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Impact of small scale fermentation technology on food safety in developing countries[☆]

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Abstract

Fermentation is one of the oldest technologies used for food preservation. Over the centuries, it has evolved and been refined and diversified. Today, a variety of food products is derived from this technology in households, small-scale food industries as well as in large enterprises. Furthermore, fermentation is an affordable food preservation technology and of economic importance to developing countries. In the report of an FAO/WHO Workshop (FAO/WHO, 1996), fermentation was reviewed and the nutritional and safety aspects of fermentation technologies and their products were assessed. Fermentation enhances the nutritional quality of foods and contributes to food safety particularly under conditions where refrigeration or other foods processing facilities are not available. Hazard Analysis and Critical Control Point (HACCP) studies of some fermented products have demonstrated that depending on the process and the hygienic conditions observed during preparation, some fermented foods, e.g. *togwa* prepared in Tanzania, may pose a safety risk. Fermented foods must therefore be studied following HACCP principles and small-scale food industries and households must be advised on the critical control points of fermentation processes and the control measures to be applied at these points. This paper reviews the risks and benefits of fermentation and demonstrates the application of the HACCP system to some fermented foods in developing countries.

Keywords: Fermentation; Food safety; HACCP; Complementary food; Pathogens

1. Introduction

Fermentation is one of the oldest technologies used for food preservation. Over the centuries, it has evolved, been refined and diversified. Today a variety of fermented foods is produced both in industrialised and developing countries using this technology at the household level, in small-scale food industry and in large commercial enterprises. A wide range of raw materials is used as substrates and panoply of products is concocted. Foods derived from fermentation are major constituents of the human diet all over the world. In some regions, mainly in African countries, fermentation plays an important role in the nutrition of infants and young children as it is used for the preparation of complementary foods.[1]

[☆] Based on Motarjemi et al., Practical Applications: Prospects and Pitfalls. Fermentation and Food Safety. Eds. M.R. Adams and M.J.R., Nout. Aspen Publishers 2001.

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[1] The term *complementary foods* refers to any food, be solid or liquid, other than breast milk given to infants and young children during the period of complementary feeding. This period of complementary feeding corresponds to the period during which other foods are provided along with breast milk.

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Although advances in food science and technology have given rise to a wide range of new food technologies, fermentation has remained an important technology throughout the history of mankind. Many benefits are attributed to fermentation. It preserves and enriches food, improves digestibility, and enhances the taste and flavour of foods. It is also an affordable technology and is thus accessible to all populations. Furthermore, fermentation has the potential of enhancing food safety by controlling the growth and multiplication of a number of pathogens in foods. Thus, it makes an important contribution to human nutrition, particularly in developing countries, where economic problems pose a major barrier to ensuring food safety.

Developments in food fermentation, particularly its traditional applications, have been based on experience gained through trial and error by consecutive generations of food producers and households who have used the technology for the domestic preparation and preservation of foods. Despite progress made in this field, the technology is still often empirically applied without a comprehensive understanding of the underlying principles of the fermentation process and the requirements for ensuring quality and safety. Such an approach presents a major pitfall, as it may lead to unsafe products depending on the process, environmental conditions and the condition of the raw materials.

This paper reviews the importance of fermentation from a public health point of view, with specific reference to the problems of developing countries. It examines the risks and benefits of fermentation for human nutrition and the prospects for promoting the technology and improving the safety and nutritional quality of derived products. It also presents two Hazard Analysis and Critical Control Point (HACCP) studies using fermented foods as examples. Studying fermentation processes according to the principles of HACCP allows for a systematic analysis of the hazards associated with fermentation processes and the identification of measures, which are critical for safety.

The subject of fermentation is very relevant to the problems of developing countries, particularly with respect to the preparation of complementary foods for infants and young children. This paper therefore has a specific focus on small-scale fermentation, the conditions of developing regions and issues associated with fermentation of complementary foods.

2. Importance of food fermentation in public health

Foodborne diseases are a major global public health problem. Developing countries, however, bear the brunt of the problem. Although statistics on the incidence of foodborne diseases are not available, the high prevalence of diarrhoeal diseases, particularly in infants and young children in these parts of the world, is an indication of an underlying safety problem.

The etiological agents responsible for foodborne diseases are broad and include bacteria, viruses and parasites. Some of the principal pathogens responsible for diarrhoeal diseases are pathogenic strains of *Escherichia coli*, *Shigella*, spp., *Salmonellae*, *Vibrio cholerae O1*, *Campylobacter jejuni*; protozoa such as *Giardia lamblia*, *Entamoeba histolytica*, *Cryptosporidium* spp. and viruses such as Hepatitis A and E, and Rotavirus.

Sources of food contamination are diverse and include polluted water, night soil, dust, flies, domestic animals, dirty utensils and food handlers. Raw foods may also be a source of contaminants as many foods harbour pathogens or originate from infected animals. Moreover, during food preparation, there is an added risk of cross contamination. One major factor leading to food contamination during food preparation and storage is time-temperature abuse, which results in the survival, growth and production of toxins by pathogens (Fig. 1).

