf crop per day will normally require some form of non-manual power, and also to emphasize the importance of reliable, efficient machinery (32).

Intermediate-scale Leaf Concentrate Production

Introduction

This section addresses the production of leaf concentrate on an 'intermediate' scale,

Box 18.4. Examples of domestic-scale leaf processing equipment.

| Description | Capacity (kg leaves/h) | Countries of use | Function | Advantages | Disadvantages |
|---|------------------------|---------------------|-----------------------------|--|---|
| Pedal-powered combined screw pulper and press | 15–20 | India Sri Lanka | Pulping and pressing leaves | Continuous operation; human-powered; combines pulping and pressing | Requires human power so can be tiring |
| Mechanized combined pulper and press | Up to 100 | Bangladesh Ghana | Pulping and pressing leaves | Continuous operation; powered by electric motor or internal combustion engine; combines pulping and pressing | Can be noisy; requires non-human power |
| Electric-powered blender: scaled-up version of domestic blender with 20-litre vessel and 0.74 kW electric motor | 100 | Mexico Nicaragua | Pulping leaves | Effective pulper; easy to manufacture and use | Requires water to be added to vessel; requires electric power; seals on motor can leak; batch operation |
| Vertical-axis rotational pulper ('impact macerator') | >150 | Mexico | Pulping leaves | Effective pulper; easy to manufacture and use; continuous operation | Can be noisy |

i.e. larger than the domestic operation discussed in the previous section, but much smaller than the existing industrial scale in France.

While domestic production operates mostly outside the cash economy, ISP functions mostly within it. Raw materials are bought, and production sold, in order to balance its budget and be sustainable.

The philosophy underlying ISP is that its size and nature can adapt to the needs of the communities that it is serving. The correct scaling of leaf concentrate production between domestic and larger systems is a crucial consideration in terms of feasibility and sustainability. An appropriately scaled project is more likely to achieve synergies with existing socio-economic activities. It limits wastage, secures in-kind benefits

and/or recycles cash benefits in the local economy. It offers some independence from fluctuations in markets for food supplies, livestock feeds and soil fertilizers, and contributes to community social stability and security.

Where circumstances are favourable, it is possible to achieve higher productivity with larger schemes which require and benefit from greater complexity. In such circumstances, production can probably exceed local needs and any surplus thus becomes available for neighbouring communities.

The optimal ISP size will vary with the context. Daily processing capacity can range from 300 kg of leaves for a village of 600 people to 30 tonnes for a region with a population of 60,000; feasibility tends to be

limited upwards by the number of livestock that can reasonably be concentrated in one place (for organizational and ecological considerations) and downwards by the minimum productivity required to balance capital investment and labour.

ISP can develop synergies with existing food systems in the following areas:

- Improving human nutrition.
- Maximizing productivity of available land.
- Improving, conserving and fertilizing the soil.
- Improving livestock feed.
- Providing employment opportunities for local people.
- Contributing to ecological sustainability.

The following subsections describe the key elements of ISP; then a case study of an ISP scheme is presented, illustrating the combination of learning from both smaller- and larger-scale production.

Fundamentals of intermediate-scale production

The fundamentals of ISP are derived from the experience of many, mostly village-scale, projects in Africa, Asia and Latin America, combined with learning from over 35 years' continuous industrial production of leaf concentrate in France.

Previous experience of intermediate-scale production

Village-scale ISP has been the subject of over 20 studies of various durations, mainly run by the NGOs Find Your Feet and Leaf for Life, in partnership with local organizations in Africa, Bangladesh, India, Latin America and Sri Lanka. Together they have provided a large amount of information regarding crop selection and management, machinery, organization and logistics and the development of markets in different cultural environments. Two of these projects are now described briefly.

1. *Kpone Bawaleshie, Ghana*. In the early 1980s, a cooperative operated in Kpone Bawaleshie, near Accra, Ghana, producing leaf concentrate, silage and potable alcohol from a variety of local leaves (33). The leaves were collected by villagers, either from their cultivated plots or the wild, and paid for in cash, thus offering a source of income even for those without the time or ability to grow suitable crops. The leaf concentrate, fresh or preserved moist with salt, was sold within the village and incorporated into the mid-day meals of pre-school children. The silage and alcohol were sold outside the community to provide a net financial income. A preliminary economic assessment indicated that the operation was potentially viable, even though income from the sale of silage had not, at that stage, been calculated: leaf concentrate could be sold at a price that would cover the direct purchase of the leaves, while the sale of the alcohol just exceeded all other costs, to provide a net profit of just over 6%.

2. *Bidkin, India*. The project at Bidkin, near Aurangabad, India, which ran in the late 1970s and early 1980s, carefully examined the economics of leaf concentrate production using equipment handling up to 150 kg of fresh lucerne per hour (34,35). The study concluded that it would be viable at a processing capacity of 500 kg/h. The leaf concentrate was sold in enriched wheat flour and in a milk replacement formula for calves, while the fibre, after mixing with some of the whey, was fed fresh to local cattle, ensiled, or incorporated into a dry cattle fodder mix. The proposal was to extend the operation to provide local farmers with an alternative to growing sugarcane or bananas, the most profitable local cash crops. For the farmers, a significant advantage of growing lucerne was that it provided cash flow: they received income each time it was harvested, on average every 3 weeks, rather than only after a year, as was the case with the other crops, thus reducing their need to borrow money. However, suitable machinery for processing leaves at this rate was not available at the time, and the funds could not be found to develop it.

