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Processed weaning foods for tropical climates

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Weaning foods must bridge the gap between breast-feeding and an 'adult' family diet. Infants aged 6–12 months are a major group of weaning food consumers. Their energy and protein requirements were used as a starting point to develop a strategy for the home or small-industrial scale manufacture of weaning foods. In addition such food must have an 'easy-to-swallow' consistency, and be microbiologically safe when consumed. On the other hand the level of anti-nutritional factors must be minimised. Ingredients must be locally available and acceptable. These would usually include a staple cereal or starchy tuber. The protein quantity and quality of the product can be optimised by adding legumes (beans, pulses) on the basis of their lysine content. Major problems to be solved include the bulkiness caused by starch gelatinisation and removal of the anti-nutritional factors which occur naturally in legumes. In addition, limited facilities for food preparation and storage allow contamination and rapid proliferation of micro-organisms which create risks of food-borne illness including diarrhoea. Several simple technologies are traditionally employed for the processing of cereals, tubers and legumes. These include roasting, germination and fermentation. Since these treatments have different effects on the quality characteristics of the final product, a combination of operations would therefore be a promising approach to optimise product quality at a minimum cost.

Introduction

Protein energy malnutrition (PEM) and diarrhoea are major factors contributing to the high mortality of children under five years of age in tropical countries, estimated at more than 15 million per year. The infant (<1 year) mortality rate in many tropical developing countries is 10–20 times higher than in the industrialised regions (Grant, 1987).

The causes of PEM are complex. Inadequate total food intake or imbalanced food intake are important aspects. In addition, the resorption of nutrients is less efficient if children suffer from diarrhoea, which may be brought about by bacterial infections

(Cravioto *et al.*, 1988; Molbak *et al.*, 1989), viral infections (Singh *et al.*, 1989), lactose intolerance and by food-related dysfunction of colon water management. Likewise, reduced nutrient absorption may result from accelerated intestinal passage caused by excessive amounts of gas from heterofermentative degradation of carbohydrates, for example.

Product requirements

Breast-feeding is considered best for infants, from nutritional and immunological points of view as well as for protection

against *Campylobacter*-associated diarrhoea, for example (Megraud *et al.*, 1990). However, time constraints and urbanisation (Uwaegbute and Nnanyelugo, 1987) are factors associated with early termination of breast-feeding. In addition, infants require complementary feeding from around the age of 4–6 months (Waterlow, 1981). A gradually increasing provision of complementary food causes a concomitant reduction in the child's dependence on breast milk; this reduction continues until the child can fulfil all his or her nutritional needs with an adult diet. Apart from nutritional concerns, the development of certain physical skills (the chewing and swallowing of relatively large quantities of solid food) determines the type of food that is appropriate at a particular age; the most problematic age is about 9–12 months, when an already considerable nutritional demand coincides with a still limited ability to masticate and swallow, and with a limited stomach capacity (Waterlow and Payne, 1975).

We have based the development of weaning foods on the nutritional requirements of children aged 6–12 months. The total food intake must supply 3500 kJ of energy and 14 g protein daily for a child weighing 7 kg (Hiel, 1984), as well as a variety of micronutrients (Renner, 1989). In addition, weaning foods must have an easy-to-swallow semi-liquid consistency (1000–3000 cP), and be microbiologically safe when consumed. The level of anti-nutritional factors occurring naturally in the ingredients must be minimised by adequate processing.

Ingredients must be locally available and acceptable. These would usually include a staple cereal or starchy tuber, such as maize, sorghums, millets, rice, cassava or sweet potato. The protein quantity and quality of the starchy staple can be optimised by adding legumes (beans, pulses) (Oyeleke *et al.*, 1985) on the basis of their lysine content, which is limiting in most staples. For enrichment purposes soya, cowpea, groundnut, pigeon pea, bambara nut, kidney bean or mungbean are suitable.

Low-cost processing techniques must be employed, using simple equipment and energy-conserving operations.

Challenges

Major problems to be solved include:

- (i) the bulkiness caused by starch gelatinisation. To supply daily 3000 kJ of energy in four feedings of 250 ml each, weaning food porridge must have approximately 20% dry matter content. At this concentration, a very stiff starch gel is obtained during cooking. Consequently, viscosity reduction is required.
- (ii) reduction of the anti-nutritional factors which occur naturally in cereals and legumes. The major ANFs are protease inhibitors, phytic acid and oligosaccharides. Protease inhibitors could be subdivided into two groups, namely: (a) proteins including the Kunitz trypsin inhibitor which specifically binds to trypsin, and (b) non-specific protease inhibitors including tannins and lectins.
- (iii) a microbial safety problem, caused by survival and growth of spoilage and pathogenic micro-organisms during the period between prepaftation and feeding. Factors contributing to this effect are inadequate food and water hygiene (Lloyd-Evans *et al.*, 1984; Molbak *et al.*, 1989; Henry *et al.*, 1990; Roberts, 1990), and the common practice of feeding left-overs stored at ambient temperature. Obviously, it is recommended that porridge should be boiled since it is the only way to inactivate viruses.

