

6. Food processing, safety and quality

The previous chapters have focused primarily on the appropriate nutritional content of complementary foods for children of different ages and the factors that influence how these foods are offered and consumed. The present section deals with the range of food processing techniques that are available to assure adequate safety and quality of these foods. Food processing may be carried out in the home, or by community groups, or as cottage industries or more formal commercial operations, with the respective sites having increasing levels of sophistication and capital requirements. Because of this report's emphasis on complementary feeding in low-income countries, most attention will be devoted to simple processing techniques that can be practised in the home. The reader is also referred to earlier publications on this topic (Cameron & Hofvander, 1983; Mitzner, Scrimshaw & Morgan, 1984; Alnwick, Moses & Schmidt, 1988; WHO, 1994d).

The aims of food processing are to ensure microbiological and chemical safety of foods, adequate nutrient content and bioavailability, and acceptability to the consumer and caregiver with regard to sensory properties and ease of preparation. Processing may have either beneficial or harmful effects on these different properties of food, so each of these factors must be taken into account in the design and preparation of complementary foods.

6.1 Food safety

The safety of complementary foods can be defined as the certainty that they will not cause harm to infants and children when prepared and fed as recommended. More specifically, food safety can be thought of as the set of conditions and practices during the production, processing, storage, distribution, preparation, and secondary (domiciliary) storage of complementary foods that are necessary to protect them from pathogenic microorganisms, exogenous chemical contaminants, naturally occurring toxic substances and newly formed toxic compounds produced during food storage, processing, or preparation (Motarjemi et al., 1993).

6.1.1 Biological contamination

Bacteria, viruses, and parasites can cause food-borne infectious diseases. Diarrhoeal diseases are the major food-borne infections (Table 34), although enteric fevers, brucellosis, poliomyelitis, helminthic infections, and other diseases are also of concern (Käferstein et al., 1996). The World Health Organization estimates that each year more than 1.5 billion episodes of diarrhoea occur in children less than five years of age in developing countries, resulting in over three million deaths (WHO, 1996c). It has been further estimated that more than half of these infections may be transmitted through food (Esrey & Feachem, 1989). Sources of microbial contamination include polluted water, night soil, dust, flies, domestic animals, dirty utensils and food handlers. Raw foods themselves may harbour pathogens or these may be introduced during processing, preparation, feeding, or secondary storage. Contamination during storage is a function of

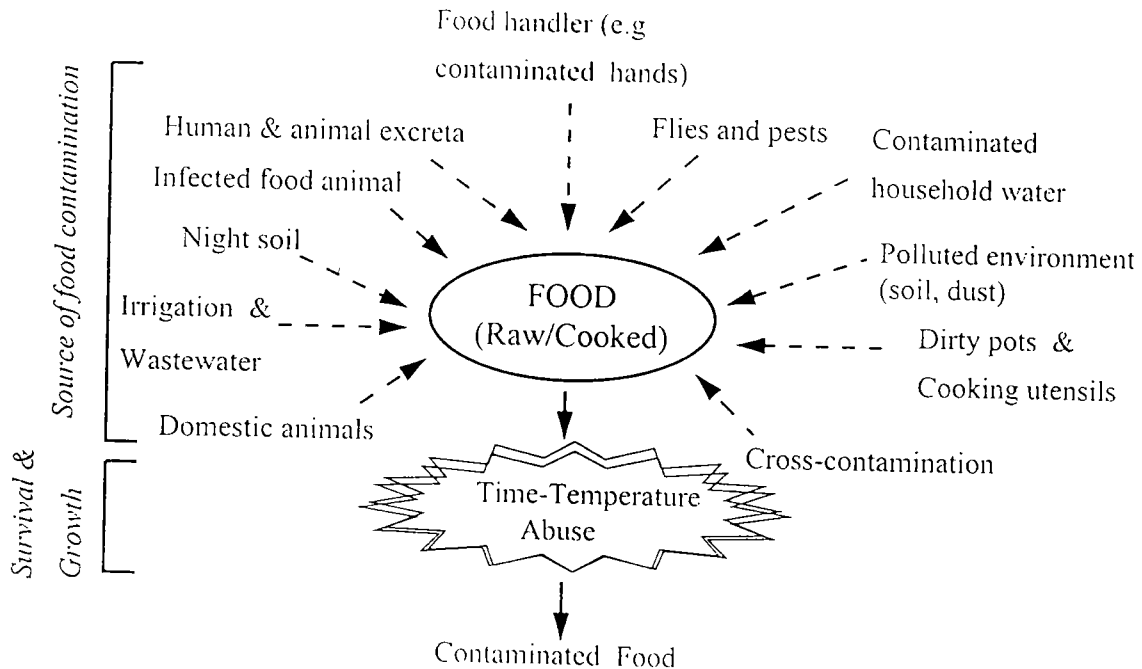
time and temperature, which may allow survival and/or proliferation of microorganisms if storage conditions are sub-optimal (Figure 7) (WHO, 1996d).