In addition to being an agent for diarrhoeal diseases, food may also be a vehicle for chemical hazards, whether naturally present in the food (e.g. cyanide) or contaminating the food as a result of poor agricultural practices (e.g. pesticide residues) or environmental pollution (heavy metals, dioxins). Depending on the dose, chemical hazards may lead to acute intoxication or long-term health problems such as cancers and other chronic diseases. Food may also contain anti-nutritional factors such as enzyme inhibitors, phytates, lectins and polyphenols, which interfere with digestion, absorption or other aspects of nutrient metabolism. In addition to increasing shelf life and enhancing the organoleptic quality of food, fermentation has the potential of inhibiting the growth of most pathogenic organisms and some anti-nutritional factors, as will be discussed later. This feature of fermentation is of major

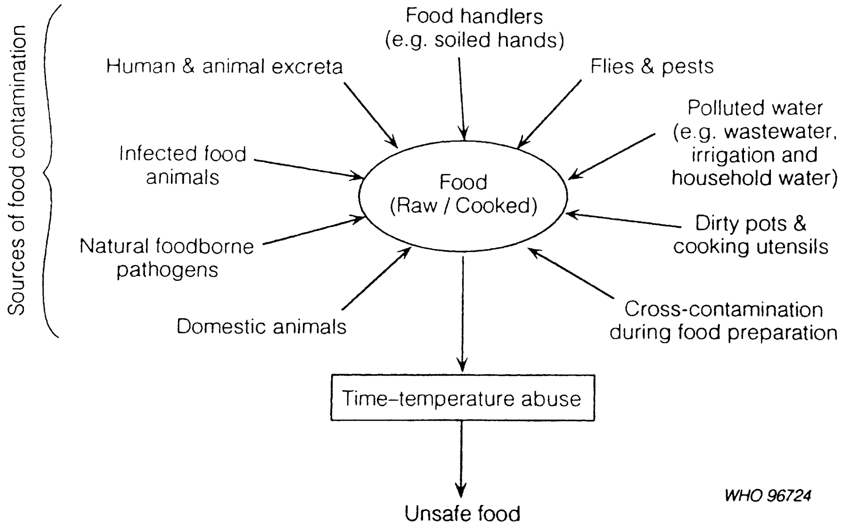

Fig. 1. Sources of food contamination during food preparation (Motarjemi and Nout, 1996).

importance for food safety and public health, particularly in developing countries.

Food processing technologies are applied to increase digestibility, enhance the edibility of food, intensify sensory quality, increase shelf life, improve nutritional quality, and/or render food safe. Food processing technologies whether carried out at the household level, based on experience, or at the industrial level are designed to optimise all of these properties in the final product. All of the above objectives can rarely be achieved using a single operation. Often, a combination of different operations is required, as is the case for fermentation. Fermentation is often part of a sequence of food processing operations, which may include unit operations such as cleaning, grinding, soaking, salting, cooking, packaging, and distribution. The potential of fermentation for improving the nutritional quality and safety of foods should therefore be viewed within the context of the complete food processing operation.

3. Benefits of lactic fermentation

There is a considerable body of evidence to show that lactic fermentation inhibits growth, survival and production of toxins by a number of pathogenic and toxinogenic bacteria (Adams and Nicolaides, 1997). The beneficial effects of lactic fermentation in degrading anti-nutritive factors and natural toxins are thoroughly reviewed elsewhere in this publication (Holzap fel, 2002).

4. Risk associated with lactic fermentation

Though simple, fermentation can result in undesirable products that are sometimes even risky or dangerous. The reasons being that the final quality and safety of the fermented product are dependent on factors such as: (i) quality of the raw material; (ii) initial level of contamination (which in turn depends on local conditions); (iii) levels of hygiene and sanitation; (iv) quality of the starter culture; (v) conditions of fermentation (e.g. temperature); and (vi) degree of acidity achieved.

These parameters are sometimes very difficult to control, particularly when processing is carried out under the rudimentary conditions of some small-scale industries or under household conditions. Some examples of documented outbreaks of foodborne diseases, associated with fermented products, are listed in Table 1. There are reasons to believe that the frequency of improper handling and unhygienic conditions during the production of fermented foods is greater than that reported in the literature. Weak-

Table 1
Examples of foodborne disease outbreaks associated with fermented foods (Motarjemi et al., 2001)