In this respect, the consumption of instant weaning formulas should not be encouraged as they invite the use of warm (not boiled) water for reconstitution. In any case, freshly prepared food will be safest. However, this is not always practicable.

There is a need for robust weaning foods which can be prepared in the morning for use throughout the day. In such foods, processing should impart anti-microbial activity to the product, thereby preventing the proliferation of post-preparation contaminations.

Several simple 'household technologies' are traditionally known for the processing of cereals, tubers and legumes. These include roasting, germination and fermentation

(Alnwick *et al.*, 1988). Since these treatments have different effects on the quality characteristics of the final product, a well-chosen combination of operations would therefore be a promising approach to optimise product quality at a minimum cost.

Roasting

Roasting or toasting can be best described as dry heating. It can be carried out on trays in an oven, on perforated carriers in a stream of hot air or in a slowly rotating drum with external heating. Due to its energy requirements, roasting is an expensive operation.

During roasting, several volatile substances including hexanal are removed by evaporation. The removal of such 'grassy' smelling substances, and the simultaneous onset of Maillard reactions give rise to an attractive flavour. Roasting has a slight viscosity-reducing effect on some cereals, but this is negligible in cereal-pulse mixtures (Nout, unpublished data). The content of tannins, phytic acid and oligosaccharides cannot be reduced by roasting.

However, roasting is carried out commonly in industrial practice to inactivate the Kunitz type of proteic trypsin inhibitors, haemagglutinins (Bressani and Elias, 1983) and lectins (Van der Poel, 1990). In soya beans, the enzyme urease is used as an indicator for adequate roasting. If this enzyme is inactivated, the Kunitz trypsin inhibitors are inactivated as well.

On the other hand, excessive roasting has a negative effect on the protein quality of the product since the Maillard reaction reduces the amount of available amino acids including lysine (Han *et al.*, 1988).

For these reasons, the time-temperature combinations during roasting should be kept under control. As a rule of thumb, roasting should be continued until the product reaches an internal temperature of 90–100°C, after which it should be cooled rapidly by removing it from the toaster and spreading it out on a cooling table. Alternatively, it may be cooled using a fan.

From a microbiological point of view, roasting strongly reduces the number of vegetative cells of bacteria and fungi.

However, it does not protect the product from proliferation of post-processing contaminations.

An alternative to roasting is steaming. Preliminary results in our laboratory (Nout, unpublished data) resulted in adequate inactivation of Kunitz trypsin inhibitors and lectins without losses of available lysine, when presoaked beans were steamed for 10–20 minutes. An added advantage of this technique is that it is easier to standardise and requires less complicated equipment than roasting.

Germination

During germination, a large variety of plant endogenous enzymes are produced or activated, all having the biological function of mobilising the reserve polymers by degrading them to easily available water-soluble products. It is obvious, therefore, that humans resorb the nutrients in germinated seeds more easily than those in native seeds. Quite a number of scientific publications have appeared, dealing with the biotransformations during germination which are of nutritional relevance. Much information has been reviewed by Chavan and Kadam (1989a). Some of the desirable effects of germination include:

- reduction of viscosity, still enabling a semi-liquid consistency at 25% sorghum dry matter concentration, for example (Svanberg and Taal, 1985)
- decrease of tannin content in *Vicia faba* and red sorghum, for example, due to complexation with proteins (Chavan and Kadam, 1989a) (lectins were also inactivated in *Phaseolus vulgaris* (Nout, unpublished data))
- increased availability of amino acids including lysine, tryptophan and methionine (Chavan and Kadam, 1989a)
- partial degradation of phytic acid; however, this is not reflected in increased availability of minerals (Khetarpaul and Chauhan, 1989a), especially not in high-tannin cereals (Svanberg and Lorri, 1988).
- gradual degradation of oligosaccharides: in *Ph. vulgaris* 77% of oligosaccharides

were removed after three days germination; the product caused a reduction in breath hydrogen levels (Trugo *et al.*, 1990).