Over the past 15 years, there have been developments in machinery that would make such a study feasible. A vertical-axis rotational pulper has been developed in the USA and was successfully used for 8 years by a cooperative of women in Zacapu, Mexico (D. Kennedy, 2007, report from Leaf for Life to APEF). The most recent prototype combines a development in the UK of this pulper with a new design of screw press, which has performed well up to a level of approximately 400 kg of fresh leaf crop per hour (see 'Brief History' above, p. 341). While facilitating studies such as that proposed by the Bidkin researchers into higher production rates, more efficient processing is likely to make leaf fractionation sustainable at lower levels as well.

Industrial production of leaf concentrate

France-Luzerne's current units are capable of processing up to 150 tonnes of freshly cut lucerne per hour to produce high-quality dried cattle feed – made from de-watered leaf fibre mixed with concentrated whey – and a dried, granulated leaf concentrate, for use in poultry diets and (since 1994) human nutrition. The processing machinery is custom-designed and the operation is fully integrated with the surrounding agricultural economy, involving thousands of hectares of nearby fields dedicated to the cultivation of lucerne and thousands of beef and dairy cattle in other regions and abroad.

The considerable volumes produced by the very large industrial plants necessitate the dehydration of press-cake and whey at high cost before their transportation to distant livestock-raising areas, which is a concern in terms of both rising energy costs and ecological impact. One distinctive feature of ISP is the absence of the high-temperature drying of the leaf concentrate's by-products. Instead, they are mainly mixed together and fed immediately as the main component of the diet to a local herd of cattle (or other herbivores). Some of the by-products will be conserved in the cheapest possible way for use out of season. Depending on climate, they will be sun-dried or ensiled.

Key elements of sustainable intermediate-scale production

Although the industrial scale of operation is substantially larger than any envisaged within ISP, there are important principles underlying its continued success – and therefore sustainability – that apply to ISP. Experience of both village-level ISP and industrial production has identified the principal requirements and benefits of ISP as described below.

REQUIREMENTS *Crop specialization and intensification.* Different leaves have different processing qualities, so the selection of a single crop allows the pulping and pressing equipment to be designed to work optimally with one type of leaf. In addition, whether the crop is grown within an integrated operation or provided by external suppliers, a single crop type makes harvesting easier to plan and undertake. Lucerne, a crop particularly suited to leaf concentrate production, also has wider agricultural benefits, which are discussed below. In addition, the nutritional qualities of lucerne leaf concentrate have been extensively demonstrated (see 'Nutritional Qualities of Leaf Concentrate' (pp. 343–345) and 'Review of Evidence' (pp. 357–361)). For these reasons, it is recommended as a starting crop, where suitable, for any new ISP; with experience, other crops better adapted to specific soils and climates will offer further opportunities.

Coordination of harvesting and production schedules. Harvesting needs to be planned in order to: (i) maximize the time that the production plant is operational; and (ii) ensure that the leaves are at the optimum state of maturity to maximize both the yields of leaf concentrate and the quality of the fibre.

Integration of livestock. The direct feeding of livestock incorporated into an ISP scheme is essential to accommodate any mismatch between harvesting schedules and production unit operation.

- Some of the fibre will routinely be conserved for the off-season as sun-dried 'hay' or, mixed with some of the whey, as

silage; integrating cattle into the scheme allows this quantity to be adjusted to herd size, crop production and relative length of wet and dry seasons.

- When the volume of crop ready for harvesting exceeds the plant's processing capacity, e.g. during the first cut or after rains, the surplus can still be harvested in peak condition but 'bypass' the extraction plant and be sun-dried or ensiled.

Appropriate processing technology. Typically, larger-scale production is more efficient but also carries higher capital cost. ISP covers a wide range of processing capacities, and different machinery is appropriate at different levels. The case study reported below utilizes technology developed from both village and industrial levels.

Creation/establishment of markets for all products. Experience at both village and industrial levels has shown that realizing the economic value of all the products – the leaf concentrate, fibre and whey – by developing markets for them, preferably in the project area, is a prerequisite for the sustainable establishment of ISP, so a scheme can only be realistically considered in areas acquainted with the raising of livestock. Some examples of successful marketing approaches and products are provided above (see 'Leaf Fractionation in a Food-based Approach' (pp. 342–343) and 'Previous experience of intermediate-scale production' (pp. 351–352)). In Mali, women's groups are also incorporating leaf concentrate into fruit pastes. Local government support and funding are likely to be required to help develop these markets.