Table 34. Pathogens associated with diarrhoea in hospitalized children in developing countries

Pathogen	Percent of cases
Rotavirus	15 - 25
<i>Escherichia coli</i>	
-enterotoxigenic	10 - 20
-enteropathogenic	1 - 5
<i>Shigella</i>	5 - 15
<i>Campylobacter jejuni</i>	10 - 15
<i>Vibrio cholerae O1</i>	5 - 10
<i>Salmonella (non typhi)</i>	1 - 5

Microbial contamination of complementary foods can be prevented by simple processing and handling techniques, such as storing non-perishable items in a safe place (e.g. labelled, clean, closed containers); washing and, if possible, peeling raw foodstuffs, especially those given in raw form like fruits and vegetables; using safe water for washing foods and frequent washing of hands; keeping food preparation surfaces meticulously clean; thorough cooking of food; avoiding contact between raw and cooked foods; protecting cooked foods from dirty utensils, hands, insects, and domestic animals; using clean feeding utensils and avoiding the use of feeding bottles and teats; consuming cooked food shortly after preparation or, if not possible, storing for as short a period as possible at cold (< 10 °C) or hot (> 60 °C) temperatures and reheating thoroughly to assure that all parts of the food reach at least 70 °C. However, in low-income settings adequate food handling may be constrained by lack of economic resources, such as soap, clean water, or fuel for boiling water and thoroughly cooking food; absence of facilities for safe storage of food; and insufficient time and knowledge to prepare food properly prior to each meal (WHO, 1996d). Possible approaches to overcoming these constraints are the use of pre-prepared food mixtures or foods subjected to lactic acid fermentation, as discussed below in more detail.

Figure 7. Sources of food contamination



6.1.2 Chemicals and toxicants in foods

Noxious components of food that impose health risks include both exogenous chemicals contaminating these foods and naturally occurring endogenous food toxicants. To assure the safety of these foods, exogenous chemical contamination must be avoided and intrinsic toxicants must be physically removed or denatured. Toxicological evaluation is accomplished by feeding increasing doses of particular substances to laboratory animals to determine the maximum level at which no observable effect occurs. Usually a safety factor of one hundred times the “no observable effect level” (NOEL) is used to establish the acceptable daily intake (ADI) for humans.

Undesirable chemical substances may be introduced into the food supply as a result of environmental contamination. In some tropical countries, for example, DDT used for the control of malaria has also been recovered from food (Käferstein et al., 1996). Mycotoxins, the toxic metabolites of certain fungi (moulds), may cause acute intoxication and longer-term mutagenic, carcinogenic, and teratogenic effects. One such mycotoxin, aflatoxin, is found in oilseeds (e.g. groundnuts), cereals, tree nuts, and some fruits under conditions of high ambient temperature and humidity. Compliance with good agricultural/manufacturing practice is of utmost importance in controlling post-harvest growth of moulds. Food additives comprise a large and varied group of chemicals that are

introduced into food to enhance keeping, nutritional, and organoleptic qualities and to inhibit the growth of pathogens. Acceptable amounts of these additives have been specified by the Codex Alimentarius Commission, as described below.

Naturally occurring toxicants in some plants are also important causes of disease in selected parts of the world. The use of some legume seeds, such as *Lathyrus sativus* which causes devastating neurological disease, and pyrrolidine-rich varieties of millet, must be avoided in the preparation of complementary foods. Other endogenous anti-nutritional components of food are discussed below (section 6.2.2).

Several committees of WHO and FAO have reviewed methods of controlling contamination of foods with heavy metals, pesticides, and drug residues. Food additives, contaminants, and veterinary drug residues fall under the purview of the Joint FAO/WHO Expert Committee for Food Additives (JEFCA). Pesticide contamination is evaluated by the Joint FAO/WHO Meeting on Pesticide Residues. These advisory groups determine the Acceptable Daily Intakes (ADIs) of these exogenous compounds, and recommend acceptable Maximum Residual Levels (MRLs) in the case of pesticides and drugs and Maximum Levels (MLs) of permissible food additives. In the case of contaminants, JEFCA may establish Provisional Tolerable Weekly Intakes (PTWI) to protect consumers against the chronic health hazards associated with these chemicals.

In developing countries existing infrastructure may not permit adequate regulation and evaluation of food contamination. Sporadic information suggests, for example, that both breast milk and some complementary foods given to young children may contain high levels of pesticides, especially organochlorine residues. Further assessments are warranted in view of the potential acute and chronic health hazards that are implied (Käferstein et al., 1996).

6.2 Food quality

Beyond the aforementioned concerns regarding food safety, the quality of food can be assessed in terms of its nutritional value, nutrient bioavailability, functional and organoleptic properties, and ease of preparation. In each case, food-processing techniques may influence these aspects of food quality. These different characteristics of foods are described briefly in the following sections.