Implicated food	Causative agent	Cases	References
Vegetables			
Paste of soybeans and wax gourds	*Clostridium butyricum*	6	Meng et al. (1997)
Sauerkraut	Histamine poisoning		Mayer and Pause (1972)
Milk products			
Yoghurt	*C. perfringens*	167	MOH (1993)
Hazelnut yoghurt (hazelnut puree was contaminated)	*C. botulinum*	27	O’Mahony and Mitchell (1990)
Sour milk	*C. botulinum*	11	Smith et al. (1979)
Yoghurt	*E. coli* O157	16	Morgan et al. (1993)
Meat products			
Semi-dry sausages	*E. coli* O111:NM	23	CDC (1995a)
Pork (labh-raw and nahm-fermented)	Trichinella	27	Khamboonruang and Nateewatana (1975)
Salami-stick	*Salmonella typhimurium*	85 (including 13 secondary cases)	Cowden et al. (1989)
Salami	*E. coli* O157	23	CDC (1995b)
Sausages (Lebanon bologna)	*S. typhimurium*	26	Sauer et al. (1997)
Fish			
Fish (seal flipper)	*C. botulinum*	1	Shaffer et al. (1990)
Fish (beaver tails)	*C. botulinum*	7	Shaffer et al. (1990)
Fish (salmon fish heads)	*C. botulinum*	8	Shaffer et al. (1990)
Salmon eggs	*C. botulinum*	15[a]	Hauschild and Gauvreau (1985)
Cheeses			
Soft cheese	*S. berta*	82 (including three secondary cases	Ellis et al. (1998)
Cheese	*S. enteridis*	≅ 700	CCDR (1999)
Soft cheese	*S. dublin*	42	Maguire et al. (1992)
Goats milk cheese	*S. paratyphi*	273	Desenclos et al. (1996)
Cheddar cheese	*S. heidelberg*	339[b] (28,000–36,000 est.)	Fontaine et al. (1980)
Mozzarella cheese	*S. typhimurium*	321	Altekruse et al. (1998)
Cheese	*E. coli* O157	22	The Pennington Group (1997)
Cheese (Brie, Camembert, Coulommiers)	*E. coli* O124 B17	387 est.	Marier et al. (1973)
Cheese (Brie, Camembert)	*E. coli* O27 H20	170	Altekruse et al. (1998)
Cheese (Brie, Camembert)	*C. botulinum*	27	Pourshafie et al. (1998)
Mexican-style soft cheese	*Brucella melitensis*	31	Altekruse et al. (1998)
Hand-pressed direct set cheese	*Staphylococcus aureus*	16	Altekruse et al. (1998)
Cheese	*S. sonnei*	50[c]	Sharp (1987)
Swiss cheese	Histamine poisoning	6	Taylor et al. (1982)

[a] 15 cases involved in seven outbreaks between 1971 and 1984.

[b] 339 cases were reported in Colorado. From the attack rates noted (28–36%) and the amount of cheese presumably consumed (2830 kg) it is estimated that between 28,000 and 36,000 persons were affected in total.

[c] Bacillary dysentery, which affected numerous persons who had eaten various French cheeses purchased at a Paris airport in 1982, was reported by several Scandinavian countries.

nesses in foodborne disease surveillance systems do not provide for identification and reporting of these outbreaks.

A number of foodborne hazards are not affected by lactic fermentation and thus fermentation should not be relied upon for the elimination or reduction of these hazards. In order to ensure food safety, fermentation should therefore be combined with a number of other processing operations, such as cooking and soaking.

A number of foodborne hazards are capable of surviving fermentation processing. Enteropathogens, such as enterohaemorrhagic *E. coli*, show some patterns of acid resistance and may survive certain fermentation processes. Yoghurt and fermented meat have been recognised as potential vehicles of enterohaemorrhagic *E. coli* infection.

Foodborne viruses are recognised as a cause of gastroenteritis, and rotavirus is one of the most common causes of childhood diarrhoea. Simian rotavirus has been shown to survive high levels of acidity during 24 h of storage in model fermented foods.

There is little information on the effect of fermentation on parasites, such as *Cryptosporidium*, *G. lamblia* and foodborne trematodes. The cysts or metacercariea of these organism often show resistance to adverse conditions, but are believed to be destroyed by adequate cooking.

Certain algae, bacteria, and moulds produce toxins that may be transmitted by food. Risk associated with mycotoxin contamination, biogenic amines and the lactic acid isomer are covered elsewhere in this issue (Holzapfel, 2002). Similarly, there is no evidence that bacterial toxins can be degraded by fermentation alone. Bacterial toxins, such as *Clostridium botulinum* toxin for example, are heat labile and may be destroyed by adequate heat treatment, whereas others such as those produced by *Staphylococcus aureus* are heat stable. Lactic fermentation has a limited effect on anti-nutritional factors, such as protease inhibitor and lectins.

5. Importance of fermentation in developing countries

Application of the basic rules of food hygiene will help prevent contamination, growth and survival of pathogens in foods and will reduce the incidence of diarrhoeal diseases. Socio-economic constraints such as an inadequacy of supplies of safe water, lack of facilities for safe preparation and storage of food (e.g. refrigeration, fuel for hot holding or thorough reheating) and time constraints for the proper preparation of food prior to each meal can, however, interfere with the application of these rules. As a result, low-income households are simply not able to apply certain essential food safety principles, such as feeding infants with freshly prepared foods, refrigeration, hot storage, and re-heating of stored foods.

Fermentation provides an economic means of preserving food and inhibiting the growth of pathogenic bacteria even under conditions where refrigeration or other means of safe storage are not available. At the same time, it enhances the nutritional quality of certain foods. In many parts of the world, particularly in Asia and in Africa, the technology has been traditionally used as a method of preservation, and to ensure food safety. In some African countries, the technology is applied in the preparation of weaning foods. In Kenya, Nigeria, the United Republic of Tanzania and Uganda, feeding infants with either fermented cereals, or fermented root-crop products is a customary practice. Fermentation has also been used in the production of beverages. In areas where the safety of water supplies cannot be assured, the technology contributes to reducing the risk of waterborne diseases.

6. Constraints to the implementation of fermentation technologies

The application of fermentation is often hampered by practical constraints related to safety, nutrition and social conditions. Recognition of these constraints is essential in the development of interventions for ensuring safety, improving nutritional quality and drawing benefits from the application of fermentation.

