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Fermentations in World Food Processing

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Introduction (Steinkraus 1995, 1996a, 1997)

Fermented foods are food substrates that are invaded or overgrown by edible microorganisms whose enzymes, particularly amylases, proteases, lipases hydrolyze the polysaccharides, proteins and lipids to nontoxic products with flavors, aromas and textures pleasant and attractive to the human consumer. If the products of enzyme activities have unpleasant odors or undesirable, unattractive flavors or the products are toxic or disease producing, the foods are described as spoiled.

Fermentation plays at least five roles in food processing:

(1) Enrichment of the human dietary through development of a wide diversity of flavors, aromas and textures in food;

(2) Preservation of substantial amounts of food through lactic acid, alcoholic, acetic acid, alkaline fermentations and high salt fermentations;

(3) Enrichment of food substrates biologically with vitamins, protein, essential amino acids and essential fatty acids;

(4) Detoxification during food fermentation processing and

(5) a decrease in cooking times and fuel requirements.

Classification of Food Fermentations (Steinkraus 1995, 1997)

Food fermentations can be classified in a number of ways (Dirar 1993): by categories (Yokotsuka 1982)— (1) alcoholic beverages fermented by yeasts; (2) vinegars fermented with *Acetobacter*; (3) milks fermented with lactobacilli; (4) pickles fermented with lactobacilli; (5) fish or meat fermented with lactobacilli; and, (6) plant proteins fermented with molds with or without lactobacilli and yeasts; by classes (Campbell-Platt 1987) (1) beverages; (2) cereal products; (3) dairy products; (4) fish products; (5) fruit and vegetable products; (6) legumes; and, (7) meat products; by commodity (Odunfa 1988) (1) fermented starchy roots; (2) fermented cereals; (3) alcoholic beverages; (4) fermented vegetable proteins; and, (5) fermented animal protein; by commodity (Kuboye 1985) (1) cassava based; (2) cereal; (3) legumes; and, (4) beverages. Dirar (1993) states that the Sudanese traditionally classify their foods, not on the basis of microorganisms or commodity but on a functional basis: (1) Kissar (staples)-porridges and breads such as aceda and kissra; (2) Milhat (sauces and relishes for the staples); (3) marayiss (30 types of opaque beer, clear beer, date wines and meads and other alcoholic drinks); and, (4) Akil-munasabat (food for special occasions). Steinkraus (1983a; 1996) classified fermentations according to the following categories that will serve as the basis for this paper:

1. Fermentations producing textured vegetable protein meat substitutes in legume/cereal mixtures. Examples are Indonesian tempe and ontjom.

2. High salt/savory meat-flavored/amino acid/peptide sauce and paste fermentations. Examples are Chinese soy sauce, Japanese shoyu and Japanese miso, Indonesian kecap, Malaysian kicap, Korean kanjang, Taiwanese inyu, Philippine taosi, Indonesian tauco, Korean doenjang/kochujang, fish sauces: Vietnamese nuocmam, Philippine patis, Malaysian budu, fish pastes: Philippine bagoong, Malaysian belachan, Vietnamese mam, Cambodian prahoc, Indonesian trassi and Korean jeotkal. These are predominately Oriental fermentations but the use of these products is becoming established in the United States.

3. Lactic acid fermentations. Examples of vegetable lactic acid fermentations are: sauerkraut, cucumber pickles, olives in the Western world; Egyptian pickled vegetables in the middle East; Indian pickled vegetables and Korean kim-chi, Thai pak-sian -dong, Chinese hum-choy, Malaysian pickled vegetables and Malaysian tempoyak. Lactic acid fermented milks include: yogurts in the Western world, Russian kefir, Middle-East yogurts, liban (Iraq), Indian dahi, Egyptian laban rayab, laban zeer, Malaysian tairu (soybean milk). Lactic acid fermented cheeses in the Western world and Chinese sufu/tofu-ru. Lactic acid fermented yogurt/wheat mixtures: Egyptian kishk, Greek trahanas, Turkish tarhanas. Lactic acid fermented cereals and tubers (cassava): Mexican pozol, Ghanian kenkey, Nigerian gari; boiled rice/raw shrimp/raw fish mixtures: Philippine balao balao, burong dalag; lactic fermented/leavened breads: sourdough breads in the Western world; Indian idli, dhokla, khaman, Sri-lankan hoppers; Ethiopian enjera, Sudanese kisra and Philippine puto; Western fermented sausages and Thai nham (fermented fresh pork).