6.2.1 Nutritional value of food

The nutritional value of foods depends on their nutrient content and the bioavailability of these nutrients. Food composition is determined by proximate analysis of carbohydrate, lipid, and protein contents, and measurement of individual vitamins and minerals, using standardized techniques. Analyses of food may further focus on amino acid content, fatty acid profiles, individual simple and complex carbohydrates, soluble and insoluble fibres, and other substances that are present in small quantities but may have important biological

functions, such as antioxidants, biologically active peptides, probiotic heterosides, and so on. The energetic value of food can be measured directly (bomb calorimetry) or estimated from the carbohydrate, lipid and protein contents, and appropriate conversion factors. These conversion factors generally include a correction for the “metabolic energy content” of foods, which is the amount of food energy actually absorbed and retained. The typically assumed energy values for 1 g of carbohydrate, lipid, and protein are 4, 9, and 4 kcal_{th}/g, respectively.

The nutritional value of food can also be assessed by *in vivo* methods in laboratory animals, typically young growing rats. These tests can provide a reasonably accurate evaluation of the nutritional value of foods, but they are expensive and cumbersome. Alternative *in vitro* tests are available to assess specific aspects of nutritional quality. For example, chemical tests of available lysine have been developed because this amino acid can be rendered partially unavailable following heat treatment of protein-containing foods in the presence of the reducing sugars glucose or galactose (the “browning reaction” or “Maillard reaction”). FAO/WHO expert committees have also suggested that the protein quality of individual foods or mixed diets can be assessed by comparing the estimated availability of individual amino acids (calculated by multiplying the amino acid content of the protein by the digestibility of that protein) with the amino acid requirements for particular age groups.

The bioavailability of nutrients can be defined as their potential for release and absorption during the digestive processes and their effective metabolic use. Bioavailability depends on the chemical nature of the nutrients (e.g. the valence of cations such as iron, the conformation of proteins, etc.); the physicochemical environment during the digestive process (e.g. pH, presence of complex carbohydrates, condensed tannins, etc.); the food processing techniques applied (e.g. thermal treatment); the presence of anti-nutritional factors (e.g. enzyme inhibitors); the overall composition of the diet (“nutrient-nutrient interactions”); and other factors. The health of the child, particularly the presence of enteric infections, may further affect nutrient bioavailability. Nutrient bioavailability is discussed in greater detail in relation to children’s nutrient requirements in section 4.5.2.

6.2.2 Anti-nutritional factors

Anti-nutritional factors in foods are those food components that interfere with the digestion, absorption, or some other aspect of metabolism of a nutrient or nutrients contained in those or other foods. Anti-nutritional factors represent a considerable number of different chemical compounds having a wide range of metabolic effects (Table 35). Some of these factors, such as enzyme inhibitors, phytates, lectins, polyphenols, and allergenic factors, are quite common, while others may be specific to just a few plant species, such as cyanogens in cassava, gossypol in cotton seed, and favism factors in broad beans and other legumes. These compounds generally make up a small fraction of the weight of foods, and their analysis may be problematic. Available methods of removing these compounds from food depend primarily on their physicochemical nature. Several

examples of anti-nutritional factors and the methods of disposing of them are reviewed in the following paragraphs.

Table 35. Antinutritional factors in food

NITROGENOUS OR PROTEIN COMPOUNDS

- Enzyme inhibitors: amylase, protease and lipase inhibitors
- Lectins, hemagglutinins
- Amino acids or derivatives : mimosine, L-DOPA, selenoaminoacid, lysinoalanine
- Lathyrogenic amino acids
- Maillard reaction products

CARBOHYDRATES

- Alpha-galactosides
- Beta-glucans

FATS

- Cyclic, oxidised fatty acids
- Erucic acid

PHYTATE

- Phytic acid and phytic acid salts

PHENOLIC COMPOUNDS

- Chlorogenic acid
- Flavonoids
- Gossypol
- Polyphenols and tannins

GLYCOSIDES, HETEROSIDES

- Cyanogens
- Favism factors: vicine
- Goitrogens: glucosinolates
- Steroidic and triterpenoid glycosides: saponins
- Phyto-oestrogens

ALKALOIDS

MYCOTOXINS

6.2.2.1 Protease inhibitors

All seeds, and especially those of legumes, contain enzyme inhibitors. Of these, the most harmful are the protease inhibitors that block activity of pancreatic proteolytic enzymes, such as trypsin and chymotrypsin, resulting in pancreatic hyperplasia and hypersecretion in small experimental animals. The structure and action of these protease inhibitors have been described extensively (Liener, 1980). Although there is limited information on their specific effects in humans, it is generally considered prudent to remove these protease inhibitors from foods prior to consumption. These inhibitors are denatured by heat and they can be removed by roasting and wet autoclaving. Boiling, however, may be insufficient to deactivate these substances fully, so dry heat (roasting, toasting) is the preferred method for home processing.

