CAN HOUSEHOLD-LEVEL FERMENTATION TECHNOLOGY ASSURE FOOD SAFETY?

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Over time, the human diet has evolved to exclude materials that are hazardous and for which there is no simple procedure to render them harmless. As a result, our food supply is generally safe, although it can never be entirely devoid of risk (Adams 2001).

The term 'fermented food' is defined as any food that has been subjected to the action of microorganisms or enzymes so that desirable biochemical changes cause significant modification of the food (Campbell-Platt 1987). Fermented foods enjoy worldwide popularity as attractive, wholesome and nutritious components of our diet. In the past, household-level fermentation technology originated and evolved through trial and error experiences gathered by successive generations of food producers. Only relatively recently have science and technology started to a better understanding of the underlying principles of the fermentation processes and of the essential requirements to ensure nutritional and sensory qualities as well as safety of fermented foods.

Fermented foods are produced on an enormous scale employing a huge variety of substrates, viz. cereals, root crops, legumes, fruit and vegetables, dairy products, fish and meat (Campbell-Platt 1994; Steinkraus 1995; Wood 1998; Nout et al 2007). Some indigenous fermented foods and their major ingredients are listed in Table 1. Fermentation is an important low-cost food processing technique and a manageable means of food preservation in lesser developed tropical countries where cold storage (refrigeration), freezing, home canning, hot-holding, or modified atmosphere packaging is prohibitively expensive. The hurdles are compounded in communities with low levels of disposable incomes and where limited infrastructure available in the food processing industry limits the use of more advanced technologies (Westby et al 1997).

Like all other processed foods, fermented foods result from a manufacturing process which involves selection of raw materials, preparatory treatments, fermentation, preservation, packaging and storage. It is noteworthy to mention that treatment of a food by the consumer influences its condition. Hence, an integrated approach is warranted during assessing the implications of individual risk factors for the safety of the consumer (Nout 1994).

Against this background, World Health Organization (WHO), jointly with Food and Agricultural Organization (FAO), organized in 1995 a workshop to assess fermentation as a household technology for improving food safety.

The present article attempts to answer the following questions: (a) are fermented foods safer than fresh or alternatively processed foods? (b) what risk factors can be identified in fermented foods? (c) can fermentation principles be exploited in enhancing their safety?

Food infection

Foodborne infections constitute approximately 80% of all food-related illnesses (Waites and Arbuthnott 1990). Food infections can occur if (a) contamination followed by survival or growth by a pathogen take place, (b) sufficient frequency and quantity of food are consumed depending on the minimum infective dose of the pathogen, and (c) the consumer is susceptible to the pathogen. Particularly the young, old, pre-natal and immuno-suppressed persons are more vulnerable than an average consumer.

Contamination may take place during the primary production of raw materials of plant and animal origin or/and during and after processing as a result of inadequate hygiene or packaging. Pathogens are normally present in the soil (and therefore on the surface of fruits and vegetables), in surface water (which results in contaminated fish and shellfish), and in the gut of animals (causing contaminated products of animal origin, such as milk and meat). To minimize risk, pretreatment of the raw materials might be helpful. The simple practice of washing removes a large portion of the pathogens (up to 90%). Most pathogens capable of infection are killed by pasteurization (e.g., milk) and by exposure to acid conditions at pH $\leq$ 4.0.

Zoning, i.e. dividing the production area into 'dry and wet' and /or 'high, medium and low care' areas, is useful in preventing product contamination. There should be areas for the storage of raw materials (low hygiene), preparation of the raw materials, i.e. washing, cutting and adding ingredients (medium hygiene), fermentation of the raw materials (medium hygiene, the filling of suitable packages (medium hygiene), and storage of the final products (medium hygiene). An example of an area of high hygiene is the room where starter cultures are prepared for the lactic fermentation of milk. Here, a potential danger is the infection of the cultures with bacteriophages (Beumer 2001).

In many countries, raw cereals and pulses are allowed to undergo uncontrolled natural fermentations. In these high-moisture and non-salted products, activities of Enterobacteriaceae and lactic acid bacteria lead to lowering of pH to 4.5-5.5, the environment which is conducive to the survival of pathogenic bacteria. However, this type of product is usually cooked prior to consumption. Thus, if consumed immediately after cooking, one would not expect any risk of food infection.