BENEFITS *Improvement in human nutrition.* The nutritional qualities of leaf concentrate have been discussed above ('Nutritional Qualities of Leaf Concentrate', pp. 343–345) while the evidence for its effectiveness is presented below ('Review of Evidence', pp. 357–361). The dried leaf concentrate produced in ISP stores well and is neither bulky nor heavy, easing transport to areas in need. It can be consumed either on its own or incorporated into a wide range of snacks, meals and drinks (see 'Consumption and Storage of Leaf Concentrate', pp. 347–348). In this way, ISP

provides an additional option at an affordable price for sourcing proteins, phytochemicals, vitamins and minerals where the capacity of a community to produce this variety in its food may be challenged by climatic, economic, social or other disorders (33).

Maximizing productivity of available land.

Two factors contribute to maximizing the productivity of available land:

- Because leaf fractionation of a forage crop produces more protein per hectare than any other use of the land, ISP reduces the area required for production of protein sources and thus releases arable land for the cultivation of staple foods (4–6).
- Extensive experience with lucerne in many countries has shown that it is particularly suited to leaf concentrate production in a variety of climates. It is high-yielding, typically producing over 50 tonnes of fresh leaf per hectare in six harvests in an 8-month growing season; under certain conditions, for example those described by Joshi *et al.* (34) near Bidkin, India, annual yields can be as high as 160 tonnes in 15 cuts, if irrigation allows cultivation throughout the year.

However, the opportunity cost of implementing an ISP in a zone experiencing competition with other food crops should also be considered (see Bidkin project under 'Previous experience of intermediate-scale production', pp. 351–352).

Soil improvement, conservation and fertilization. Lucerne brings the following additional agricultural benefits (some are shared by other legumes):

- Year-round soil cover and a strong root system help prevent leaching and loss of topsoil, thus improving soil structure, favouring organic activity and encouraging biodiversity. Through reducing soil erosion, lucerne also helps to prevent downstream irrigation canals and streams from silting up. This protection against erosion extends to intercropping periods when techniques such as direct seeding or seeding under vegetal cover may be employed.

- As a legume, lucerne fixes atmospheric nitrogen in its root nodules, thus reducing its need for artificial fertilizer. This also benefits subsequent non-leguminous crops, as lucerne roots can take up to 18 months to degrade. Moreover, lucerne will preferentially use soil nitrogen when it is in excess, thus helping to regulate the soil nitrate level and protect groundwater from leaching.
- Lucerne is drought-resistant, thanks to its long roots, and hence well suited to surviving the dry season, although it is not suited to arid conditions, requiring approximately 50 mm of water per tonne of leaf.
- Some of the whey can be used to water livestock.

In some areas, livestock security problems can restrict extensive grazing, thus exacerbating the feeding problem by increasing the concentration of cattle. ISP is consistent with penning, which also facilitates the recovery of manure for use as fertilizer (after composting).

Provision of employment opportunities. Any ISP scheme will require management and labour for production. In addition, marketing and sales will be necessary for the operation to establish itself. These will all depend on the scale of the ISP scheme. The case study in the next section, for example, would provide employment for seven people, just on the production side. In certain circumstances, labour-intensive methods of harvesting may be appropriate, which would offer substantial employment opportunities for most of the year.

Ecological sustainability. The direct agricultural benefits of the nitrogen-fixing properties of lucerne, and legumes in general, are mentioned above. The cultivation of forage crops for leaf fractionation has further advantages (4):

However, lucerne is not suited to acidic soils: if the soil pH is 6.5 or less, it will need to be adjusted, for example by addition of lime or dolomite.

Improvement in livestock nutrition. Limited availability of cattle fodder is the norm in many countries in the dry season. An inadequate diet significantly reduces, and may terminate, milk production with serious economic consequences for rural families, as this activity represents one of their few cash-raising opportunities. The implementation of ISP contributes to solving that problem as follows:

- Regular harvesting, typically at intervals of between 3 and 6 weeks, reduces the time available for pest communities to become established, thereby almost eliminating the need for pesticides.
- As mentioned above (see 'Crop selection, management and harvesting, p. 347), the dense leaf cover of forage crops helps to prevent the growth of weeds, thus reducing the need for herbicides.
- On a dry-matter, weight-for-weight basis, the fibre and whey, when mixed, have nutritional characteristics similar to (or sometimes better than) those of the original forage (15,16). The fibre alone, with moisture content lower than that of the original leaf crop, is more amenable to sun-drying for use as hay or may be ensiled with minimal losses, using some of the whey to ensure anaerobic conditions and add water-soluble carbohydrates, thus enhancing the silage.
- Where the weather is too damp for sun-drying during the growing season, ensiling is a highly valuable option, both for fibre and for any surplus unextracted crop, preferably in combination with other crops such as whole maize or residues such as bagasse and straw (6).
- Apart from the cost savings already mentioned, the diminution in the use of chemically produced fertilizers, herbicides and pesticides induces wider ecological benefits, such as the protection of groundwater from chemicals and the lessening of atmospheric carbon. The Rodale Institute, which has been carrying out a continuous comparison of organic and conventional agricultural methods for more than 23 years in the USA, has found that legume and manure-based approaches (36):
- Emit one-third fewer greenhouse gases than conventional methods (use of

chemical fertilizer and pesticide applications) by eliminating the energy inputs required to produce pesticides and fertilizers.

- Remove atmospheric carbon in a way that conventional methods do not, sequestering up to 4000 kg CO₂/ha in the soil per annum.

