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PAPER

# Technological aspects of preparing affordable fermented complementary foods*

M. J. R. Nout[†‡] and P. O. Ngoddy[§]

*The requirements and manufacturing procedure of complementary (weaning) foods is discussed. Nutritional requirements for infants (aged 6–12 months) include approx. 3 MJ energy and 14 g digestible protein per litre, of a semi-liquid porridge. Microbiological safety is enhanced by biological acidification (lactic acid fermentation) until pH ≤ 4.5. An evaluation of processing operations, e.g. soaking, germination, roasting, and fermentation is presented and their effect on safety and digestibility of the final product is discussed. Some scenarios are presented for complete processes to obtain shelf-stable, dry powdered formulas that meet the above requirements. Blends of cereals, rootcrops and proteinaceous legumes are prepared and subjected to lactic acid fermentation using a simple enrichment starter to ensure adequate acidification. Enzyme rich flour is used to reduce bulkiness. At small-scale production level, cooking and drying is best done by dry-toasting. Extrusion cooking is a promising technique that can be feasible at medium and larger-scale production levels. © 1997 Published by Elsevier Science Ltd.*

**Keywords:** cereals; legumes; fermentation; complementary food; process evaluation; low cost

## INTRODUCTION: PRODUCT REQUIREMENTS

Breast-feeding is considered best for infants, from nutritional and immunological points of view as well as for protection against e.g. Campylobacter-associated diarrhoea (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 (weaning) 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 stomach capacity (Waterlow and Payne, 1975).

This paper discusses product and process development trials done in The Netherlands and Nigeria. We have based the development of complementary foods on the nutritional requirements of children aged

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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, complementary foods must have an easy-to-swallow semi-liquid consistency (1000–3000 cP), and be microbiologically safe when consumed. The level of antinutritional 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 bean, 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:

- The bulk 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 stiff starch gel is obtained during cooking. Consequently, viscosity reduction is required.
- Reduction of the antinutritional factors (ANF) which occur naturally in cereals and legumes. The major ANFs are protease inhibitors, phytic acid and oligosaccharides. Two groups of protease inhibitors are usually distinguished namely: (a) proteins including the Kunitz trypsin inhibitor which specifically binds to trypsin, and (b) non-specific protease inhibitors including tannins and lectins.
- A microbial safety problem, caused by survival and growth of spoilage and pathogenic micro-organisms during the period between preparation 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 and vegetative microbial cells.

'Instant' (i.e. pre-cooked and dehydrated) complementary formulas are convenient as they easily reconstitute, even when cold or luke-warm water is used. However, this property also invites serious risks of gastro–intestinal diseases in situations of inadequate water quality. Consequently, water must always be boiled before using it to reconstitute instant formula.

As the consumer is always in a hurry, and cooking fuel is usually in short supply, it is tempting to use un-cooked water instead. Seen from this perspective, we believe that it is safer to produce dry formula that must still be cooked by the consumer. In such case, a residual or water-borne virus of bacterial contaminant will be inactivated in the process of porridge preparation.

In any case, freshly prepared food will be safest. However, this is not always practicable.

There is a need for robust complementary foods which can be prepared in the morning for use throughout the day. In such foods, processing should impart antimicrobial 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 the product quality at a minimum cost.

Obviously ingredients should be of wholesome quality. Microbiological experiments have shown that microbial pathogens and viruses do not survive the manufacturing process. However, mycotoxins already present in e.g. maize (aflatoxins, fumonisins) are quite stable and will not be easily removed or detoxified. *Table 1* summarizes major quality parameters and cost factors of relevance.

## BRIEF PROFILE OF TECHNOLOGIES, TREATMENTS, AND THEIR EFFECTS

### Dehulling and/or peeling

Dehulling and/or peeling remove unwanted parts of raw materials. In that process, they serve several functions:

- Significantly reduces the levels of poisonous phytotoxins such as cyanogenic glycosides in tuber crops, e.g. cassava (Cooke and De La Cruz, 1982; Gomez and Valdivieso, 1984), and germinated sorghum (Panasiuk and Bills, 1984; Dada and Dendy, 1987; Dada and Dendy, 1988).
- Significantly reduces alkaloids, tannins and other polyphenols in pigmented seeds. Alkaloids are not only irritants but also induce allergies in infants. Tannins have a significant negative effect on the availability of limiting amino acids such as lysine.
- Removal of the aleurone layer of the seed bran eliminates significant levels of phytates which bind calcium and other minerals (Salunkhe *et al.*, 1982).