6.1. Food safety constraints

Time requirements for food preparation can pose a major constraint in many households. This may have serious implications for the safety and nutritional quality of fermented products, as the time saved by shortening the fermentation period may jeopardise the

Table 2
Application of the HACCP system to the preparation of *uji* in households

Step	Hazards	Control measures	CCPs	Critical limit	Monitoring procedure	Corrective actions
(1) Raw material (i) Maize sorghum millet	(a) Mycotoxins	(a) (i) Obtain assurance from supplier of adequate pre-harvest and post-harvest handling of the grains	(a) Yes	(a) (i) No mouldiness, good smell	(a) (i) Observation, smelling	(a) (i) Discard the raw material and change supplier
		(ii) Store grains in dry (and if possible cool) area, limit storage time		(ii) Adequate time, temperature, humidity of storage area	(ii) Time keeping (measurement of temperature or humidity if possible)	(ii) Utilise the raw material as quickly as possible, when temperature and humidity are not appropriate for storage
	(b) Agrochemicals	(b) Obtain assurance from supplier of adequate pre-harvest and post-harvest handling of grains	(b) No			
	(c) Pathogens: *Bacillus cereus*, *Salmonella, E. coli*	(c) Heat treatment, correct fermentation	(c) No			
	(d) Physical: insects and stones	(d) Manual cleaning	(d) Yes	(d) No visible insect fragments or stones	(d) Observation	(d) Re-clean
(ii) Crystalline sugar	Filth, dirt, insect, glass	Use clean sugar	Yes	No visible foreign matter	Observation	Clean the sugar (e.g. sieve) and if cleaning is not possible, discard the sugar

(2) Grinding	Introduction of filth, dirt, and foreign matter	Use clean and properly maintained equipment	No			
(3) Dough preparation	Contamination with water	Use safe water	No			
(4) Fermentation	(1) Growth and formation of toxin by *S. aureus*	(a) Rapid fermentation	(a) Yes	(a) Acid taste and characteristic odour within 24 h	(a) Observation	(a) Discard the material
	(2) Growth of toxigenic moulds	(b) Remove surface mould growths	(b) Yes	(b) No visible moulds	(b) Observation	(b) Remove more of the top layer
(5) Boiling water	Survival of pathogens	Thorough boiling	Yes	Bubbles	Observation	Continue boiling
(6) Dilution (to 4–5% solids in continuously boiling water)	Survival of non-spore forming pathogens	Continuous boiling	Yes	Gelatinization, well cooked	Observation	Keep boiling
(7) Sweetening (in hot *uji*)	No hazard (for hazards associated with sugar see step 1 (iii)					
(8) Serving	(a) Re-contamination by hands, utensils, environment	(a) Wash hands and use clean utensils	(a) Yes	(a) Washing with soap and thorough rinsing with clean water	(a) Observation	Thorough reheating (steam, bubbles)
	(b) Growth of pathogens and spores of *Bacillus cereus*, if consumption delayed for more than 4 h	(b) Consumption without delay	(b) Yes	(b) Use within 4 h	(b) Time keeping	

Table 3
Application of the HACCP system to the preparation of *togwa* in household

Step	Hazards	Control measures	CCPs	Critical limit	Monitoring procedure	Corrective actions
(1) Raw material (i) Maize sorghum millet	(a) Mycotoxins	(a) (i) Obtain assurance from suppliers of adequate pre-harvest and post-harvest handling of grains	(a) Yes	(a) (i) No mouldiness, good smell	(a) (i) Observation, smelling	(a) (i) Discard the raw material and change supplier
		(ii) Store grains in dry (and if possible cool) area, limit storage time		(ii) Adequate time, temperature, humidity of storage area	(ii) Time keeping (measurement of temperature or humidity if possible)	(ii) Utilize the raw material as quickly as possible
	(b) Agro-chemicals	(b) Obtain assurance from supplier of adequate pre-harvest and post-harvest handling of grains	(b) No			
	(c) Pathogens: *Bacillus cereus*, *Salmonella*, *E. coli*	(c) Heat treatment, fermentation	(c) No			
	(d) Physical: insect and stones	(d) Manual cleaning	(d) Yes	(d) No visible insect fragmentation or stones	(d) Observation	(d) Re-clean
(ii) Water	(a) Chemical contaminants, depending on the source	(a) Obtain assurance about the source of water; use only safe water	(a) Yes	(a) Clear, free of odour and off-taste	(a) Observation, smelling and tasting	(a) Use another source of water
	(b) Pathogens, e.g. *E. coli*, *Campylobacter*, *V. cholerae*, *Salmonella*, *Cryptosporidium*, *Giardia lamblia*, *Entamoeba histolytica*, Rotavirus	(b) If safe water (i.e. filtered and disinfected) is not available, boil the water	(b) Yes for step 2; No for step 8	(b) Bubbles	(b) Observation	(b) Re-boil