However, germination does not appear to affect the Kunitz trypsin inhibitors and it does not improve the *in vivo* protein efficiency ratio (PER) (Malleshi and Desikachar, 1988; Ahrens *et al.*, 1989; Chavan and Kadam, 1989a).

During germination, considerable respiration takes place which can cause dry matter losses of up to 25% (Chavan and Kadam, 1989a). It is therefore important to optimise the germination process and to use it only for those ingredients which will be nutritionally improved by it.

From a microbiological point of view, germination is a risky enterprise. There is an enormous increase in *Enterobacteriaceae*, fungi, *Bacillus* spp. etc., including potential pathogenic and toxinogenic species (Nout, 1980; Ogundiwin *et al.*, 1991). In order to contain the proliferation of this microflora during later processing stages, the germinated seeds should be decontaminated by heating, or some other inhibitive principle must be applied.

Fermentation

In principle, several types of fermentation are suitable for processing cereals and legumes. Fungal fermentations, e.g. tempe fermentations by *Rhizopus oligosporus* and related organisms, have been well-documented and are known to contribute to better digestibility and degradation of ANFs including phytic acid and oligosaccharides (Paredes Lopez and Harry, 1989; Liew and Buckle, 1990; Nout and Rombouts, 1990).

Within the African context, bacterial and yeast fermentations are better known and accepted. One of these is the fermentation of proteinous seeds by *Bacillus subtilis*, *B. polymyxa*, *B. pumilus* etc., giving aromatic products with a high degree of hydrolysis and a neutral pH. Such fermentations might present interesting additional or alternative pre-treatment options, particularly for legumes.

Whereas yeast alcoholic fermentations are not desirable in weaning food, yeasts

can play a role as a minority group in mixed microbial populations dominated by bacteria. Some yeasts possess carbohydrate degrading enzymes, e.g. α -galactosidase, which are absent in certain lactic acid bacteria of plant origin. Also, yeasts supply vitamins, peptides and other micronutrients into the environment which support the growth of fastidious organisms, e.g. lactic acid bacteria.

Fermentation of cereals or roots crops alone or in mixtures with legumes can be carried out with *Enterobacteriaceae* of plant origin and lactic acid bacteria. The common characteristic of such fermentations is the production of organic acids resulting in a reduction of the pH and a typical sour taste. In the African continent, this type of fermentation is widely distributed and popular, especially in the rural communities.

Such lactic fermentation processes can be distinguished by the starter and reaction conditions employed as shown in Table 1. The first two types of processes can be described as simple, low-technology, low-cost and semi-artisanal. On the other hand, controlled pure culture processes require adequate equipment and training. They are economically feasible at industrial scale production and at conditions of adequate efficiency. This type of process can offer specific advantages, e.g. the use of improved microbial strains, but from the food security point of view the inherent centralisation of production makes for a vulnerable situation.

Effects of lactic fermentations

Biotransformations. The impact of fermentation on the nutritional value of cereals has been reviewed by Chavan and Kadam (1989b). As far as we have been able to

Table 1. Fermentation starters and reaction conditions

Starter	Conditions	Character of process
None	Non-sterile	Wild or spontaneous
Stable natural	Non-sterile	Controlled mixed
mixed culture		culture
Single or mixed	Sterile	Controlled pure
pure cultures		culture

measure, lactic fermentations do not affect the Kunitz trypsin inhibitors. They do not cause a reduction of the viscosity in the boiled product; on the contrary, the acidity causes a viscosity increase in mixtures with soya or black gram (*Phaseolus mungo*), for example (Changala Reddy *et al.*, 1989). From a nutritional point of view, the level of B vitamins increases (especially riboflavin) and there may be a slight increase of available lysine and methionine (Tomkins *et al.*, 1990).

With reference to the ANFs, phytic acid (Khetarpaul and Chauhan, 1989b) and oligosaccharides (Zamora *et al.*, 1989) are significantly reduced; also tannins are partly reduced (Khetarpaul and Chauhan, 1989b). As a result, the availability of minerals increases (Svanberg and Sandberg, 1989) as well as the digestibility of the proteins (Lorri and Svanberg, 1988). The PER of sorghum porridge increased from 2.06 to 2.34 during 24 h of fermentation with *Lactobacillus plantarum* (Ahrens *et al.*, 1989). The RNV (relative nutritive value) of mungbean increased by 24% after fermentation with a mixture of lactic acid bacteria (Zamora *et al.*, 1989). No information on the fate of lectins is available.