**Table 1.** List of quality parameters and cost factors that are relevant to complementary formula development

| Factors | Quality parameters | Cost-factors |
|---|---|---|
| A. Measures of Nutritional Efficiency | | |
| 1. amino-acid profile (lysine availability) | x | |
| 2. vitamins | x | |
| 3. minerals | x | |
| 4. digestibility | x | |
| 5. *in vivo* protein efficiency | x | |
| B. Antinutritional Factors (ANFs) | | |
| 6. protease-inhibitors | x | |
| 7. lectins (haemagglutinins) | x | |
| 8. oligosaccharides | x | |
| 9. phytic acid | x | |
| 10. tannins | x | |
| C. Measures of Food Safety | | |
| (i) toxins | | |
| 11. glycosides | x | |
| 12. aflatoxins | x | |
| (ii) food hygiene | | |
| 13. microbial load | x | |
| (iii) anti-microbial properties | | |
| 14. porridge pH | x | |
| 15. porridge acidity | x | |
| D. Physical Properties | | |
| 16. viscosity | x | |
| 17. swelling capacity | x | |
| E. Economic Coefficients | | |
| 18. product yield | | x |
| 19. aggregate investment profile | | x |
| 20. employment | | |
| 21. capital/labour ratio | | |
| 22. manufacturing cost of product | | |

- In infant formulas, decortication reduces the total level of indigestible fibres so that infants are able to handle legumes earlier in their diet (Kadam and Salunkhe, 1985).

## Washing and soaking

Washing and soaking involve washing and extended steeping in an excess of cold or warm water. Soaking induces the leaching-out of water-soluble antinutritional factors. Glycosides, alkaloids, phytates, oligosaccharides and tannins are all significantly reduced (Kadam and Salunkhe, 1985). Although water-soluble micronutrients are also lost by leaching, extended soaking has the net effect of enhancing the protein solubility index and the availability of limiting amino acids of edible grains, in some reported cases by as much as 50% or more (Borhade *et al.*, 1984).

## Germination or malting

Germination or malting of seeds triggers the enzyme systems of sprouting seeds leading to the breakdown of complex macro molecules of proteins, carbohydrates and lipids into simpler forms that are more easily assimilated. Some vitamins such as C, E and B-complex are known to increase. Antinutrients such as oligosaccharides, starches, lectins, tannins and phytates also decrease. Amylolytic enzymes residual in seed malts can be resourcefully applied for the purpose of viscosity-thinning to facilitate the design of high nutrient density porridges (Malleshi and Desikachar, 1988; Chavan and Kadam, 1989a; Lorri, 1993).

## Lactic acid fermentation

In a spontaneous form that need not involve the use of expensive starter and pure cultures, other costly inputs and process controls, lactic acid fermentation has many advantages (Nout *et al.*, 1989a,b; Nout, 1992; Lorri, 1993):

- By increasing the titratable acidity and reducing the pH of the porridge to levels below 4.5, it precludes proliferation of contaminating acid-intolerant species of bacteria and fungi. By averting the invasion of these potential contaminants, lactic acid fermentation imparts attributes of robust stability and safety in the product, and thereby pre-empts disease infections such as diarrhoea and salmonellosis, and high spoilage velocity of porridge in unsanitary environments (Mensah *et al.*, 1990; Nout, 1991; Lorri, 1993; Nout, 1994).
- Furthermore, protein solubility and the availability of limiting amino acids are enhanced in some cases by as much as 50%. The micronutrient availability is also enhanced because of significant reductions in phytates. Tannins are reduced by as much as 50% and oligosaccharides by as much as 90% in some reported cases (Kadam and Salunkhe, 1985; Chavan and Kadam, 1989b; Lorri, 1993).
- The effect of fermentation, as an isolated treatment, on the viscosity of porridge is still uncertain, and even controversial. While microbial exo-enzymes from the fermentation can have a thinning effect on the viscosity due to the hydrolysis of starches and proteins, a lowered pH of the medium toward the iso-electric point of porridge proteins may induce a neutralising effect on the viscosity (Lorri, 1993; Wanink *et al.*, 1994).

## Dry roasting or toasting

Dry roasting or toasting is a hydrothermal treatment at high temperature which can be carried out in simple low-cost mechanical equipment that is easily made in developing countries. Problems associated with a high propensity of wet starches to stick and burn on equipment surfaces during toasting, can be contained by careful manipulation of the moisture content and the particle size. These same parameters are also applied together with stirring and the regulation of the process temperature to control the rate of heat transfer. In the process, both cooking and drying occur simultaneously. It requires a delicate balancing of both unit processes to achieve an acceptable end-product (Kadam and Salunkhe, 1985).

Because toasting is a high temperature hydrothermal treatment, it reduces the level of protease inhibitors and lectins. It also reduces the level of volatile glycosides that may be present. Although the level of titratable acidity is also reduced, this adverse effect is not likely to be significant (Bressani and Elias, 1983).

Because of significant degrees of dextrinization of starches during high temperature dry-toasting, it has a diminishing effect on porridge viscosity. However, this is counteracted to some extent by the increased swelling capacity of cooked, gelatinized starch.

As a conventional thermal process, dry-toasting has a severe adverse effect on protein solubility as well as the availability of both limiting amino acids and vitamins (Han *et al.*, 1988).