Nitrous oxide, a gas released by the application of nitrogen fertilizers, is another greenhouse gas contributing to global warming that is not produced by the cultivation of lucerne or other legumes.

Intermediate-scale production: case study

This section presents a case study of what a particular ISP scheme might look like in practice. It has been chosen to illustrate the use of equipment developed from both smaller and larger leaf concentrate production units, as the pulper is a development of the latest village-scale design while all other components are miniaturizations of the France-Luzerne industrial technology. The selected scheme benefits from the continuous production of the industrial operations and is based on a unit capable of processing up to 2 tonnes of fresh lucerne per hour, producing approximately 500 kg of dried leaf concentrate daily, for an expected 240 working days per year. This would provide enough leaf concentrate for 47,000 children, at an average of 7 g/day.

This level of production is presently considered to be the smallest at which the improved efficiency of the industrially based equipment would outweigh its extra complexity and greater capital cost.

The production steps are described in Box 18.5 and shown schematically in Fig. 18.1. Box 18.6 presents the production potential of such a unit. In tropical or subtropical latitudes, where harvesting might be possible for 8 months per year, there is a realistic maximum of about 3500 hours of production per year, given ideal conditions. This would involve harvesting during daylight for 12 hours in two shifts, with an additional 2.5 hours of processing a 5-tonne stockpile of leaves at the end of the day.

The establishment of a scheme such as this, if no smaller leaf concentrate production or market were in existence beforehand, would initially need some external support, such as a government grant, and a partner organization, such as an agricultural school or research station, with a sufficiently large herd of dairy cows. Subsequently, operations could be extended to farms in the immediate surrounding area in order to reach the 'critical mass' required for sustainability in terms of land area, herd size and consequent economics. The best approach, or approaches, for encouraging engagement will naturally depend on local conditions; one method might be an arrangement between production plant and farmers to exchange fresh fodder for sun-dried or ensiled fibre/whey (stored on site) plus some remuneration.

Box 18.5. Intermediate-scale leaf fractionation: production steps.

1. Fresh leaf crops are harvested and transported to the production plant in a trailer.
2. A conveyor belt carries the chopped leaves to a vertical-axis rotational pulper.
3. The pulped leaves fall directly from the pulper into a screw press.
4. On being expelled from the screw press, the fibre is collected in a container, where it is subsequently mixed with the leaf concentrate whey before being used as ruminant feed.
5. The green leaf juice is collected and its pH is adjusted to 8.5, to slow down the action of phenyloxidase and to improve the structure of the curd.
6. As it is pumped to a continuous horizontal centrifugal decanter, the juice is brought to a temperature of >90°C by steam injection.
7. The curd and whey are separated in the centrifuge, the whey is re-mixed with the leaf fibre before being directly fed to the cattle (alternatively, some of the leaf fibre will be sun-dried or remixed with some of the whey before being ensiled for use during the dry season).
8. The curd is dried on a fluidized-bed dryer, cooled and bagged at about 6% moisture.

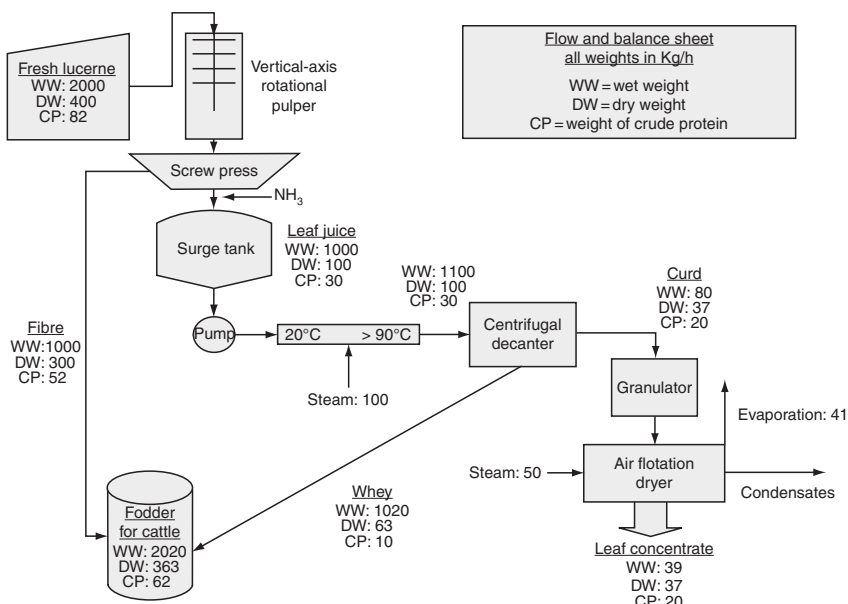


Fig. 18.1. Intermediate-scale leaf fractionation: schematic process diagram.