6.2.2.2 Phytates

Phosphorus is stored in plant seeds linked to inositol to form different compounds of inositol phosphate, known as phytates. Phytates can make up as much as 1-5% of the dry weight of some grains. Depending on the number of phosphorus molecules they contain, phytates may bind strongly to minerals and trace elements in the diet, rendering them unavailable for absorption (see section 4.5.2). Phytates also form stable bonds with protein and may inhibit the activity of some enzymes, such as amylases and proteases.

Phytates are not hydrolysed in the small intestine of humans, but the phytate content of raw foods may be modified by the action of endogenous (plant) or exogenous (microbial) phytases. Endogenous phytases are activated during soaking and germination. Microbial phytases can be produced during certain forms of food fermentation, such as lactic fermentation. Microbial phytases are also produced industrially by organisms like *Aspergillus ficuum*, *Bacillus subtilis*, and others, although there is little, if any, experience in the use of these latter phytases for small-scale food processing in developing countries. Recent reports of genetically modified, low-phytate cereal grains offer another possible approach, which deserves further attention (Mendoza et al., 1997).

6.2.2.3 Lectins

Lectins, or agglutinins, are found throughout the plant kingdom and in all parts of plants. They are particularly abundant in legume seeds, where they may make up as much as 1-3% of dry weight. Lectins are high molecular weight proteins that have a high affinity for the glycan fraction of glycoproteins and other complex glyco-conjugates. The anti-nutritional effects of lectins are due to their adherence to glycoproteins of the intestinal mucosal membrane surface, causing decreased digestive and absorptive capacity, and symptoms of nausea and diarrhoea. Some lectins, such as kidney bean phytohemagglutinins and castor bean lectins, may also be cytotoxic. By contrast, lectins from peas, lentils, and broad beans do not appear to have adverse effects. The harmful effects of lectins can be removed by heat treatment, as described for protease inhibitors.

6.2.2.4 Tannins and other polyphenols

Polyphenols are a diverse group of compounds that may be more or less polymerized or condensed. The condensed polyphenols, like tannins, consist of polymerized proanthocyanidins that are neither hydrolysed nor absorbable. They are abundant in some cereals, such as sorghum, and in legume seeds. Tannins interfere with protein digestibility and lysine availability, but may also have beneficial antioxidative effects. Tannins are not denatured by heat treatment, so avoidance requires elimination of those parts of the plant that have the highest tannin contents.

6.2.2.5 Alpha-galactosides

Alpha-galactosides, which are found in legume seeds, are galactose-containing oligosaccharides, whose glycoside bonds cannot be hydrolysed by digestive enzymes in the human intestine. When these oligosaccharides pass into the large intestine they are fermented by colonic microflora, causing gas, distension, flatulence, and possibly diarrhoea. Alpha-galactosides can be eliminated partially by solubilization or enzymatic hydrolysis during germination or fermentation. Microbial alpha-galactosidases are also available commercially.

6.2.3 Functional and organoleptic properties of food

The functional properties of foods refer to their solubility, hydration, gel formation, coagulation, foaming, emulsifying properties, and so on. The organoleptic characteristics of food are their sensory properties, such as taste (sweet, salty, bitter, sour), aroma, colour, and texture. The acceptability of food depends to some extent on these characteristics, as well as culture-specific beliefs and preferences. Complementary foods are perhaps unusual in that both the caregiver and the child must appreciate these food properties. Organoleptic characteristics that are of particular importance for complementary foods are their consistency, taste, and possibly colour.

Consistency can be defined as “the degree of density, firmness, viscosity, or resistance to movement or separation of constituent particles” (Webster’s dictionary). Viscosity is commonly used as an objective measure of the consistency of starch-based gruels. The viscosity of a material is its resistance to flow under mechanical stress, or, in quantitative terms, the ratio of the shear stress to the shear rate. A number of instruments have been designed to measure the viscosity of starch-containing foods under different conditions. Because the results of these tests depend on the type of instrument, the measurement conditions, and the nature of the food, results cannot be easily compared across studies. Simple, field-appropriate tests of viscosity have been described (Trèche et al., 1995). The relationship between the viscosity of complementary foods and consumption of these foods by young children was discussed in section 3.7.

The taste and colour of complementary foods are other factors that may influence consumption. The importance of taste was discussed in section 3.6. Little information is available on the importance of colour, although in most cultures light-coloured gruels or porridges seem to be preferred.

6.3 Effects of food processing

A large number of techniques have been developed throughout history to improve the safety, nutritional value, and sensory and functional properties of foods. These food processing techniques can be classified as:

- Physical processes, such as thermal treatment (heat or cold), mechanical treatment (physical separation, centrifugation, filtration), reduction of water activity (dehydration or addition of solutes), and irradiation
- Chemical processes, such as addition of acid, alkaline, oxidizing, or reducing agents
- Enzymatic processes, such as hydrolysis of proteins and polysaccharides or inactivation of toxic compounds
- Biological processes, such as fermentation and germination.

Some of the specific effects of different processes will be described in the following sections.