In developing country circumstances, the high energy cost of dry-toasting is counterbalanced by the comparatively low cost of installation, depreciation and maintenance.

### Steam toasting

In theory, steam toasting should be a more efficient thermal process than dry toasting because of the infinitely enhanced thermal capacity of wet steam used. But the wetting and resulting gelatinization of formula starch-mass result in a level of stickiness which makes it almost impossible to convert into a dryable end product. Although intact grains can be steam toasted and dried prior to grinding, formulation and fermentation, this alternative route is likely to make the production of a pre-cooked dry formula cost-inefficient relative to other competing techniques such as dry toasting.

### Extrusion cooking

Extrusion cooking is a high temperature, short time (HTST) thermal process which cooks, dries and restructures the product in one integrated operation. Significant levels of drying can result from expansion in the product which occurs at the extruder die. Although the cost of installation, depreciation and maintenance (because of rapid screw and barrel wear) is high, the low operating cost of cooking extruders and their low manning requirements have a significant reducing effect on the overall process cost. Extrusion cooked products exhibit quality attributes that are generally superior to those heated by other means as regards protein solubility and functionality, the availability of limiting amino acids and residual levels of antinutritional factors achieved. Dextrinization of starches should lead to lowered porridge viscosity. Low-moisture cooking in extrusion leads also to a reduced profile of swelling in the porridge. The Kunitz protease inhibitors, haemaglutinins, oligosaccharides, phytates, as well as phyto- and mycotoxins, are all reduced in different degrees of significance (Harper, 1979; Van Zuilichem *et al.*, 1980; Harper and Tribelhorn, 1985).

Technically, successful extrusion in low-cost single screw extruders demands the reduction of feed moisture content below the 25% level.

To achieve this moisture level, a fermented dough (40–50% moisture content) may be mixed with previously dehydrated product. This pre-drying can be achieved using e.g. a drying cabinet, but it is also possible to recycle part of the extruded product and mix it with the wet mass entering the extruder.

### Drum drying

Drum drying involves the pre-cooking to full gelatinization of a wet slurry of the fermented mass, prior to application, drying and scraping-off from rotating steam-heated cylindrical drums. This system has very high installation costs that include the additional cost of a steam plant. It has been found to be technically efficient and cost-effective only at high throughput capacities. The end product of drum-drying is very attractive from the aesthetic point of view. Nutrient retention and protein quality are comparable to other cooking methods. Antinutritional factors are significantly reduced. Most multinational companies already producing dehydrated infant formulas in developing countries use this method because operational capacities are favourable. In many cases the drum-drying equipment is already written off but still going strong, so that fixed costs are low.

## A FRAMEWORK FOR PROCESS OPTIMIZATION

*Figure 1* provides a globalized framework that attempts to chart comprehensively the range of competing pathways of process optimization in weaning formula development, as derived from analysis of available experimental and theoretical evidences that have been discussed. The flowchart has four main features that should be stressed.

- The 3 primary raw materials of tropical eco-systems: the cereals, legumes and root/tuber crops provide a large reservoir from which a choice of manufacturing ingredients which satisfy a range of objectives, can be performed. A large reservoir of this sort enhances the possibility of all-season cost-minimization. From the standpoint of creating more balance in the amino acid profile of formula-blends, cereals and legumes are complementary. Starches from roots and tubers in many tropical eco-systems are the cheapest source of energy in the diet. Tubers, therefore, blend with other ingredients to minimize overall costs.
- Formula Processing Stage 1 (preparative operations): this stage involves a sequence of conversion operations to transform agricultural raw materials

into compatible ingredients that can blend harmoniously with others, in spite of their unrelated derivations.

- Formula Processing Stage 2 (mixing operations): this stage entails the blending of all primary ingredients which are brought together in carefully regulated proportions to create a fundamental stream for further processing. It is necessary that blends are chosen on the basis of inherent nutritional and cost considerations that ensure a successful formula. Increasingly, there are linear programming computer softwares which help to pursue and realise these objectives in an efficient manner.
- Formula Processing Stage 3: this stage embraces a sequence of treatments and unit operations that encompass natural lactic fermentation, the possibility of enzyme admixing and incubation at alternative points, cooking by four alternative methods: drying, fine-grinding, finish-blending and packaging.