Fermented milk and milk products are of great economic importance. Numerous types of cheese are produced from pasteurized or raw milk. The latter procedure allows the survival of pathogens of animal origin, e.g. *Listeria* and *Salmonella* spp. The high buffering capacity of cheese curd prevents a significant decrease in pH during ripening, even in the presence of active cheese starter lactic acid bacteria. Outbreaks of listeriosis and salmonellosis from raw milk cheddar cheese have been reported. In hard cheeses, contaminating pathogens do not survive the maturation which involves several months of storage (Nout 1994).

In fermented meats, pathogens, e.g. *Salmonella typhimurium*, may survive and grow in raw meat cured sausages under improper acidification and high moisture content, i.e., not in the pH and a_w ranges of 4.5-5.0 and 0.92-0.99, respectively (Nout 1994). In Japan, *Vibrio parahaemolyticus* infections are common and can be associated directly with the custom of eating raw or fermented raw fish. Lack of heating or smoking is said to be the reason why fermented fish was much more frequently (25% of the samples) contaminated with *L.*

monocytogenes than smoked (9-14% of the samples) fish (Jemmi 1990).

The addition or in-situ production of microbial inhibitory metabolites enhances safety. Although numerous bacteriocins have been discovered, at present, the application of bacteriocins in food preservation is limited to nisin. It, considered as 'generally recognized as safe' (GRAS), is used as an additive or is formed by *Lactococcus lactis* starter cultures in the product. Nisin is able to inhibit germination of *Clostridium botulinum* spores in canned foods and kill *Listeria* spp. in raw or fermented food. In order to be attractive as food preservatives, bacteriocins must have a broad-spectrum of antimicrobial activity. The efficacy of bacteriocins is limited by the fact that they are usually only active against Gram-positive cells, although theoretically this could be overcome by the addition of chelating agents such as ethylenediamine tetraacetic acid. In addition, they must be stable to heat and other adverse conditions.

Food intoxication

Food intoxications may occur depending on the quantity and nature of the ingested toxin. There are three different sources of such toxins: (a) those already present in the raw material, (b) microbial toxins produced during or after processing, and (c) toxic by-products of fermentation.

A number of raw materials naturally contain toxic substances, e.g. cyanogenic glycosides and glycoalkaloids. Cassava is an important staple food crop, especially in Africa. Cassava roots contain the cyanogenic glycosides, linamarin and lotaustralin. These can be hydrolysed to the corresponding ketone and glucose by the endogenous linamarase when cellular damage occurs. Dietary cyanide from cassava has been implicated with a number of health problems, like goiter, cretinism, paralytic disease konzo and tropical ataxic neuropathy. Such poisoning occurs when food shortage and social instability induce shortcuts in established processing methods or when high cyanogens varieties are introduced into an area lacking appropriate processing techniques (Westby et al 1997). Westby and Choo (1994) demonstrated that fermentation was essential for efficient cyanogens reduction.

Other anti-nutritional compounds of interest in plant foods are oligosaccharides, phytate, tannins, saponins, oxalates, lectins and enzyme inhibitors. Although soybeans are valued for their high oil and protein contents, their consumption is limited because soybeans contain high levels (12-15%, dry weight basis) of α-galactosides of sucrose, causing internal gas production in humans. Over 90% of the sugars present in ripe soybeans comprise sucrose, raffinose and stachyose. It was observed that although the pre-fermentation treatments (soaking and cooking) of soybeans during kinema production caused a 73-88% reduction in the oligosaccharide content, fermentation lowered these levels below the limit of detection, thus eliminating a potential cause of flatulence for consumers (Sarkar et al 1997).

In the field and during storage, plant foods may become contaminated with mycotoxins. In lactic fermentations at pH ≤ 4.0, aflatoxin B_1 is readily converted into aflatoxin B_{2a} which is less toxic. Certain *Rhizopus* spp. were able to degrade 87% of aflatoxin B_1. This might provide opportunities for detoxification of food and feed in solid substrate fermentations.