6.3.1 Effects on microbiological quality

Food processing techniques can be used to eliminate, reduce, or control microbial contamination (Motarjemi et al., 1995). Pathogens can be eliminated by heat treatment (boiling, roasting, frying, baking), chemical disinfection, freezing, and irradiation. Heating food above the temperature of microbial viability for a sufficient length of time is the most common and effective method to ensure microbial safety. At temperatures above 70 °C most pathogenic microorganisms are destroyed. Heat treatment simultaneously improves shelf life and the organoleptic and nutritional characteristics of food. At the industrial level, heat treatment at the prescribed temperature-time combination (pasteurization) destroys vegetative forms of pathogens while having minimal effect on the composition, flavour and nutritional value of food.

Disinfection with chemical agents, such as chlorine, is one of the most common treatments used in public health disease control programmes, primarily in the treatment of water supplies. Freezing can be used to inactivate helminths, such as *Trichinella* and *Taenia* in meat or *Clonorchis* in fish. Although not used commonly in developing countries, irradiation is effective in low doses (up to 3.0 kGy) to destroy parasitic larvae in meat or inactivate metacercariae of trematodes in fish, and in higher doses (3-7 kGy) to kill bacteria, such as *Salmonella*, *Shigella*, *Campylobacter*, *Vibrio*, and *Yersinia*.

Temperature, pH, control of water activity, and use of antimicrobial agents are the available methods to prevent the growth of organisms or production of microbial toxins in food. Hot-holding or chilling, as described above, can slow the growth of pathogenic bacteria. Reducing pH below 4.0-4.5 by fermentation or acidification with acid foods can similarly inhibit proliferation of bacterial pathogens, as can reduction of water in food by drying, or decreasing the availability of water to microorganisms by adding salt or sugar or by freezing. In addition to salt, sugar, and organic acids, other antimicrobial agents are curing salts, such as nitrites; bacteriocins, such as nisin; and gases like CO₂ which can be used as preservatives.

Packaging and disinfection of utensils and food processing equipment are the primary means of reducing re-contamination during or after processing. Packaging is also useful

to protect foods against moisture.

6.3.2 Effects on nutritional value

Depending on the nature and intensity of food processing techniques, they can either improve or worsen the nutritional quality of food. Heat treatment at low or moderate temperature, such as blanching, pasteurization, and the majority of cooking techniques, generally leads to improved digestibility and inactivation of anti-nutritional factors. By contrast, the most severe conditions of high temperature or extreme pH may impose severe nutritional losses and induce formation of toxic derivatives in food. These issues are most relevant to large-scale food processing enterprises, so they will not be discussed herein. Further information can be obtained from standard texts of food science and technology.

6.4 Common methods of processing complementary foods

The most common forms of processed complementary foods are semi-solid gruels or porridges. These are generally prepared in two steps. The first step consists of processing the available staple food (cereal, root, or tuber) and major protein source (usually a legume or oilseed) into intermediate flours or doughs, which can be stored for variable lengths of time prior to preparation of the food mixture from these intermediate products. It may be completed in the home, the community, or at the industrial level. The second step consists of the actual preparation and cooking of the mixtures from the intermediate products, and generally takes place in the home, although it can also be performed in the local health post or other community centre. These processes are generally easy to perform and do not require sophisticated equipment.

6.4.1 Processing into intermediate dry products

Preparation of dry flours or powders from staple foods requires a sequence of processes, which may vary according to the level of technological sophistication. This sequence involves cleaning and physical separation of inedible or undesirable parts of the raw foods, size reduction, drying, and possibly precooking and enzymatic treatment. Cleaning consists of hand-picking to remove stones, mouldy grains and other undesirable material, and subsequent washing or dry cleaning. Processes for removing undesirable or inedible parts depend on the type of food and technological capability. For cereal and legume seeds, this consists of removing the husk or hull followed by winnowing, both of which may be accomplished either manually or mechanically. These processes decrease the content of anti-nutritional factors but simultaneously remove vitamins and minerals, especially when the cereal germ is separated from the rest of the seed. On the other hand, because the germ is usually richer in fat content, its removal decreases the susceptibility of flour to become rancid and therefore prolongs its shelf life. For roots and tubers, the peeling of inedible parts is usually accomplished manually.

Size reduction into flour or powder can be carried out by pounding with a pestle and

mortar and sieving with a meshed material, or by grinding and sieving dry grains in an electric or diesel mill, generally a hammer mill. The size of the resulting particles affects the organoleptic characteristics of the flour.

Blending of the different dry constituents can be achieved in a pan or mechanized blender. When flours are blended in the home, this may be done just prior to preparation of the cooked product. The method of storing these flours or blends depends on the type of product and expected storage time. In the home, intermediate products are usually stored for just a few days, so they only need protection from dusts, insects, and animals. At the industrial level, when intermediate products are stored for longer periods of time, packaging is necessary to protect against humidity, light, and gas exchange, as well as contamination. The appropriate type of packaging depends on the expected storage conditions. Low-density polyethylene bags are most common because of their low cost, but are only useful for storage periods of less than 3-6 months.