Box 18.6. Intermediate-scale leaf fractionation: production potential.

| | |
|------------------------------------|--|
| Crop: | Lucerne (alfalfa) |
| Total crop cultivation area: | 100 ha yielding 15 t dry matter/ha |
| Growing/harvesting season length: | 8 months/240 days |
| Production schedule: | 14.5 h/day (+ washing down = 2 shifts of 8 h, 7 days/week) |
| Processing capacity: | 2 t/h (leaf) 29 t/day |
| Leaf concentrate production: | 35 kg/h (dried leaf concentrate) 500 kg/day 120 t/year at most (at 240 days' production) |
| No. of daily portions: | 17 million/year at 7 g/day (average per portion) i.e. daily supply for 47,000 children |
| Fibre/whey animal feed production: | 2 t/h 30 t/day (including added steam) |
| Energy requirements: | 70 kW (mechanical), 150 kg of steam/h |
| Water requirements: | 200 l/h, washing included |
| No. of dairy cows & heifers: | 400 |
| Potential milk production: | 1.5–2 million l/year depending on the breed of livestock and its husbandry |

Table 18.5 presents an estimate of a number of budget items. The figures are based on the following assumptions.

- Total capital cost: €600,000. This cost is for equipment produced in France. If

the equipment were made locally or elsewhere, it is possible that this cost could be reduced.

- Depreciation costs only are taken into account. It is assumed that the cost of initial equipment is donated or

Table 18.5. Intermediate-scale production: example outline of budget items.

| Item | €/kg leaf concentrate | % |
|---|-----------------------|-----|
| Depreciation on capital investment (10 years) | 0.50 | 23 |
| Maintenance | 0.08 | 3 |
| Cost of forage minus income from by-products | 0.23 | 11 |
| Transport | 0.00 | 0 |
| Electricity for machinery at €0.10/kWh | 0.20 | 9 |
| Gas for steam generation at €0.10/ kWh | 0.40 | 19 |
| Salaries for one manager and two shifts of three staff each | 0.23 | 11 |
| Miscellaneous costs at 10% | 0.16 | 8 |
| Profit at 20% | 0.36 | 17 |
| Selling price | 2.16 | 100 |

covered by a grant and no repayment is required.

- Leaf crop raw material is not purchased but produced within the ISP organization. Consequently, all costs attached to existing raising livestock, crop harvesting and transportation, drying/ensiling and storing for the off-season are not considered here; only additional workshop costs are listed.
- A conservative estimate of 9% yield (dry matter) of leaf concentrate. It should be possible to improve this performance with careful management of harvesting at optimal crop maturity.
- Gas is used as the fuel to produce the steam. Other energy sources, such as coal, wood or rice husk, could result in significant savings.
- The residual fibre/whely mix has the same value (per kg dry weight) as the original leaf crop. The cost indicated corresponds to the lost dry matter due to leaf concentrate production.

These are representative costs and it is recognized that they have the potential to vary considerably depending on location. However, they indicate the potential feasibility of such a project.

Review of Evidence

This section reviews, in chronological order, studies and trials that have provided evidence

of the effectiveness of consuming leaf concentrate in improving human nutritional status.

Between 1960 and 1990, there were more than a dozen studies aimed at estimating the effects on malnourished children and adults of consumption of leaf concentrate from a variety of species of plant. With a few exceptions, the leaf concentrate used was prepared with small-scale equipment from local crops. The serving was typically one or two tablespoons of fresh moist leaf concentrate incorporated in the normal diet. Such a serving adds 4–8 mg β -carotene and 5–10 mg iron, together with 5–10 g protein, 3–6 mg vitamin E, 25–50 μ g folic acid, 175–350 μ g zinc and 300–600 mg calcium. Most of the trials compared the effectiveness of leaf concentrate with that of conventional alternatives such as cow or buffalo milk and/or pulses.

In the early 1960s, three papers by Waterlow and co-workers (37–39) described nitrogen-balance studies on malnourished infants undergoing rehabilitation in hospital. These compared freeze-dried canned leaf concentrate (made from several types of leaf at Rothamsted Experimental Station, UK) with liquid milk as protein sources. Nitrogen absorption and retention from leaf concentrate were respectively 90% and 93%, compared with 93% and 91% from milk. On an equal protein intake basis, weight gain on a leaf concentrate/milk mix (in which one-half to one-third of the protein came from the leaf concentrate) was as good as on milk alone.

A possible allergic reaction to leaf concentrate in two children was reported. One such reaction was also found in a short study in India in 1971 (40). It was believed that pheophorbide might have been the cause, and consequently the coagulation temperature for the preparation of food-grade leaf concentrate was raised from 75–80°C (sufficient to coagulate the protein) to a minimum of 90°C to inactivate chlorophyllase. No further cases have been reported of allergy or of any other serious adverse side-effects.

The first long-term (6-month) feeding trial, conducted by the Central Food Technology Research Institute in Mysore, India, used leaf concentrate produced locally from lucerne and compared four groups of 20 children aged 6–12 years (41). The control group followed their normal diet based on ragi (*Eleusine coracana*), while two groups received an additional 10 g protein from either sesame flour or leaf concentrate, and the fourth group received 0.5 g lysine. The leaf concentrate group gained height and weight more than any other group (height gain in leaf concentrate group: 4.84 cm versus 2.20 cm in control group, 3.51 cm in sesame group and 4.25 cm in lysine group; weight gain in leaf concentrate group: 1.28 kg versus 0.47 kg in control group, 0.86 kg in sesame group and 1.05 kg in lysine group; *t* test $P < 0.001$ for comparisons of leaf concentrate height and weight gain with all other groups). Although the traditional basal ragi diet was rich in iron, there was a greater increase in mean haemoglobin (Hb) in the leaf concentrate group: 0.87 g/dl versus 0.29 g/dl in the control group (*t* test $P < 0.001$), 0.64 g/dl in the lysine group (*t* test $P = 0.08$) and 0.71 g/dl in the sesame group (*t* test $P = 0.3$).