(2) Soaking	Growth of microorganisms	As far as possible at low temperature	Yes	Water should remain free from odour or foam	Observation, smelling	Refresh water
(3) Germination	Growth of microorganisms: e.g. toxigenic moulds	As far as possible at low temperature	Yes	Grains should remain free of mouldiness	Observation	Remove mouldy grains
(4) Sun-drying	(a) Contamination	(a) Protect the sprouts	Yes	(a) No foreign matter	(a) Observation	(a) Clean if possible. If not, discard
	(b) Inadequate drying may lead to growth of microorganisms during storage	(b) Ensure thorough and fast drying		(b) Sufficient time, adequate exposure to sun, dry ambient conditions, adequate air circulation, no mould	(b) Time	(b) As long as there is no mould growth, re-dry under proper conditions, otherwise discard
(5) Storage of sun-dried germinated grains	(a) Contamination	(a) Protect the grains	Yes	(a) No foreign matter	Observation	(a) Clean if possible. If not, discard
	(b) Growth of toxigenic moulds, if the moisture content is high	(b) Keep dry		(b) Dry conditions of storage, no mould		(b) Discard
(6) Grinding to power flour	Introduction of filth, dirt and foreign matter	Use clean and properly maintained equipment	No			
(7) Grinding	same as step 6					
(8) Slurry preparation	Contamination through utensils and/or water	Use clean utensils and safe water	No			
(9) Boiling	Survival of pathogens	Thorough boiling	Yes	Bubbles	Observation	Re-boil
(10) Cooling	(a) Growth of bacterial spores	(a) Ensure rapid cooling	Yes	(a) Short time, room temperature within 4 h	(a) Time keeping	(a) Re-boil
	(b) Contamination	(b) Protect the porridge during the cooling process		(b) No foreign matter	(b) Observation	(b) Depending on the nature of contamination, either clean, re-boil or discard

(continued on next page)

Table 3 (*continued*)

Step	Hazards	Control measures	CCPs	Critical limit	Monitoring procedure	Corrective actions
(11) Addition of:						
(a) Power flour	(a) Contamination by power flour	(a) Ensure hygienic quality of power flour	Yes	(a) Power flour and *togwa* of high hygienic quality	Observation	Use another power flour and *togwa*
(b) *Togwa*	(b) Contamination with acid-resistant pathogens by *togwa*	(b) Ensure the safety of previously prepared *togwa*		(b) Absence of disease upon consumption of *togwa*		
(12) Fermentation	(a) Growth and formation of toxin by *S. aureus*	(a) Rapid fermentation	(a) Yes	(a) Acid taste and characteristic odour within 24 h	(a) Observation	(a) Discard the material
	(b) Survival of acid-tolerant pathogens	(b) Minimize contamination with acid tolerant pathogens (see step 11)[a]	(b) No			
(13) Serving	Recontamination by hands, utensils, environment	Wash hands and use clean utensils	Yes	Washing with soap and thorough rising with clean water	Observation	Thorough reheating

[a] As there is no critical control point in the subsequent steps which would ensure the killing of acid-tolerant pathogens surviving the fermentation step, the present process of *togwa* preparation may lead to a high-risk product.

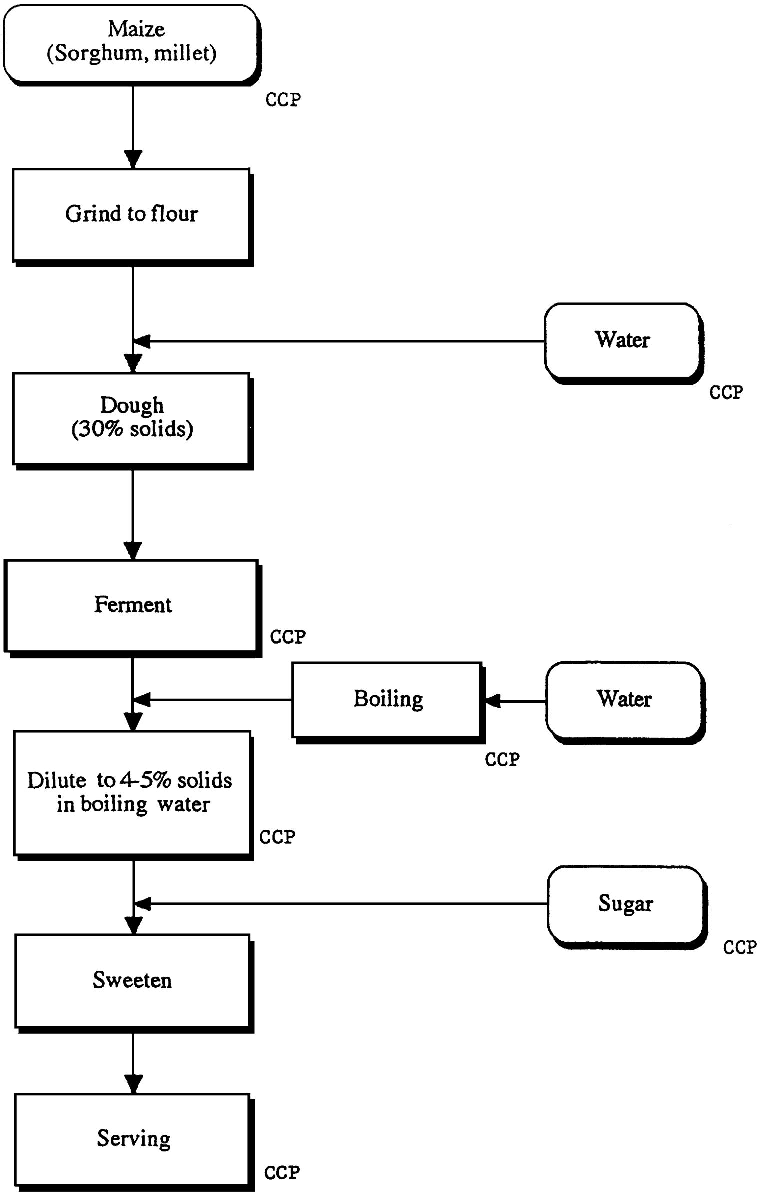

Fig. 2. Flow Diagram for Preparation of *uji*.

effectiveness of acidification by lactic acid bacteria or the enzymatic degradation of plant toxins and antinutritional factors. Other food safety problems may arise from shortcomings in handling and processing and result in different types of hazards as discussed in Section 5.