During preparation of flours, thermal processing may be used for drying, roasting, or precooking the raw products. Drying is necessary after washing cereal and legume seeds and after peeling roots or tubers. This may be accomplished by sun-drying in tropical countries or with roasting equipment. At the industrial level, the roller drying technique permits simultaneous cooking and drying, resulting in "instant" (precooked) flour. Roasting, or toasting, can be done in a pan at the household level or in a roaster at the community or small-scale industrial level. As described above, exposing food to dry heat decreases the activity of several anti-nutritional factors, destroys some pathogens, and can improve organoleptic characteristics, although over-treatment can destroy thermolabile vitamins (Mao, Lee & Erbersdobler, 1993). Roasting is generally considered an obligatory step for legumes because of their anti-nutritional components.

At the industrial level, low-cost extrusion cookers may be used to precook dry intermediate products (Harper & Jansen, 1985; Harper, 1995). The extruder is a mechanical device that produces high temperatures (up to 150 °-180 °C) and high pressure (up to 25 mPa) for relatively short residence times of 1-2 minutes (Cheftel, 1986). Depending on the processing conditions and type of food mixture, extrusion cooking causes some degree of swelling and rupture of starch granules, increased cold-water solubility, starch gelatinization, and the release of amylose and amylopectin. For these reasons, gruels with greater energy density and lower viscosity can be prepared from extruded flours compared with non-extruded flours (Hellström et al., 1981; Jansen et al., 1981; Asp & Björk, 1989; Camire, Camire & Krumhar, 1990). Extrusion cooking also improves protein digestibility and the bioavailability of sulphur-containing amino acids (Harper & Jansen, 1985). Additional benefits of extrusion cooking for ultimate food quality have been described, although poorly controlled processes may also decrease the nutritional value of the foods (Björk & Asp, 1983; Cheftel, 1986; Mercier, 1993). For example, under certain processing conditions extensive loss of lysine may also occur due to the Maillard reaction (Cheftel, 1986; Camire, Camire & Krumhar, 1990).

When the process is well controlled, there is no doubt that extrusion cooking can be used to produce safe, precooked flours with good nutritional quality. However, widespread use of this technology is limited by the high capital costs for purchase of the equipment and the need for local expertise for its maintenance. When these conditions are satisfied and there is a large enough local market to justify the initial investment, centralized units can produce flours that are more economical than imported products (Metohoue, 1995). Populations using precooked flours must be taught to prepare them properly with clean water and appropriate hygiene.

6.4.2 Processing into doughs (fermentation)

Processing of cereals, roots, and tubers into doughs almost always involves fermentation, which can be defined as a desirable process of biochemical modification of food products brought about by microorganisms and their enzymes (WHO, 1996d). Fermentation is typically part of a sequence of food processing operations, which include cleaning, grinding, soaking, cooking, etc. Fermentation is a traditional household technology in many parts of the world.

Food fermentations can be distinguished according to the microorganisms responsible (e.g. bacteria, filamentous fungi, yeasts) or to the characteristics of the fermented products (e.g. lactic acid fermented foods, breads, food-flavouring sauces and pastes, vinegars, alcoholic beverages). Fermented foods intended for infants and young children consist mainly of lactic acid fermented dairy products, cereals, roots and tubers.

The process of fermentation may be carried out in several different ways (Steinkraus, 1983; Tomkins Alnwick & Haggerty, 1988; Hounhouigan et al., 1993a). Often the flour is mixed with water and then allowed to ferment for several days, as with *uji* from Kenya and *mawe* from Benin. In other cases, fermentation is carried out twice, initially by soaking the whole grains for several hours, and then again after grinding the soaked grains. The latter technique is used for Nigerian *ogi*, Ghanaian *kenkey*, and Congolese *poto-poto*. In some areas, a mixture of flour and water is cooked first and fermented afterwards, as with *togwa* from Tanzania (Lorri & Svanberg, 1993; Lorri & Svanberg, 1995). In all cases, a succession of naturally occurring microorganisms will result in a population dominated by lactic acid bacteria. At the same time, the pH decreases from about 6.0 to about 3.5, and the titratable acidity and volatile acid content increases (Odunfa & Adeyele, 1985; Hounhouigan et al., 1993b). Adding a starter culture containing active bacteria, either by adding some of a previous batch of fermented dough (a process known as "back-slopping") or inoculating with some carrier material that contains lactic acid bacteria can accelerate fermentation.