In 1972, the results of a study in Nigeria were published (42) in which 26 children with kwashiorkor attending a hospital outpatients' clinic were given leaf concentrate to be added to their home diet. Their mothers were provided with cans of freeze-dried leaf concentrate and instructed to stir a tablespoonful into each of their three daily meals. Within 10 days oedema had subsided in all children, as had diarrhoea, and there was spontaneous remission of anaemia, attributed by the authors in part to the folic acid in the leaf concentrate. Appetite and alertness also quickly

improved. There was no comparison group in this study.

There followed a series of trials with children aged 2–5 years in Coimbatore, India (43–45) and children aged 7–14 years in Lahore, Pakistan (46,47). These trials lasted from 6 months to 2 years and compared the incorporation in the diet of leaf concentrate with various conventional alternatives including cereal/pulse mixes, skimmed milk powder and whole fresh buffalo milk. All resulted in very satisfactory growth patterns together with improvements in Hb and vitamin A status and diminished morbidity. For example, in the second Coimbatore trial (44), after 18 months the mean increases in Hb and serum retinol in the leaf concentrate group were 3.4 g/dl and 1.34 $\mu\text{mol/l}$ respectively, compared with 2.5 g/dl and 0.80 $\mu\text{mol/l}$ in the control group (who received an isoenergetic tapioca supplement).

A subsequent trial of leaf concentrate for pre-school children in Sri Lanka, which was intended to replicate the favourable findings of the trials in Coimbatore and Lahore, was largely unsuccessful (48). This was principally due to problems with the local production of leaf concentrate (incorrect manufacture of machines) (32) and to the target population being generally well-nourished (no iron, folate or protein deficiencies) (49). However, it was reported that leaf concentrate was highly acceptable to children, and almost all of their mothers perceived benefits from its consumption (32).

Devadas and Murthy, in a 4-month trial (50), attempted to assess the biological utilization of β -carotene from leaf concentrate. They compared three sources: amaranth leaves, leaf concentrate prepared from amaranth leaves and a standard β -carotene solution. The subjects were 15 children aged 3–5 years, attending a nursery school where, in addition to their home diet, they received a daily snack formulated after a weighed food survey. During the first month they received this snack as control. In each of the next three months the daily snack had added to it, in turn, 40 g amaranth, 8 g dried leaf concentrate and then 1 ml standard solution, each supplying 1200 μg β -carotene. During the last three days of each month, faeces were collected to

estimate excretion of β -carotene and hence utilization from each source. They found that amaranth leaves, amaranth leaf concentrate and standard solution had percentage utilization (mean \pm standard deviation (SD)) of respectively $61.4 \pm 9.4\%$, $76.7 \pm 7.5\%$ and $85.4 \pm 6.1\%$; thus amaranth leaf concentrate was better utilized than the unprocessed amaranth ($P < 0.001$). This finding was replicated in a more recent study, which reported a retinol equivalence (i.e. how much of the 'provitamin A' in the substance under examination was required to provide $1 \mu\text{g}$ of retinol) of $6.9 \mu\text{g}$ for leaf concentrate from spinach, compared with $13.6 \mu\text{g}$ for the unprocessed leaf (51), the latter figure being consistent with recent work by others (52). These results support studies in which serum retinol was measured in children and adults who had received leaf concentrate; it has invariably been found that hypovitaminosis A diminished or disappeared (43–45).

In a trial with predominantly anaemic children aged 4–9 years in a primary school in Maharashtra, India (53), two groups of 30 children were given a 100 g snack (providing 1674 kJ (400 kcal) and 12 g protein) six days each week for 9 months. The snacks in one of the groups were fortified with 9% by weight of dried leaf concentrate made from lucerne on a village farm (34). A green vegetable dye was added to the control group's snack in an attempt to blind participants to their allocation. Measurements were made of weight, height and Hb status, all of which showed a larger mean increase in the group which received 9% leaf concentrate compared with the control group (mean \pm SD: 2.5 ± 0.5 kg versus 2.0 ± 0.4 kg, $P < 0.001$; 6.3 ± 0.9 cm versus 5.2 ± 0.9 cm, $P < 0.001$; 1.7 ± 0.9 g/dl versus 0.5 ± 0.9 g/dl, $P < 0.001$, respectively). The proportion of children with anaemia (Hb < 12 g/dl) in the 9% leaf concentrate group was reduced from 100% to 36%, compared with no change in the control group (90% to 87%).