## FORMULATION AND OPTIMIZATION

An attempt was made to formulate and process fermented cereal–legume weaning food, at minimum cost. Requirements to be fulfilled included:

- Nutrient density and other nutritional quality specifications are as defined in the Codex standards for cereal-based complementary formula.
  - ► energy is stipulated at 4 kcal/gm-solids or 1 kcal/ml-porridge at 4:1 dilution.
  - ► protein at 15% of formula with an availability score >70% casein.
  - ► micro-nutrients satisfy specified levels.
  - ► residual levels of ANFs and toxigenic substances should be below detectable levels.
- Other functions to be served include the following:
  - ► at consumptions the formula should reconstitute into a semi-liquid and easy-to-swallow porridge

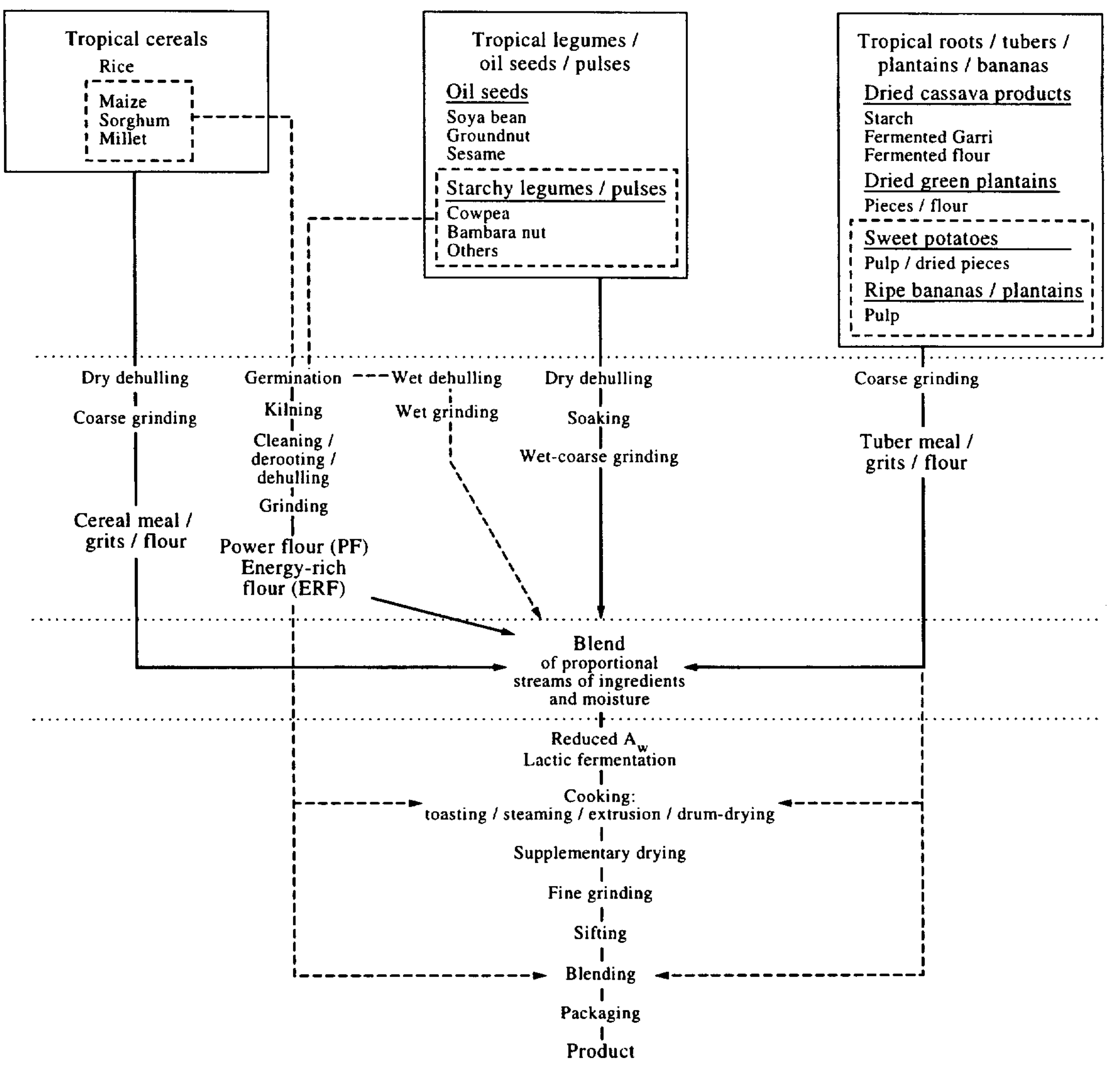


**Figure 1.** Flowchart showing candidate pathways in the optimization of the manufacturing process of cereal–legume complementary food formulation

**Table 2.** Optimized dry formula model system as generated by Micromix linear programming software based on 1994 Nigeria commodity prices

| | Alternative complementary formula | | | |
|---|---|---|---|---|
| Ingredients* | A | B | C | D |
| Cereals (dehulled + degerminated) | 74% | 60% | 43% | 45% |
| Tuber starch (cassava) | — | — | 12% | 15% |
| Soya beans (dehulled) | 25% | — | — | 15% |
| Cowpeas (dehulled) | — | 33% | 38% | 22% |
| Palm oil | 1% | 7% | 7% | 3% |
| Micro-nutrients (supplemental) with mineral + vitamin mix | +** | + | + | + |
| Total | 100% | 100% | 100% | 100% |

*the moisture content of cereals and legumes are assumed at 11.5%.
** + means that the formula was supplemented with mineral and vitamin mix.

that supplies the daily nutrient requirement of the child in roughly one litre.