In countries where cassava forms a major portion of children's diets, such as those in central and eastern Africa, the bitter forms of cassava containing high levels of cyanogenic glucosides can be detoxified by using a heterolactic fermentation following grating and/or soaking (Mlingi, 1988; Treche & Massamba, 1991; Cornu et al., 1993; Agbor Egbe et al.,

1995). Peeled cassava roots can also be stacked under plastic sheets and fermented with desirable moulds, such as *Mucor*, *Rhizopus*, or *Neurospora spp.*

Lactic acid fermentation has several benefits for the resulting food products. For example, lactic acid fermentation inhibits the growth, survival, and toxin production of a number of food-borne pathogens (Mensah et al., 1988; Mensah et al., 1990; Mensah et al., 1991; Nout, Rambouts & Havelaar, 1989; Svanberg et al., 1992; Olukoya et al., 1994; Kimmons et al., 1997). Several antimicrobial factors associated with lactic acid fermentation have been identified (Mbugua & Njenga, 1992), although the most important seems to be the production of lactic and acetic acids (Adams & Hall, 1988; Yusof, Morgan & Adams, 1993; Simango, 1995). The extent to which pathogens are inhibited depends on the organism in question, the initial level of contamination, the temperature, the amount of acid produced, and the buffering capacity of the food. In the absence of refrigeration or facilities for hot-holding, lactic acid fermentation provides an affordable method to extend the shelf life of food and reduce contamination with food-borne pathogens.

Lactic acid fermentation is also associated with a reduction of naturally occurring plant toxins, as described above for cyanogenic glucosides of cassava (Agbor Egbe et al., 1995). Moreover, favourable changes in nutrient composition occur during fermentation. For example, the content of certain B vitamins and vitamin C may increase during fermentation, and some amino acids are synthesized. The concentrations of starch, soluble sugars, and non-digestible oligosaccharides usually decrease. Fermentation increases the protein digestibility of cereal-based gruels, particularly when prepared from high-tannin cereals (Lorri & Svanberg, 1993). Fermentation reduces the content of anti-nutritional factors such as phytates and tannins, and is therefore likely to enhance mineral absorption (Svanberg & Sandberg, 1988; Mukuru et al., 1992; Lorri & Svanberg, 1995). Finally, the organic acids and other metabolites of fermentation contribute to the taste and aroma of fermented products.

Despite the numerous benefits of fermentation, it must be recognized that not all pathogens are susceptible to its effects and other methods of control are necessary. For example, some enteropathogens, such as *E. coli* O157 : H7 and some enteric viruses are acid resistant. There is little information on the impact of fermentation on enteric parasites, such as *Cryptosporidium*, *Giardia*, and trematodes, which often show resistance to adverse environmental conditions. Likewise, preformed heat-stable toxins of *Staphylococcus aureus* and *Bacillus cereus*, and toxins produced by certain moulds are probably not affected by fermentation. The risk of contamination of raw materials by mycotoxins is a serious food safety hazard in hot, humid environments, and it is unlikely that this problem can be controlled by fermentation. Another disadvantage of fermentation is the time required for household processing, although this can be reduced somewhat by the use of starter cultures, as noted above. Alternatively, fermentation can be carried out in small production units at the community level, as is already being done in many African countries.

In summary, lactic acid fermentation is a technology that can be carried out in the home or community with multiple benefits for food safety and quality. On its own, fermentation cannot eliminate all food-related health risks, but it can contribute to overall food safety and nutritional value, especially when combined with other processing techniques, such as soaking, grinding, and cooking.

6.4.3 Processing intermediate products into gruels

Preparation of special transitional foods for young children involves three major steps. First, the recipe, product, or mixed diet must be formulated according to the nutritional principles and cultural concerns described in the previous chapters. Raw materials should be chosen according to local availability, cost, nutrient content, and safety. Second, these raw materials must be processed to improve storage conditions, microbiological safety, nutrient content and bioavailability, and organoleptic characteristics, as described in the earlier sections of this chapter. Preliminary testing of product acceptability is described briefly in section 8.2. Third, the final products themselves must be prepared by mixing and cooking, either in the home or the community.

Processing of intermediate products (flour or dough) into gruels requires blending (if not done previously), addition of water (in the case of dry products), and cooking. Several methods exist for preparing gruels from non-instant flours. Ingredients can either be suspended into all or part of the water at room temperature and then heated gradually, or the partial suspension can be mixed with boiling water and then cooked. Some ingredients, such as sugar, milk, etc., can be added during cooking. The quality of gruels depends to a large extent on the cooking process. Because it is difficult to standardize the temperature of simple wood, charcoal, or kerosene fires, a double saucepan can be used for better temperature control. In the case of instant flours, like extruded blends, gruels can be prepared by simply mixing the flours with warm water. The microbiological safety of the final gruel will depend on the initial quality of the water used. When the quality of the water is uncertain, it should be boiled to prevent secondary contamination of the food. Another factor influencing the bacteriological quality of mixed foods is the time lapse between cooking and consumption (Black et al., 1989). When foods are stored at room temperature in tropical environments, bacteria proliferate rapidly.