4. Alcoholic fermentations. Examples are grape wines, Mexican pulque, honey wines, South American Indian chicha and beers in the Western World; wines and Egyptian bouza in the Middle East; Palm and Jackfruit wines in India, Indian rice beer, Indian madhu, Indian ruhi; in Africa, Ethiopian tej, Kenyan muratina, palm wines, Kenyan urwaga, Kaffir/bantu beers, Nigerian pito, Ethiopian talla, Kenyan busaa, Zambian maize beer; in the Far East, sugar cane wines, palm wines, Japanese sake, Indonesian tape, Malaysian tapuy, Chinese lao-chao, Thai rice wine, Indonesian brem, Philippine tapuy.

5. Acetic acid/vinegar fermentations. Examples are apple cider and wine vinegars in the West; palm wine vinegars in Africa and the Far East, coconut water vinegar in the Philippines; tea fungus/ Kombucha in Europe, Manchuria, Indonesia, Japan and recently in the United States; Philippine nata de pina and nata de coco.

6. Alkaline fermentations. Examples are Nigerian dawadawa, Ivory Coast soumbara, African iru, ogiri, Indian kenima, Japanese natto, Thai thua-nao.

7. Leavened breads. Examples are Western yeast and sourdough breads; Middle East breads.

8. Flat unleavened breads. The above classes of fermented foods are found around the world. The lines between the various classifications are not always distinct. Tempe in class 1 involves a lactic acid fermentation during soaking of the soybeans. Yeast (alcoholic)/lactobacilli (lactic acid) interactions are rather frequent-for example in sourdough breads, in primitive beers and wines and in Chinese soy sauce/Japanese shoyu/Japanese miso fermentations (Wood 1985). Nevertheless, Steinkraus (1983a, 1996) has found the above classification useful and a way of predicting what microorganisms may be involved and what chemical, physical and nutritive changes may occur in new unfamiliar fermented foods. The classification also relates well to safety factors found in fermented foods.

Fermented foods were originally household and expanded to cottage industry as consumer demand required. Some food fermentations such as Japanese shoyu, miso and sake, South African maize/sorghum beers, South African mageu/mahewu Nigerian ogi and gari have been industrialized (Steinkaus 1989).

Evolution of Indigenous Fermented Foods (Steinkraus 1996a)

Philosophy includes theory or investigation of the principles or laws that regulate the universe and underlie all knowledge and reality. Archaeology is the scientific study of the life and culture of ancient peoples. Anthropology is the study of races, physical and mental characteristics, distribution, customs, social relationships, and so on. When we start to study man's foods, we become involved in all the above. In fact, when we study fermented foods, we are studying the most intimate relationships among man (men/women-humans), microbes and foods. There is a never-ending struggle between man and microbes to see which will be first to consume the available food supplies.

Religion was an attempt by humans to explain the unexplainable origin of the universe, the earth and man long before there was a scientific method or the means to study these difficult problems and no concept of, for example, microorganisms, knowledge of which we obtained only about 300 years ago when Leeuwenhoek discovered tiny animacules under his primitive lenses and only a little more than a hundred years ago when Pasteur demonstrated the role of microorganisms in fermentation and Koch showed that microbes cause disease. And it is only in the last 50 years that knowledge of the role polymeric deoxyribonucleic acid (DNA) plays in all forms of life was discovered.

According to present scientific thought, the earth is about 4.5 billion years old. The first forms of life to appear or evolve on earth were microorganisms. Fossil organisms have been found in earth rocks 3.3 to 3.5 billion years old (Schopf and Packer 1987). Since then and still today, microorganisms have had and have the principal task of recycling organic matter in the environment. As such they are absolutely essential to the health of the earth, whereas, humans are nonessential polluters who may eventually make the earth uninhabitable.