6.2. Nutritional constraints

Current methods applied in the preparation of fermented complementary foods pose a number of nutritional problems. These include: (i) low protein content and limited quality of the raw material (e.g.

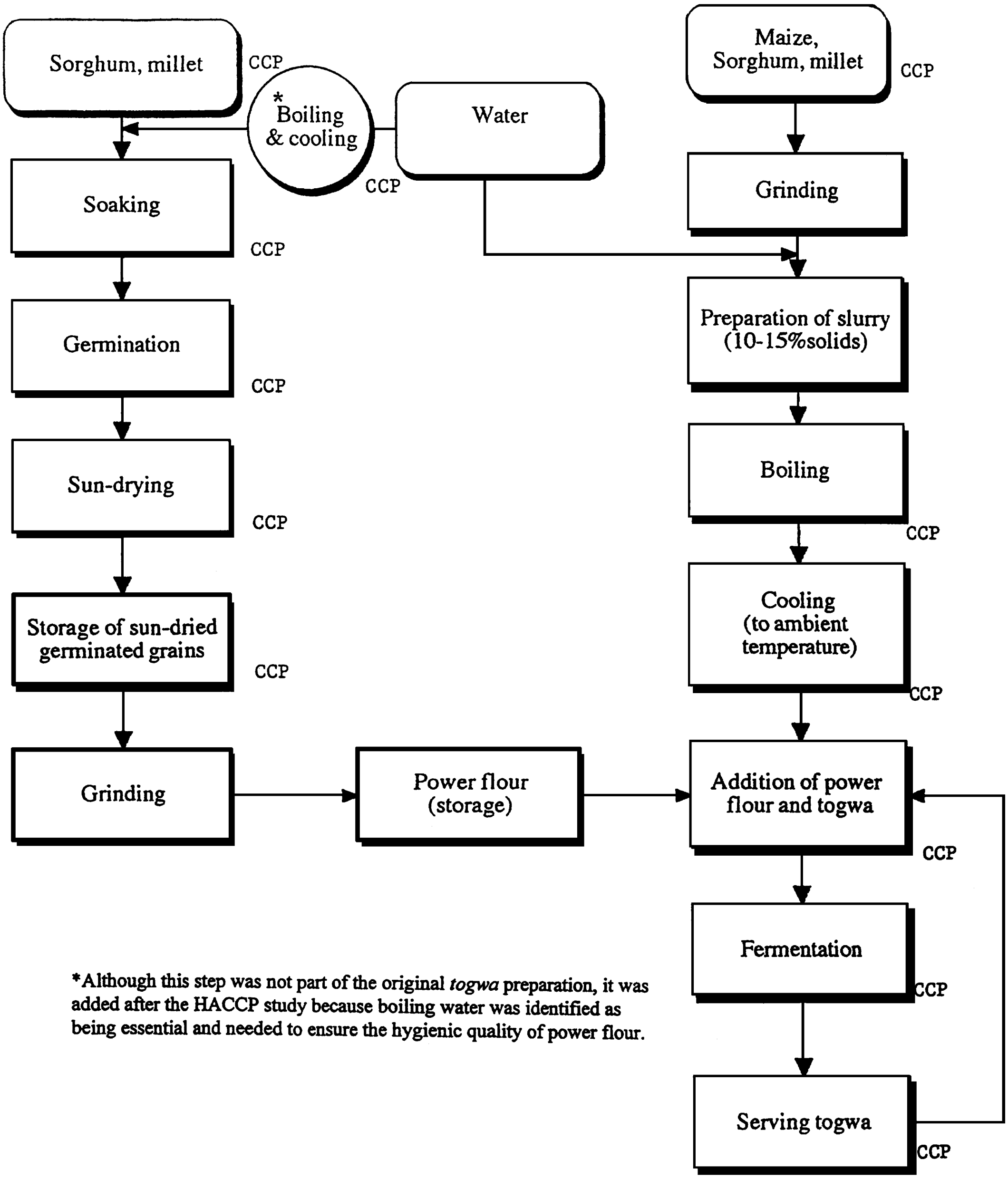

Fig. 3. Flow diagram for preparation of *togwa* (the high number of CCP's in this study is reflecting the fact that the study is considered in very rudimentary hygenic conditions).

cereals, root crops) used for fermentation; (ii) low nutrient density of prepared foods; and (iii) poor or low bioavailability of proteins and minerals in the finished product.

6.3. Sociocultural constraints

The image of fermented foods is generally poor when compared to that of industrial products, which are, in general, considered superior in quality and represent a symbol of progressiveness. Poor hygienic conditions and lack of specific education in food safety by food handlers present potential food safety problems which are of concern in promotion of the technology, particularly in areas where facilities for the safe preparation of food are either scarce or lacking.