Microbial toxins may be produced by contaminating microorganisms. In country-cured ham or in insufficiently heated or cured sausages, there is a chance that *Clostridium perfringens* or *C. botulinum* could grow and produce toxins. To ensure safety, adequate combination of

NaCl, nitrite, water activity (a_w) and pH is warranted. In cheese made from raw milk, *Staphylococcus aureus* may grow and produce enterotoxins. As *S. aureus* is inhibited in the presence of competing microflora, the presence of actively growing starter cultures strongly reduces the chance of enterotoxin formation (Nout 1994). The acidification, taking place during the preparatory soaking of soybeans, plays a role in the development of tempe microflora. Poorly acidified beans allowed the survival and growth of toxinogenic bacteria including *Bacillus cereus*, *Yersinia enterocolitica* and *S. aureus*. It has been shown that the growth of *Salmonella* spp., Enterobacteriaceae and *S. aureus* during the stage of fungal fermentation is inhibited if competing lactobacilli are present (Nout and Rombouts 1990). Soybean tempe has never been incriminated as a cause of foodborne disease. However, tempe bongkrek, made from coconut presscake in Central Java, may enable the growth of *Pseudomonas cocovenenans* which produces the toxins bongkrek acid and toxoflavin, causing several fatal poisonings. Interestingly, Ko (1985) established that a large inoculum size of *Rhizopus oligosporus*, or incorporation of 2% NaCl are adequate to inhibit the growth and toxin production. In fermentations involving non-cooked raw materials, the combined effect of a_w, salt concentration, pH, anaerobiosis, temperature and competitive microflora must be optimized. In this respect, predictive modeling of the behaviour of toxinogenic microorganisms such as *C. botulinum* (Lund et al 1990) is a useful tool.

Several by-products of fermentation may have toxinogenic property. A substance occurring in a variety of fermented foods is ethyl carbamate (urethane), a carcinogenic and mutagenic compound which results from the esterification of ethanol with carbamic acid. The latter can be formed from several precursors including naturally occurring citrulline, as well as yeast metabolites from L-arginine and L-asparagine, e.g. urea and carbamylphosphate. In addition, vicinal diketones, and HCN liberated from cyanogenic glycosides act as precursors. Heat and light enhance the formation of ethyl carbamate. Research with wine and stone fruit (cherry, plum) indicates that reducing the level of precursors by enzyme treatment, selection of yeast strains and control of fermentation conditions, and treatment of the pH adjusted fermented pulp with $CuSO_4$ could be useful in keeping the ethyl carbamate levels to a minimum (Nout 1994).

Biogenic amines, like, ethylamine, putrescine, histamine, cadaverine, tyramine, phenylethylamine and tryptamine are another group of mildly toxic compounds which can be formed in fermented foods, mainly by decarboxylation of amino acids. Approximately 1000 ppm is supposed to elicit toxicity, and from a 'good manufacturing practice' (GMP) point of view, a total of 100-200 ppm is regarded as acceptable. Biogenic amines are especially associated with wine and lactic fermented products. The major biogenic amine producers in foods are Enterobacteriaceae. Most functional lactic acid bacteria do not produce significant levels of these compounds. Presence of free amino acids, low pH of the product, high NaCl concentrations and microbial decarboxylase activity correlate with higher levels of biogenic amines (Ten Brink et al. 1988). Pasteurization of cheese milk, hygienic practice and selection of starters with low decarboxylase activity are measures to avoid the accumulation of these undesirable products.

The understanding of mechanisms by which toxic substances are reduced during fermentation is the key to ensuring that research work on food fermentations achieves its potential. An understanding of the dynamics of food fermentations and mechanisms by which

they can be controlled, offers the potential to improve toxin reduction through the promotion of specific groups of microorganisms.

Conclusion

Due to competition and metabolites of starter microorganisms, many fermented foods are a less likely vehicle for food infection or intoxication than fresh foods. On the other hand, they are not as stable as canned or frozen foods. The following risk factors are of importance: (a) the use of contaminated raw materials; (b) lack of pasteurization; (c) the use of poorly controlled natural fermentations or of sub-optimum fermentation starter cultures; (d) inadequate storage or maturation conditions enabling survival of pathogens, or growth and toxin production; and (e) consumption without prior heating (Nout 1994).