- the porridge shall have a pH<4.5 and the titrable acidity that enables it to withstand a 24 h storage at 37°C without microbiological risk to health.
- the cost of the manufacture of the formula should be affordable. As a rough guide, it should not exceed twice the cost of all ingredients plus the packaging.

Highlight of findings

- The construction of a formula model system:

*Table 2* summarises the outcome of ingredient cost-minimized optimization using Nigerian food commodity prices in 1994 in a linear programming software, Micromix. Micromix is used in The Netherlands for formula construction in the livestock feed industry. It has an integral data-base specifying the properties of raw ingredients and their cost implications within the range of operating conditions anticipated by the analysis. Nutrient requirements applied as an objective function in Micromix are as detailed in the Codex Alimentarius Specifications as the Codex Standard 156-1987 for follow-up formula (Worldwide Standards), and the Codex Standard 74-1981 for processed cereal-based foods for infants and children (Worldwide). *Table 2* leads to a number of significant conclusions regarding the broad composition of base-formula construction.

- the general rule of thumb for satisfying macronutrient requirements in infant formula is to apply a 70:30 cereal/tuber : legume ratio. This is in agreement with the recommendations of Cameron and Hofvander (1971) and of the WHOs Weaning Guide for Health and Community Workers (1988). Tuber starch can be as much as 15% of the formula, with cereals contributing up to 55%.
- micronutrients are best provided on the basis of a supplementary micronutrient mix provided commercially as a mineral/vitamin mix. Such mixes are available from reputable food ingredients suppliers at a tonnage price that is only a fraction of the corresponding food commodity raw material cost.
- palm oil at the level of 1–3% can be very effective in meeting the vitamin A requirement.

- Process optimization:

*Process stage 1.* Stage 1 of the process (*Fig. 1*) represents the range of preparative operations to which the raw ingredients are subjected prior to primary blending at stage 2.

Because of the high cost of installation of grain milling systems and/or tuber starch processing equipment and the variable results of decentralized operation of such equipment, it is best to purchase good quality flours and starches from specialized ingredient manufacturers. In the long run it is more cost effective to do so and the ingredient quality obtainable is more dependable. In most countries, flour and starch mills for producing primary ingredients are available. These ingredients include:

- dehulled and degermed-cereal grits/flours,
- dehulled, full-fat legume and/or oil seed meals and
- cyanide-free cassava starch.

The availability of primary ingredients in these forms leaves us with only questions relating to how best to handle the malt-stream in process stage 1. *Table 3* summarizes findings that relate to the comparative performance of maize, sorghum, millets and cowpea during malting and the potency of amylolytic enzymes of the resulting malts. It is clear from this table that sorghum and millet malts are superior to maize or cowpea malts. Yields and germination rates for sorghum and millet malts are eminently higher, losses are significantly less and the enzyme potencies are significantly higher. Maize malt performance is poor. Cowpea malt amylolytic enzyme activity is very poor compared with the two cereals recommended.

As regards the point of optimum addition of enzyme-rich flour (ERF) or power flour (PF), experimental trials at all three points suggested in *Fig. 1* lead to the following conclusions:

- Admixing ERF/PF at stage 2 is ineffectual because the starch granules are still raw and intact. In the

**Table 3.** Malting performance of selected grain seeds

| Grain | Performance indices | | | | |
|---|---|---|---|---|---|
| | Number of days required for malting (days) | Germination percentage achieved (%) | Percentage of losses recorded after derooting (%) | Amylolytic enzyme activity* | Comments |
| 1. maize | 4–5 | 35 | 75 | low relative to sorghum | after 3rd day sample began to mould and ferment; confirms that maize malts poorly |
| 2. sorghum (white) | 3 | >95 | 32 | high | high malting losses + malt shattering during milling confirm wisdom of restricting the use of malt to <5% as PF or ERF only |
| 3. millet | 3 | >98 | 30 | high | |
| 4. cowpea | 2 | >90 | 35 | very low relative to sorghum and millet | after 48 h of malting, moulding and fermentation set in; low amylolytic enzyme activity disqualifies cowpea as potential source of PF or ERF |

*Enzyme activity was estimated by observing thinning effect of 5% malt flour on maize meal porridge @20% solids level.

raw, intact (or unbroken) state, starch cannot be attacked by viscosity-thinning amylolytic enzymes.