7. Practical interventions for improving the safety and nutritional quality of fermented foods

A realistic approach, which incorporates considerations for technical, safety and nutritional concerns as well as the socio-economic and cultural conditions of the target population, is required for overall improvement of fermented foods. Interventions geared toward improving the safety and nutritional quality of fermented foods should therefore be based on: (i) application of the HACCP system and identification of control measures that are essential for ensuring food safety; (ii) examination of socio-economic and cultural patterns and identification of support requirements for improving the safety and nutritional quality of food.

Data collected from the HACCP study would allow the validation of a particular fermentation process, or identify the need for its modification. Based on the socio-economic and cultural information gathered through anthropological studies, modification of the process may be required in order to render it accessible and acceptable to the target population. HACCP and anthropological studies further facilitate the identification of training and educational requirements. Certain practices, particularly those identified as essential control measures, and thus critical control points, may need to be modified or reinforced through training and education. The training and education of operators to respect critical limits through qualitative or quantitative monitoring methods as applicable are also important.

Application of the HACCP system to several African fermented foods has resulted in the identification of a number of critical control points during the preparation of these foods and has identified the need for educating operators in the correct application of control measures at these points (FAO/WHO, 1996).

Processing time constraints might be alleviated through the use of fermentation starter cultures (Holzapfel, 2002).

Nutritional factors are of particular importance when considering complementary foods for infants and young children. Protein content can be increased through the addition of legumes such as soybeans or cowpeas at a ratio of 30 parts legume to 70 parts starchy staple.

8. Application of HACCP to fermented foods

Certain practices applied in the preparation of fermented foods pose a high food safety risk. The application of HACCP to two fermented foods, namely *uji* and *togwa* summarised in Tables 2 and 3, and Figs. 2 and 3, respectively, clearly identify the critical control points and risks associated with the preparation of these foods.

9. Considerations for the promotion of fermentation

Social and cultural patterns vary tremendously from one place to another and are subject to change over time. The impact of these patterns on food safety and nutrition as well as on the solutions to problems encountered are therefore specific to location and time. The importance of studying both socio-economic and cultural factors as a basis for assessing the feasibility of technology transfer has been discussed elsewhere in this publication (Rolle and Satin, 2002). The need to educate those who will apply the technology, on safety factors and nutritional adequacy of the food, should be particularly emphasised.

10. Research requirements

Research on fermented food used throughout the world was comprehensively reviewed at a 1995 FAO/WHO Workshop (FAO/WHO, 1996). Conclusions of this Workshop emphasised the need for an improved understanding of the potentials and effects of using fermented foods as weaning foods. The Workshop attempted to evaluate the status of knowledge in the following areas:

- The potential for the use and promotion of fermented foods as safe and nutritious foods, particularly for feeding infants and young children.
- Research requirements for improving the safety of fermented foods prepared at the household level.
- Priority areas for research in small-scale food processing, in order to ensure the safety of fermented foods to the consumer.
- Socio-economic and cultural issues that need to be addressed in order to ensure the adoption of fermentation both at the household and cottage levels.

Each identified research need was analysed in order to determine relative research priorities, with consideration for both the status of current knowledge and the severity of the problem. The need for recognition of differences between rural and urban dwellers was also noted.

Research issues in four areas, namely: food safety, nutritional value, technology development, technology transfer and related socio-economic aspects were considered.

10.1. Food safety

10.1.1. Efficiency of fermentation in biological safety

The efficacy of lactic fermentation in inhibiting a wide range of pathogenic bacteria has been extensively studied. A meta-analysis would enable quantitative analysis of the data and therefore enable quantitation of trends. Mathematical models describing the survival of pathogens in lactic fermentation would be of useful predictive value without recourse to challenge testing. A few research opportunities specific to the survival of sub-lethally injured organisms and certain acid-tolerant pathogens such as *E. coli* O157:H7 currently exist.

Little information exists on the destruction of parasites (such as trematodes) during fermentation, and information on the fate of viruses during fermentation is limited. There is still, however, a need for further model studies on the survival of these organisms under defined conditions of fermentation. Lack of information on viruses and parasites is partly due to the problem of enumerating these organisms.

Studies on the efficacy of fermentation in inhibiting pathogenic microorganisms should distinguish between pathogenic microorganisms present in raw materials and those introduced into the product during and after processing (for example, after cooking). Laboratory observations on the inhibition of pathogenic organisms under household conditions also require verification.

Research into the epidemiology of diarrhoea among infants and young children who consume both fermented and non-fermented foods is required. Such studies will necessitate very careful control of epidemiological design for the confounding variables and the differences that might occur between experimental and control groups. It is recommended that a carefully produced protocol be subjected to widespread critical peer review prior to the implementation of these studies.

10.1.2. Effect of fermentation on biochemical and chemical toxicants in raw materials

Fermentation cannot be seen as a means of cleaning up contaminated raw materials. In recognition of the frequent use of contaminated raw materials for fermentation processing, further research on a number of issues related to the effect of fermentation on raw materials is, however, justified.

The importance of water quality in fermentation processes needs to be addressed. Likewise, there is a need for studies into the effects of fermentation on mycotoxins and the toxicity of mycotoxin breakdown products. In addition, further research is required to assess the reduction of aflatoxins by lactic fermentation, and the effect of fermentation on bacterial toxins. Despite the justification for work in these areas, the long-term solution lies in improving the quality of the raw material.