To minimize these risks, it is essential to ensure the wholesomeness of raw materials. Inspection and sorting to remove damaged or obviously infected raw material is a basic protective barrier. Cleaning and vigorous washing of raw materials may reduce the load of surface-associated contaminants by 1-2 log cycles. In addition, further optimization of starter cultures either by conventional selection and mutation, or by recombinant-DNA manipulations can result in increased levels of safety of fermented foods. In particular, selection of starters which are not toxinogenic, antagonize pathogens, produce broad-spectrum bacteriocins, or which have detoxifying ability should have priority. However, introduction of genetically modified organisms into fermented foods needs careful discussion with authorities and consumer organizations. Many fermented foods contain living microorganisms, and if these microorganisms are genetically modified, one should consider them as a potential source of DNA for horizontal gene transfer. Hence, the risk assessment should show that the safety hazard related to the newly introduced gene(s) is zero, and consequently, the risk for consumer is zero. Whenever possible, without losing the consumer benefit, the environmental hazard should preferably be zero or at the most 10^{-8} per product unit produced. Consumer studies show that provided there is a clear benefit and risk is absent, most consumers will not hesitate to accept these products.

Fermentation is and will continue to remain an important technology. To take advantage of the benefits that fermentation offers and, at the same time, to minimize its risks, simple hygienic codes based on 'hazard analysis and critical control points' (HACCPs) could inform food handlers and households about appropriate fermentation techniques.

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Table 1. Some household-level traditional fermented foods

Name of product	Country /area	Substrate	Functional microorganism[a]
Cereal /starch crop products			
Ang-kak	China, Southeast Asia	Rice	M
Banku	Egypt	Maize /cassava	Y, LAB
Gari	Nigeria, West Africa	Cassava	LAB, Y
Jnard	India, Nepal, Bhutan	Finger millet	M, Y, LAB
Kenkey	Ghana	Maize	LAB, Y
Naan, bhatura	Afghanistan, Iran, Pakistan, India	Wheat	Y, LAB
Tapé	Indonesia	Cassava /rice	M, Y
Legume products			
Dawadawa	West Africa, Nigeria	African locust bean	B
Kinema	India, Nepal	Soybean	B
Oncom	Indonesia	Peanut press-cake	M
Tempe	Indonesia	Soybean	M, B
Wadi	India, Pakistan, Bangladesh	Blackgram	LAB, Y
Cereal + legume products			
Dhokla	India	Rice, Bengalgram	LAB, Y
Idli	India, Sri Lanka	Rice, blackgram	LAB, Y
Miso	Japan	Soybean, rice	M, Y, LAB
Vegetable products			
Gundruk	India, Nepal	Mustard leaves	LAB
Soibum, mesu	India, Nepal	Young bamboo shoot	LAB, Y
Kimchi	Korea	Cabbage	LAB
Sauerkraut	Europe, Russia, USA	White cabbage	LAB
Sinki	India, Nepal	Raddish tap root	LAB
Dairy products			
Cheeses	Europe	Cow's /sheep's milk	LAB, (M)
Dahi	India, Pakistan, Bangladesh, Sri Lanka	Cow's /buffalo's milk	LAB
Kefir	Scandinavia, Russia	Mare's milk	LAB, Y
Lassi	India	Cow's /buffalo's milk	LAB
Fish products			
Bagoong	Philippines	Fish /shrimp /oyster	B
Izushi	Japan	Fish, rice, vegetable	LAB
Som-fak	Thailand	Fish fillet, rice	LAB
Meat products			
Nham	Thailand	Pork, cooked rice	LAB
Salami	Europe, USA	Pork, beef	LAB
Miscellaneous products			
Basi	Philippines	Sugarcane juice	Y, LAB
Kombucha	Japan, Indonesia, China, Russia	Tea liquor, sugar	AAB, Y
Miang	Myanmar, Thailand	Tea leaves	LAB
Palm wines	Tropical palm-growing countries	Sap of palm trees	Y, LAB, B, AAB

[a]AAB, acetic acid bacteria; B, bacteria; LAB, lactic acid bacteria; M, mould; Y, yeast