- ERF/PF addition during cooking is effective, if and only if, the cook protocol allows for sufficient enzyme incubation during which the enzyme can act on pre-cooked starches at temperatures between 40 and 50°C.
- Admixing of ERF/PF at 5% level at the stage of finish blending in stage 3 is effective and always dependable, provided that the porridge reconstitution protocol also allows for a period of enzyme incubation (at 40–50°C) prior to the final boiling. It should be stressed that the presence of malted cereal flour as ERF or PF in the formula blend need not induce instability in formula storage provided that the water activity is low and the pH is less than 4.5. In addition, any vegetative microbial cells introduced with ERF will be killed during the final cooking of the porridge. Bacterial heat-resistant spores originating from ERF will not be able to germinate and multiply under the prevailing acid conditions.

*Process stage 2.* Stage 2 (*Fig. 1*) is the primary point for blending/mixing all the major ingredients. It is best at this stage to first blend all primary ingredients in their dry form into a homogenous mix. Water is subsequently admixed to bring the bulk moisture content to the pre-calculated level required for fermentation.

Stage 2 was found to be the optimum point for the addition of the tuber starch stream. This is because the introduction of significant quantities of any raw ingredient(s) into the product stream at any point after the fermentation step runs the risk of engendering titratable acidity-dilution and pH alteration away from the preferred range between 4 and 4.5.

*Process stage 3*

Accelerated lactic acid fermentation was carried out at four different moisture levels, viz. 30, 35, 40 and 50% (wet basis). The method of back-slopping of Nout (1992) was applied with 10% of each fermenting batch recycled as a culture-enrichment inoculum from the preceeding batch. *Table 4* summarizes the general pattern of fermentation observed. It is significant to note that at 25°C, a temperature typical of many tropical environments, efficient lactic acid fermentation is possible at all moisture contents between 30 and 50% (wet basis). Acidification is faster (18 h) at 50% and slower but effective (60 h) at 30%. Low moisture content of fermentation means lower cost of eventual drying of the formula later in the process.

Four cooking techniques are charted through stepwise optimization options in *Fig. 2*. A performance profile of the four techniques is outlined in *Table 5*. *Fig. 2* shows that steam toasting, dry toasting and extrusion cooking fall within an identical protocol in stage 3. An important intermediate cooking step is represented as the second step of this protocol: ('toast-cook without drying at high temperature above 150°C'). Toast cooking at this stage enables the starch granules to swell and break so that when cooled down and mixed with enzyme-rich flour in subsequent steps, the amyolytic enzymes can act on the cooked broken starch granules.

The drum drying protocol is featured on the right hand side of *Fig. 2* and contrasts from the other three cooking techniques because it requires a higher moisture content of the fermented mass stream fed into it. Drum drying is most efficient when the feed is fully slurried and pre-cooked before introduction on

**Table 4.** The effect of the moisture content on the pattern of accelerated lactic acid fermentation of formula

| Moisture content (wet basis) % | Time (h) | Temperature °C | pH | Titratable acidity % lactic acid |
|---|---|---|---|---|
| 30 | 60 | 25 | 4.10 | 1.658 |
| 35 | 36 | 25 | 4.08 | 1.806 |
| 40 | 24 | 25 | 3.90 | 1.910 |
| 50 | 18 | 25 | 3.80 | 2.102 |