Whether it was by chance or by design, it was extraordinarily fortunate that the earth was originally colonized by microorganisms which are capable of recycling organic matter including dead bodies, and so on. Without them, the earth would be a gigantic, permanent waste dump. The earth was inhabited by microorganisms for probably a billion years before other forms of life evolved.

The next forms of life to evolve, according to present scientific thought, were plants that serve as a basis for man's food. For at least a billion years before man arrived, plants were producing food consisting of leaves, stems, seeds, nuts, berries, fruits, tubers, and so on So when humans were created or evolved on earth, the basis for their foods was already present and productive.

Both plants and animals evolved where the microbes were ready, willing and able to recycle all organic matter. Plants and animals had to evolve into and survive in a microbial environment. They had to develop ways of resisting microbial invasion and consumption. Plants did this, in part, by having a lignocellulosic body very resistant to microbial breakdown.

Until recently, we might have accepted the hypothesis that microorganisms, insects, animals, plants, humans were all created or evolved independently. There was no good reason to believe that all forms of life are closely interrelated. This changed when Watson and Crick unraveled the structure of DNA, the basis of the genetic code demonstrating that it is based upon a 4 molecule alphabet that controls the structure and function of all forms of life including microorganisms, plants and all animals including man.

Early plant evolution was essential as plants not only provide the basis for food for animals and man but they were principally responsible for the development of the oxygen atmosphere necessary for man and animals.

Plants also introduced a very effective way of transforming the sun's radiation into food materials such as sugars, starches and cellulose through the green pigment chlorophyll. Plants and plant structures such as leaves, stems, roots and seeds all of which serve as food for microorganisms and animals including ourselves are literally sun's energy, radiation converted to matter.

Humans also had to evolve from the sea of microorganisms. They had to develop internal and exterior systems of protection against invasion by microorganisms. Then, as now some microorganisms could invade the live animal or human and cause disease. Animals including humans evolved with a "normal" flora of microorganisms that live in the skin, mouth, throat, intestinal tract, vagina, and so on. The normal flora protects us against invasion by other microorganisms which might cause disease. Nowhere is this more pronounced or more evident than in the human infant.

Within the uterus, the infant is essentially sterile but it can be readily invaded by wide variety of microorganisms in the birth environment. The fact is, however, that, if the infant is breast-fed, as nature intends, its intestinal tract becomes colonized by a particular species of bacteria, *Bifidobacterium bifidus* which produces lactic acid and protects the infant against both intestinal and respiratory diseases. The skin of the human also is fairly resistant to invasion by undesirable microorganisms because of its "normal" flora of cocci. Occasionally cocci may invade the skin and cause infection but their role as "protectorants" is of much greater importance.

Early man very likely consumed fruits, leaves, berries, seeds, nuts probably tubers foraging from place to place as apes do today. Their bodily wastes, as well as their bodies at death, were recycled by microorganisms. There was a relatively large potential food supply and relatively few humans. Excess food supplies, fruits, berries, fell on the ground and the seeds either germinated or the carbohydrates, proteins, fats, and so on, were consumed by microorganisms using enzymes that converted fermentable carbohydrates to alcohol or acids and finally to water and carbon dioxide. Seeds and nuts and other protein-containing components were converted to their essential amino acids, peptides and finally to ammonia and water and a wide variety of chemical products. All of these reactions occurred (as recycling) for a billion years before man arrived or evolved on earth.

As population increased it became desirable for humans to collect fruits, berries, nuts, seeds, leaves as a store of food to tide humans over during periods of bad weather (winter, for example) when fresh food was not readily available.

Insects, rodents, birds and most types of animals were already well-established on earth when man arrived. Food consumed by insects or other animals is not available to man unless the insects and animals are, in turn, consumed as food.