Consideration must be given to the effect (including changes to bioavailability) of fermentation on environmentally acquired (in food and soil) chemical contaminants, such as heavy metals, trace elements, herbicides, and pesticides.

10.1.3. Additional considerations in the promotion of fermentation

Studies need to be undertaken in order to ascertain the physiological consequences of ingesting D (–)

lactate acidosis in fermented foods, particularly in malnourished children, who may have impaired buffering capacity. Optimisation of various processing steps during the preparation of fermented foods so as to avoid the generation of biogenic amines or other toxic materials such as ethyl carbamate during fermentation is required.

10.2. Nutritional value

A major objective of fermentation in developing countries is to provide infants and young children with foods of high nutritional value. Consideration should therefore be given to evaluating the entire food processing operation, rather than the fermentation step, when assessing the nutritional value of fermented foods.

Reducing the levels of anti-nutritional factors as well as improving micronutrient bioavailability requires attention. A comparison should be made between the micronutrient status and growth of infants and young children fed with and without fermented and non-fermented cereals. Approaches in this regard have been made by Svanberg and Lorri (1997).

10.3. Technology development

10.3.1. Characterisation of fermentations

The microbiological characterisation of a number of fermented foods has been extensively studied. Studies on the dynamics of natural fermentation, however, need to be pursued.

Processing methodologies for fermented foods are, in general, very well documented. Gaps in the literature and existing data, however, require verification. The dissemination of currently available information is of high priority.

10.3.2. Development/improvement of fermentation systems

Priority should be given to the development of appropriate starter cultures for use in fermentations. Approaches to the development and application of these technologies have been extensively reviewed elsewhere in this publication (Holzapfel, 2002).

10.3.3. Probiotics

The consumption of live lactic acid bacteria (e.g. *Lactobacillus acidophilus*) is believed to assist in the prevention of diarrhoeal disease and is desirable for the production of weaning foods. A study of the functional properties of probiotic strains associated with traditional fermentations, and mechanisms for their incorporation into starter culture development would therefore be useful.

10.3.4. Effect of processing step on food safety

Single and combined processing steps such as cooking, washing, peeling, grinding, dehydration, packaging and fermentation play a critical role in the safety of the final product. The order of these steps, (e.g. cooking and fermentation in the preparation of weaning gruels) is very important, and has implications for food safety.

10.3.5. Application of quality and safety systems (including HACCP)

Few studies have assessed fermentation as a household level technology within the context of food quality and safety. Application of the HACCP approach and principles of good manufacturing practice offer great potential for focusing education and extension programmes.

10.4. Technology transfer and related socio-economic aspects

10.4.1. Consumer and producer perceptions and needs

Research is required in order to better understand consumer and producer (processor) perceptions on food safety, particularly where fermentation is concerned. Whether the relative importance of food safety is significant in its own right for the adoption of changes in traditional fermentation practices by target groups remains unclear. In cases where the consumption of fermented food is promoted as a means of reducing the incidence of diarrhoeal diseases in children, the benefit to households must be obvious if change is to take place.

Fermentation is applied as a means of preservation for the purposes of shelf-life extension, adding variety to the diet, income generation, nutritional benefit, and the processing of otherwise unusable raw materials. Even with these advantages, the use of fermentation has been discontinued by some communities. The initial step in improving the safety of a fermentation process is understanding the basis for the use of this process. Establishing the basis for the use of a process is an important element of a needs assessment, and should be the initial step in any research programme. The needs assessment should also determine what the perceived issues and problems are both for the processor and the consumer.

Existing fermentation systems may be modified or new systems introduced for food safety purposes, if advantages such as extended shelf-life, cost savings, reduction in processing time, and improvement in taste or in nutritional quality are to be demonstrated. This would, however, necessitate an understanding of consumer and processor needs and perceptions. If fermented products are to be promoted as safe weaning foods, the contribution of these foods to nutritional requirements of the child must be determined.

During the implementation of any research project, the maintenance of continued interaction among scientists, processors and end-users is critical so as to ensure acceptable practical and cost-effective changes to the process or product.

10.4.2. Transfer of information and technology to meet the needs of target groups in relation to food safety

Requirements for the transfer of fermentation technologies were thoroughly reviewed elsewhere in this publication (Rolle and Satin, 2002). Transfer of information of relevance to health, hygiene, food safety and nutrition may also be feasible in conjunction with technology transfer.

10.4.3. Research issues of relevance to the household

Food security is a driving force behind the adoption of fermentation for infant feeding and domestic use. Safety issues are important, but are probably of a lower profile from the perspective of the mother, than from the commercial perspective. Key issues at the household level include the quality of raw materials, ease of processing, energy use, and the extension of shelf life. The role of women is a specific issue that will determine the nature of the technology and mechanisms for its transfer. It will be important to make changes in small incremental steps so as to allow for sustainable development. One suitable approach may be the development and dissemination of fermentation kits.

10.4.4. Research priorities for cottage industry

The adoption of fermentation at the commercial level is driven both by the need for profit, and existing food regulations. Research priorities are consequently dictated by these issues. Starter cultures may be more relevant for cottage industry, than for domestic use, and the application of the principles of good manufacturing practice and other quality/safety criteria should be appropriate. Safety is critical to improving commercial reputation, and the need for product distribution would provide a driving force for shelf-life extension.

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