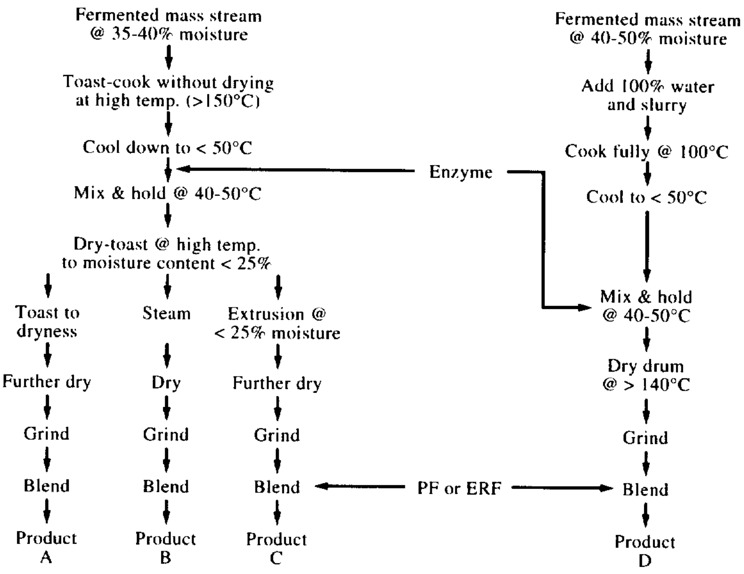


**Figure 2.** Flowchart showing current outcome of step-wise optimization of cooking, drying and further stages

**Table 5.** Performance profiling of formula cooking systems

| | Cooking options | | | |
|---|---|---|---|---|
| Performance indices | A. Dry-toasting | B. Steam toasting | C. Extrusion cooking | D. Drum drying |
| 1. Upper limit of feed moisture content allowance (% wb) | 40% | <25% | <25% | ≥50% |
| 2. Operating temp. range in product (°C) | >100°C | >100°C | >120°C | >100°C |
| 3. Time frame of process (min) | 15 | 10 | <1 | <1 |
| 4. Throughput capacity profile | small/medium | | small/medium/large | large |
| 5. Relative cost profile | low | | moderate | very high |
| 6. Residual level of ANFs relative to Codex Standard | ok | ok | ok | ok |
| 7. Product quality relative to Codex specifications | satisfactory | satisfactory | satisfactory | satisfactory |
| 8. Porridge viscosity (1000–3000 cp) | ok | ok | ok | ok |
| 9. Porridge pH | <4.5 | <4.5 | <4.5 | <4.5 |
| 10. Resistance of porridge to pathogen infections in 24 h storage test | robust | robust | robust | robust |
| 11. Comments | promising @ small/medium scale | product too sticky to handle, technically questionable | promising @ all scales | system only cost effective @ very large through-put capacity |

the hot cylindrical drums. This, of course, means that it is also more energy intensive than the other three competing systems.

*Table 5* shows that with the exception of steam toasting, the other three cooking techniques (dry toasting, extrusion cooking and drum drying) can all be efficient depending on the scale of production desired. Steam toasting poses extreme difficulties because of the stickiness of the gelled starch mass encountered. This gelled starch mass is energy intensive and costly to work mechanically and to dry. Dry toasting is recommended for low to medium capacity operations in developing countries. Dry toasting hardware is a well tested and known technology in tropical environments where it is used in the processing of traditional foods such as gari-making in West Africa. Extrusion cooking is efficient especially at medium and large scales. Drum drying can only be applied at high capacity above 1000 tonnes per year of formula output.

*Packaging*. The most affordable and yet integer packaging is in plastic pouches. These can be labeled according to local requirements and heat-sealed.

*Consumer use*. As mentioned earlier, contamination of drinking water with bacteria or viruses requires obligatory boiling of water prior to reconstitution of 'instant' porridge formulas.

The distribution of non-instant dry porridge formulas would have added safety potential as these necessitate cooking of reconstituted product in order to render it palatable.

# REFERENCES


Alnwick, D., Moses, S. and Schmidt, O.G. (eds) (1988) Improving young child feeding in eastern and southern Africa, Household level food technology, *Proceeding of a workshop held in Nairobi, Kenya, 12-16 October 1987*. Publication IDRC-265e, Ottawa, Canada: International Development Research Centre.

Borhade, V.P., Kadam, S.S. and Salunkhe, D.K. (1984) Solubilization and functional properties of moth bean, marechal and horsegram proteins. *Journal of Food Biochemistry* **8**, 229.

Bressani, R. and Elias, L.G. (1983) Guidelines for the development of processed and packaged weaning foods. *UNU Food and Nutrition Bulletin* **5(3)**, 57–64.

Cameron, M. and Hofvander, Y. (1971) *Manual of feeding infants and young children*. United Nations, New York.

Chavan, J.K. and Kadam, S.S. (1989a) Nutritional improvement of cereals by sprouting. *CRC Critical Reviews of Food Science and Nutrition* **28(5)**, 401–437.

Chavan, J.K. and Kadam, S.S. (1989b) Nutritional improvement of cereals by fermentation. *CRC Critical Reviews of Food Science and Nutrition*, **28(5)**, 349–400.

Cooke, R.D. and De La Cruz, E.M. (1982) The changes in cyanide content of cassava (*Manihot esculanta Crantz*) tissues during plant development. *Journal of the Science of Food and Agriculture* **33**, 269–275.

Dada, L.O. and Dendy, D.A.V. (1987) Preliminary study of effect of various processing techniques on the cyanide content of germinated sorghum. *Tropical Science* **27**, 101–104.

Dada, L.O. and Dendy, D.A.V. (1988) *Cyanide content of germinated cereals and influence of processing techniques*, pp. 359–365, in Alnwick, D. *et al.*

Gomez, G. and Valdivieso, M. (1984) Changes in cyanide content of ʻassava tissues as affected by plant age and variety. In *Proceedings of the 6th Symposium of the International Society of Tropical Root Crops, Lima, Peru*, 21–26 Feb., pp. 323–328.

Han, I.K., Kim, S.W., Chae, B.J., Ha, J.K., Park, Y.J. and Lee, Y.S. (1988) Bio-availability of amino acids in cereals and legumes. In *Proceedings, Fifth Asian Congress of Nutrition. Osaka, Japan, 26–29 October 1987*, eds. Yasumoto, K. *et al.* Tokyo: Center for Academic Publications, pp. 351–354.

Harper, J.M. (1979) Food extrusion. *CRC Critical Reviews of Food Science and Nutrition* **11(2)**, 155–215.

Harper, J.M. and Tribelhorn, R.E. (1985) Comparison of relative energy costs of village-prepared and centrally processed weaning foods. *UNU Food and Nutrition Bulletin* **7(4)**, 54–60.