Leaf concentrate has also been evaluated in a hospital setting with sick and elderly patients. A study of 30 patients with end-stage renal disease in the chronic haemodialysis programme at St John Hospital, Bucharest, Romania (54), included only patients with Hb = 7–8.5 g/dl. For 3 months they received

15 g dried leaf concentrate daily; Hb was measured fortnightly. Initial mean Hb of the group was 7.9 g/dl, after 1 month 8.0 g/dl and finally 8.4 g/dl ($P < 0.05$). A shorter study (55) on 50 hospitalized subjects aged 50–86 years (40 female, ten male) receiving 15 g dried leaf concentrate each day for 15 days, added to soup or by spoon, concluded that iron-deficiency anaemia and sideremia in the elderly may be corrected by leaf concentrate in the absence of iron therapy; increases in levels of serum retinol, calcium and magnesium were also observed.

The effects of leaf concentrate on the health of pregnant women, and on the birth weight of their babies, were studied in Jaipur, India (56). The participants were 105 women from the slums of Jaipur. The women were recruited from among attendees at eight primary health centres involved in a government programme. This programme provided a 120 g industrially produced cereal-based snack, rich in phytates but low in micronutrients. The women were 18–35 years of age and they were enrolled in the 14th–16th week of their pregnancy and divided randomly into two groups. The control group continued to take the regular snack (six days each week), while the experimental group received a similar snack in which dried leaf concentrate, made locally from lucerne, at 6% by weight, had replaced the standard ingredients in such a way that the control and experimental snacks were isoenergetic and isoproteinaceous. This had the effect of significantly raising the micronutrient content of the snack, particularly in iron, calcium, β -carotene and folic acid. The two groups were monitored monthly and one week after delivery. In the experimental group there was a reduction (from 52% to 38% at term) in the proportion of women with moderate or severe anaemia (Hb ≤ 8.5 g/dl), compared with an increase in the control group (from 60% to 83% at term). Mean Hb in the experimental group was unchanged (8.8 g/dl at baseline, 9.0 g/dl at term) compared with a decrease in the control group (from 8.4 g/dl to 7.8 g/dl at term, $P = 0.02$). Mean \pm SD birth weight in the experimental group was higher than in the control group (2695 ± 322 g versus 2540 ± 299 g, $P = 0.02$). A subsample of 20 infants (ten from

each group) was followed for 6 months. Those from the experimental group all gained weight faster than those from the control group, and their mothers reported better and quicker recovery after delivery. A number of these mothers chose to continue taking the leaf concentrate snack throughout their lactation, but no further outcomes were measured.

In the same setting, at Jaipur, the relative effectiveness of leaf concentrate compared with iron and folic acid supplements for treating anaemia in adolescent girls has been studied (28). The study was a randomized controlled two-arm trial ($n = 102$) over 3 months: one group received a daily iron and folic acid supplement (60 mg iron, 500 μg folic acid); the other group received a daily serving of 10 g of dried leaf concentrate supplied by APEF (providing 5 mg iron, 15 μg folic acid). Hb, mean red cell volume, serum ferritin, serum iron and total iron-binding capacity were measured pre- and post-intervention. At the start of the trial, of the 102 girls, four (3.9%) were severely anaemic (Hb < 7 g/dl), 28 (27.5%) were moderately anaemic (Hb \geq 7 g/dl and <10 g/dl) and 70 (68.6%) were mildly anaemic (Hb \geq 10 g/dl and <12 g/dl). In the iron and folic acid group, 11 girls (20.4%) withdrew due to side-effects of the supplement, compared with one girl (2.1%) in the leaf concentrate group. At the end of the trial, none of the remaining 86 girls was severely anaemic, nine (10.5%) were moderately anaemic and 26 (30.2%) were mildly anaemic; 51 (59.3%) had normal Hb levels (\geq 12 g/dl). These proportions were comparable in both groups. After adjustment for baseline values, the effectiveness of leaf concentrate in improving serum iron parameters was comparable with iron and folic acid, and the authors concluded that leaf concentrate was a viable, and more palatable, alternative to iron and folic acid supplements for treating anaemia in adolescent girls in this setting.

Another randomized controlled trial using dried leaf concentrate supplied by APEF was conducted in Lima, Peru, involving two groups each of 30 chronically malnourished children aged 3–5 years (57). One group received for 12 months a daily 10 g

serving of leaf concentrate and the other group 15 g of skimmed milk powder with equivalent protein content. The children were monitored clinically (weight, height, morbidity) and biochemically (serum protein, albumin, transaminase and creatinine). The leaf concentrate and milk were taken daily in the children's homes, mixed into a maize porridge, and their intake was monitored. The two groups of children had similar characteristics at entry to the study (body mass index, age, sex, Hb), except for serum protein and albumin which were, respectively (mean \pm SD), 59.3 \pm 4.5 g/l and 27.8 \pm 1.1 g/l for the leaf concentrate group compared with 62.2 \pm 5.3 g/l and 28.6 \pm 0.8 g/l for the skimmed milk group. The leaf concentrate was well accepted by the children (consumption 91%) and produced no digestive, kidney or liver complaints. Losses to follow-up were fewer in the leaf concentrate group (four children at 3 months and six children at 12 months) compared with the skimmed milk group (nine and 16 children, respectively). Growth estimated by mean increases in weight and height was similar for the two groups. Leaf concentrate improved Hb levels (33% anaemic at entry, 0% after 12 months) whereas this proportion was unchanged in the skimmed milk group. No untoward effects were recorded that could be attributed to the leaf concentrate, nor were there abnormal increases in transaminases and creatinine. Biological markers for protein deficiency (serum protein and albumin) were similarly corrected in the two groups at 12 months. The investigators concluded that leaf concentrate was as effective as skimmed milk in treating protein malnutrition in children, with the additional benefit of treating anaemia. These findings were replicated in a subsequent study carried out in the same district with similar methodology but on a larger sample (70 children in each group) over 6 months, and with powdered whole (instead of skimmed) milk given to the control group (E. Bertin, F. Vitry and J. Adnet, 2010, paper submitted to *Journal of Human Nutrition and Dietetics*).