Regardless of the site at which food processing and preparation takes place, continuous quality control is essential to assure a safe and nutritious final product. In recent years the Hazard Analysis and Critical Control Point (HACCP) system has been developed to enhance the safety of industrially-processed foods through the identification, evaluation, and control of biological, chemical, and physical hazards at the point in processing that they are most likely to occur. Guidelines for the application of the HACCP system have been elaborated by the FAO/WHO Codex Alimentarius Commission (WHO, 1997), and examples of adaptation for household use have also been described recently (WHO, 1993; WHO, 1996d). However, there have been few attempts to apply this analytic process in households in low-income settings.

6.4.4 Viscosity reduction

The importance of appropriate energy density and viscosity of complementary foods has been described previously (sections 3.2 and 3.7). As noted in these earlier discussions, the relatively high concentrations of starch-containing staple foods that are often needed to achieve adequate energy density of porridges may result in final preparations that are too thick, or viscous, for young children to consume in a reasonably short period of time. To reduce the viscosity of these porridges, the amylose and amylopectin fractions of starch must be partially broken down so that they will swell less during cooking and thereby retain less water (Hellström et al., 1981). The most effective method for partial digestion of these starch fractions is by addition of exogenous amylase, which can be obtained by germination of cereal or legume seeds or produced microbiologically.

Germination is the sprouting of cereal and legume seeds that is induced by soaking in water (Ashworth & Draper, 1992). As soon as the seed is hydrated, chemical changes occur, which result in partial breakdown of storage components, such as starch and protein; transport of materials from one part of the seed to another; and synthesis of new substances, such as vitamins. Simultaneously, amylases are synthesized in varying quantities, depending on the species and variety of seed and the duration of soaking and germination. The optimum steeping times range from two hours for pearl millet to 12 hours for maize and sorghum (Gopaldas et al, 1988). The optimum duration of germination is that which results in maximum amylolytic activity without undesirable changes, such as growth of moulds, development of unpleasant flavours, or excessive growth of roots and shoots. The range of optimum germination times is approximately 12 hours for quinoa, 48-72 hours for wheat, millet, sorghum, mung bean, and cowpea, and 72-96 hours for maize, rice, soya, and groundnut (Ashworth & Draper, 1992).

After germination the so-called malted grains are dried, the roots and shoots are removed (i.e., the seeds are “devegetated”), and the grains are ground into flour. Once prepared, the shelf life of the resulting amylase-rich flours (ARF) depends on their moisture and fat contents. In India, Gopaldas, Deshpande & John (1988) have found that sun-drying followed by toasting on a charcoal-fired flat griddle resulted in maximal amylase activity and a shelf life of 2-3 weeks at ambient temperature and humidity. ARF prepared from grains with a high fat content have a shorter shelf life because the fats become rancid.

To reduce the viscosity of a porridge, a small amount of ARF can be added to the mixture either before heating or after cooking and partial cooling. The degree of viscosity reduction that can be achieved with ARF depends on the quantity of amylase that is present in the malt flour and the amount of time that it is exposed to the gelatinized starch of the porridge at the appropriate range of temperature. If the ARF is added prior to cooking and the porridge is heated too quickly, the amylase activity may be destroyed before adequate reduction of viscosity is achieved. Likewise, if the ARF is added to porridge immediately after cooking, the amylase activity may be reduced. Thus, the timing of the addition of ARF to the porridge is an important factor in viscosity reduction. By the same token,

excessive reduction of viscosity (resulting in a watery final product) can be prevented by heating the porridge sufficiently to destroy the amylase activity once the desired consistency of the product has been obtained.

The main concerns associated with malting are the potential hazards of cyanide toxicity, aflatoxin production, bacterial contamination, and osmotic diarrhoea due to hydrolysis of starch into simple sugars and oligosaccharides (Ashworth & Draper, 1992). Cyanide toxicity appears to occur only with sorghum that has not been properly devegetated and subjected to heat treatment. Thus, it would seem prudent to avoid using sorghum as a source of ARF unless these steps in processing can be assured. Aflatoxin contamination can theoretically occur with any kind of grain if germination is allowed to proceed too long and growth of mould occurs. Bacterial contamination of ARF can be eliminated by boiling porridges after the ARF has been added and adequate viscosity reduction has been achieved. The theoretical concern regarding the possibly elevated osmolality of ARF-treated porridges (Wahed et al, 1994) has not yet been documented to be a clinical problem. Further study of this issue is needed.

In conclusion, ARF appears to be an effective means to reduce the viscosity of starch-containing porridges with appropriately high energy density. However, potential disadvantages of home-prepared ARF include 1) the variability in amylase content of ARF and difficulty in standardising the conditions of germination, 2) risks of microbial contamination and toxin production, and 3) the time required for careful production and use of ARF in strict adherence with the aforementioned indications and the likely difficulty in communicating these guidelines successfully to individual producers.

An alternative approach that can be used to reduce viscosity with exogenous amylase is the incorporation of an industrially produced enzyme (Trèche, 1995). A wide range of suitably stable, food-grade amylases are commercially available at reasonably low cost. These can be added to dried flours during blending at the cottage industry or larger scale industrial level or at the time of cooking in the household.