Henry, F.J., Patwary, Y., Huttly, S.R.A. and Aziz, K.M.A. (1990) Bacterial contamination of weaning foods and drinking water in rural Bangladesh. *Epidemiology and Infections* **104**, 79–85.

Hiel, A.M.M. (1984) *Young children and supplementary feeding programmes: a field guide for the use of local foods and dried skim milk in Africa*. Wageningen: The Netherlands Nutrition Foundation.

Kadam, S.S. and Salunkhe, D.K. (1985) Nutritional composition, processing and utilization of horse gram and moth beans. *CRC Critical Reviews of Food Science and Nutrition* **22**, 1–26.

Lloyd-Evans, N., Pickering, H.A., Goh, S.G.J. and Rowland, M.G.M. (1984) Food and water hygiene and diarrhoea in young Gambian children: a limited case control study. *Trans. Royal Society Tropical Medicine and Hygiene* **78**, 209–211.

Lorri, W.S.M. (1993) Nutritional and microbiological evaluation of fermented cereal weaning foods. PhD thesis, Chalmers University of Technology, Goteborg, Sweden.

Malleshi, N.G. and Desikachar, H.S.R. (1988) Reducing the paste viscosity (dietary bulk) of roller dried weaning foods using malt flour or fungal amylase. *Journal of Food Science and Technology, India* **25**, 1–3.

Megraud, F., Boudraa, G., Bessaoud, K., Bensid, S., Dabis, F., Soltana, R. and Touhami, M. (1990) Incidence of Campylobacter infection in infants in western Algeria and the possible protective role of breast feeding. *Epidemiology and Infections* **105**, 73–78.

Mensah, P.P.A., Tomkins, A.M., Drasar, B.S. and Harrison, T.J. (1990) Fermentation of cereals for reduction of contamination of weaning foods in Ghana. *The Lancet* **336**, 140–143.

Molbak, K., Hojlyng, N. and Jepsen, S. (1989) Bacterial contamination of stored water and stored food: a potential source of diarrhoeal disease in West Africa. *Epidemiology and Infections* **102**, 309–316.

Nout, M.J.R. (1991) Ecology of accelerated natural lactic fermentation of sorghum-based infant food formulas. *Internationl Journal of Food Microbiology* **12**, 217–224.

Nout, M.J.R. (1992) Accelerated natural lactic fermentation of cereal-based formulas at reduced water activity. *International Journal of Food Microbiology* **16**, 313–322.

Nout, M.J.R. (1994) Fermented foods and food safety. *Food Research International* **27**, 291–298.

Nout, M.J.R., Rombouts, F.M. and Havelaar, A. (1989) Effect of accelerated natural lactic fermentation of infant food ingredients on some pathogenic micro-organisms. *International Journal of Food Microbiology* **8**, 351–361.

Nout, M.J.R., Rombouts, F.M. and Hautvast, G.J. (1989) Accelerated natural lactic fermentation of infant food formulations. *UNU Food and Nutrition Bulletin*, **11**(1), 65–73.

Oyeleke, O.A., Morton, I.D. and Bender, A.E. (1985) The use of cowpeas (*Vigna unguiculata*) in improving a popular Nigerian weaning food. *British Journal of Nutrition* **54**, 343–347

Panasiuk, O. and Bills, D.D. (1984) Cyanide content of sorghum sprouts. *Journal of Food Science* **49**, 791–793.

Renner, E. (ed) (1989) *Micronutrients in milk and milk-based food products*. Elsevier Applied Science, London, UK.

Roberts D. (1990) Sources of infection: food. *The Lancet* **336**, 859–861.

Salunkhe, D.K., Jadjar, S.J., Kadam, S.S. and Chavan, J.K. (1982) Chemical, biochemical and biological significance of polyphenols in cereals and legumes. *CRC Critical Reviews of Food Science and Nutrition* **17**, 277.

Uwaegbute, A.C. and Nnanyelugo, D.O. (1987) Differences in the infant-feeding practices in urban and rural Nigeria. *Journal of Nutritional Education* **19**, 83–89.

Van Zuilichem, D.J., Bruin, S., Jansen, L.P.B.M. and Stolp, W. (1980) Single screw extrusion of starch- and -protein-rich materials. Proc. Int. Conference on Engineering and Food II, *Food Processing and Engineering 1980*, pp. 745–756.

Wanink, J.F., van Vliet, T. and Nout, M.J.R. (1994) Effect of roasting and fermentation on viscosity of cereal–legume based food formulas. *Plant Foods for Human Nutrition* **46**, 117–126.

Waterlow, J. (1981) Observations on the suckling's dilemma—a personal view. *Journal of Human Nutrition* **35**, 85–98.

Waterlow, J. and Payne, P.R. (1975) The protein gap. *Nature* **258**, 113–117.

WHO (1988) *Weaning from breast milk to family food: a guide for health and community workers*, ISBN 9241542363.