A 3-month trial in the Democratic Republic of the Congo (DRC), in partnership with the DRC Research Centre for Health Sciences, compared the effects of 10 g of dried

leaf concentrate versus 15 g of skimmed milk powder on growth and measures of malnutrition (e.g. albuminaemia) in two groups each of 30 children aged 3–5 years. Acceptability of leaf concentrate was similar to that of milk powder, as were the effects of the two nutritional supplements on gains in height and weight, and improvements in measures of malnutrition (E. Bertin, 2008, report to APEF).

A wealth of observational and anecdotal evidence for the apparent benefits of leaf concentrate has been accumulated from programmes in more than a dozen countries (17–23). Although inadmissible in a systematic review of evidence, these reports (mainly observational case series and testimonials by medical professionals) are supported by the findings of the randomized controlled trials summarized above. Programmes in several countries have instigated randomized controlled trials in order to provide rigorous evidence. Most notably, in Burundi and Cameroon, two randomized controlled trials involving the consumption of leaf concentrate by people living with HIV/AIDS have shown promising results, following very favourable case-series reports from programmes in these countries ((29) and APEF, 2007, internal document).

Leaf Concentrate, Past and Future

The previous sections have described some of the applications and benefits of leaf fractionation within a food-based approach for combating micronutrient malnutrition. This section briefly reviews the major factors that have hitherto hindered the widespread adoption of leaf concentrate and leaf fractionation, explains how these may be overcome, and discusses the potentially wider role of leaf concentrate in alleviating human malnutrition.

Over the past 40 years, the use of leaf concentrate in human nutrition has had a chequered history, with three main cyclical factors inhibiting its more general use:

- A lack of public awareness of the existence of leaf concentrate and its benefits has resulted in a lack of ‘demand’ for it.

- The lack of such ‘demand’ has discouraged the initiation of production.
- The lack of production (supply) has meant that there has been little public awareness.

Until recently, there have been two further, connected, obstacles:

- Lack of efficient, village-level, intermediate-scale processing machinery (up to 500 kg of leaf per hour) enabling consistent and profitable production of locally made leaf concentrate.
- Lack of robust, comparable scientific data on the effectiveness of leaf concentrate in combating malnutrition based on the consumption of a consistent product.

In addition, the vast majority of potential beneficiaries of leaf concentrate are severely impoverished, struggling even to afford the extremely low ‘cost price’ of the industrial product (currently €1/kg, ex-works in France, i.e. just over €3.5/year at 10 g/day per person); this has made leaf concentrate an unattractive option for commercial investors seeking a rapid return on their investment.

The availability of the French industrially produced leaf concentrate is now permitting the accumulation of an increasing body of evidence regarding the nutritional effectiveness of leaf concentrate (see previous section), not only in directly combating specific deficiencies (e.g. iron or vitamin A) but also in improving general health, resisting infection and accelerating recovery; of particular interest are the positive effects observed in people living with HIV/AIDS (18,19,29,58).

The French leaf concentrate also offers the potential for the creation of a local demand for leaf concentrate pending the establishment of a local ISP scheme, while the development of a new village-scale combined pulper and press, which has performed well in trials, would widen the range of scales at which ISP might be started, bringing to a larger number of people the benefits of leaf fractionation outlined earlier.

Although the first ISP scheme may require a relatively high initial capital investment, experience of manufacturing outside Western Europe indicates that costs may be

substantially reduced (F.-C. Richardier, 2009, personal communication).

Possibly outside the immediate scope of the current work, but closely linked, are two further potential uses of leaf concentrate.

- As part of emergency food stocks held by the World Food Programme, as there is increasing testimony to the benefits of leaf concentrate in the field (17–23).
- Incorporated into a ready-to-use therapeutic food (RUTF) formulation. The general health benefits noted when leaf concentrate is incorporated into a variety of diets judged to be deficient in micronutrients (see ‘Leaf Fractionation in a Food-based Approach’, pp. 341–342) bear strong similarities to those attributed to pro- and prebiotics (59). A formulation has been developed using the French leaf concentrate (Dibari, 2007, internal report, Valid International), with which initial trials will be undertaken. In the long term, a locally produced RUTF containing leaf concentrate from an ISP scheme could be produced, independently of imported mineral–vitamin mixes (S. Collins, 2009, personal communication).

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