Microbial products. The formation of organic acids including lactic, acetic, butyric, propionic and isobutyric acids causes characteristic flavour. Probably more important, the combination of reduced pH and the presence of approximately 1–1½% (w/w) lactic and acetic acid significantly inhibits the growth of *Bacillaceae*, *Micrococcaceae* and *Enterobacteriaceae* and consequently has a powerful stabilising effect on the microbial population in the product.

In addition, lactic acid bacteria produce small amounts of H₂O₂ and CO₂ which both have some anti-microbial effect (Schaack and Marth, 1988). Recently, much interest has developed concerning the production and anti-microbial activity of bacteriocins (Spelhaug and Harlander, 1989), substances of proteinic nature which are inhibitive to similar organisms as the producer. Although there are limited application possibilities of bacteriocins in industrial food preservation, their importance should not be exaggerated

because their stability is limited and they usually do not have a broad spectrum of anti-microbial activity.

Effect of live cells. It has been shown that certain fermented milk products, e.g. yoghurt and bifidus milk, have therapeutic effects in diarrhoeal disease (Boudraa *et al.*, 1989). In these products, the presence of live cells of lactic acid bacteria is considered essential since they can survive the gastric barrier and produce enzymes, e.g. β -galactosidase, in the duodenum (Pochart *et al.*, 1989). Also, live lactic acid bacteria may play a role in the exclusive colonisation of the gut and contribute to the colonisation resistance against intestinal pathogens. *Lactococcus lactis* increased the IgA production in mice and provided protection against *Salmonella typhimurium* (Perdigon *et al.*, 1990a). Similar effects were observed with *Lactobacillus casei* and *Lb. acidophilus* (Goldin, 1989; Perdigon *et al.*, 1990b).

Microbial safety

When we consider the safety of the product at the time of consumption, lactic fermentation significantly contributes to the microbial safety (Nout *et al.*, 1989a; 1989b; Mensah *et al.*, 1990), if the pH of the ready-to-eat product is ≤ 4.5 and preferably ≤ 4.0 . Such pH values usually correspond to 1–1½% (w/w) lactic acid. Whether these conditions will be met depends on the adequacy of the fermentation process, the ingredients used and their buffering capacity, the dry matter content of the product and factors such as temperature and timing.

Like the other operations, fermentation also has possible disadvantages. The most important is that it is carried out in a high moisture product. This requires a more complex process compared with the production of a dry flour mixture. In addition, if a dry flour is the desired final product, the wet fermented material must be dehydrated. Both aspects (equipment and dehydration) increase the processing cost.

A second point is that extremely acidic products might not be tolerated by all individuals. In particular, sick people or those who are acidotic or suffer heartburn

Figure 1. Technological options for weaning food manufacture

should determine cautiously whether they can take the sour lactic-fermented products (Tomkins *et al.*, 1990).

Integration (at household or small-industrial scale)

In the above sections it has been shown that specific benefits may be expected from roasting, germination and lactic fermentation. The optimum choice of technology and scale of production will depend on factors such as:

- raw materials available at the time, and their price – this will determine the combination of staples and legumes with maximum nutritive potential and consumer acceptance (Bressani and Elias, 1983)
- local cost of energy, building construction, road transport, wages and other indirect production costs (Harper and Tribelhorn, 1985)
- composition of the market, e.g. consumer density per km², level of education, and extent of Government campaigning or institutional policy to popularise the consumption of the formulated weaning food

With reference to the process, several scenarios are outlined as follows (Figure 1):

- (i) during raw material preparation:
 - germination of cereals,
 - roasting of legumes
- (ii) during manufacturing of a formulated food:
 - natural controlled lactic fermentation and drying to give a powder with long

shelf-life. This type of product has the best properties for nationwide distribution and shelf-stability, but requires most work and fuel energy at the household level.

- natural controlled lactic fermentation and direct sale to the consumer who uses the product to prepare weaning porridge at home as soon as possible. This option is suitable only if no distribution is required, e.g. production and use within the household, or sale within an urban market. The case of Mawé in Cotonou is a good example of such situation. Mawé (Hounhouigan *et al.*, 1992) is a traditional lactic fermented maize dough, sold at the market as an intermediate product to be prepared into a variety of dishes at household level.
- single or mixed pure culture fermentation in pre-cooked and (preferably) pre-packed product. This option is a bit more sophisticated and expensive, but offers in exchange:
 - saving of time and fuel energy at the household level,
 - product integrity by proper packaging,
 - the possible beneficial effect of living lactic acid bacteria in the intestine.

At present, preliminary impact trials are being undertaken with the objective of testing the acceptability of combi-processed weaning foods and the feasibility of their manufacturing process.

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