Foods invaded by bacteria producing toxins or by fungi producing mycotoxins are dangerous to man. If the products of invasion are ill-smelling, off-flavored or toxic, human consumers try to avoid them and the foods are described as spoiled. If the microbial products are pleasantly flavored, have attractive aromas and textures and are nontoxic, the human consumer accepts them and they are designated as fermented foods.

Certain flavors such as sweet, sour, alcoholic and meat-like (savory) appeal to large numbers of humans. Milks sour naturally. Fruit and berry juices rapidly become alcoholic. Over many centuries, people have developed tastes for such products that continue on in modern man. Some anthropologists have suggested that it was stimulation and desire for alcohol that motivated man to settle down and become agriculturists (Braidwood 1953; Katz and Voight 1987).

Safety of Fermented Foods (Steinkraus 1995, 1997)

Fermented foods generally have a very good safety record even in the developing world where the foods are manufactured by people without training in microbiology or chemistry in unhygienic, contaminated environments. They are consumed by hundreds of millions of people every day in both the developed and the developing world. And they have an excellent safety record. What is there about fermented foods that contributes to safety?

While fermented foods are themselves generally safe, it should be noted that fermented foods by themselves do not solve the problems of contaminated drinking water, environments heavily contaminated with human waste, improper personal hygiene in food handlers, flies carrying disease organisms, unfermented foods carrying food poisoning or human pathogens and unfermented foods, even when cooked if handled or stored improperly. Also improperly fermented foods can be unsafe. However, application of the principles that lead to the safety of fermented foods could lead to an improvement in the overall quality and the nutritional value of the food supply, reduction of nutritional diseases and greater resistance to intestinal and other diseases in infants.

Principles Behind Safety of Fermented Food Processes

The safety of food fermentation processes is related to several principles.

The first is that food substrates overgrown with desirable, edible microorganisms become resistant to invasion by spoilage, toxic or food poisoning microorganisms. Other, less desirable (possibly disease producing) organisms find it difficult to compete. An example is Indonesian tempe (Steinkraus 1996). The substrate is soaked, dehulled, partially cooked soybeans. During the initial soaking, the soybeans undergo an acid fermentation that lowers the pH to 5.0 or below, a pH inhibitory to many organisms but highly acceptable to the mold. Following cooking the soy cotyledons are surface dried which inhibits growth of bacteria that might spoil the product. The essential microorganism is *Rhizopus oligosporus,* or related *Rhizopus* species, which knit the cotyledons into a compact cake that can be sliced or cut into cubes and used in recipes as a protein-rich meat-substitute. These molds have the ability to grow very rapidly at relatively high temperatures, that is, 40 to 42 °C too high for many bacteria and molds. The mold utilizes the available oxygen and produces CO_2 which inhibits some potential spoilage organisms. The mold also produces quantities of spore dust that permeate the environment and contribute to inoculation of the desired microorganisms. The combination of a relatively low pH, no free water and a high temperature in the fermenting bean mass enables *Rhizopus oligosporus* to overgrow the soybeans in 18 h. Organisms that might otherwise spoil the product are unable to compete with the mold. In addition, the mold also produces some antibiotic activity that inhibits other organisms that might invade and spoil the product (Wang and others 1969). The principle is that, as soon as the substrate is overgrown by the desired organism (s), it is resistant to invasion by other microorganisms. An additional safety factor is that the raw tempe is sliced or cut into cubes and cooked before consumption which destroys vegetative microorganisms that are present.

Soybean tempe (tempe kedelee) has an excellent record of safety in Indonesia and Malaysia where the product is fermented as above and has been used for centuries. In temperate countries including the United States, soybeans do not undergo natural lactic acid fermentation during soaking. The pH remains closer to 6.0 a level that permits growth of contaminating bacteria. It has been shown (Tanaka and others 1985) that unacidified soybeans can be invaded by a variety of food poisoning organisms including *Staphylococcus aureus*, *Bacillus cereus* and *Clostridium botulinum*. This can be prevented by artificially acidifying the soybeans or inoculating the soak water with *Lactobacillus plantarum*; but American producers have often been careless and used unacidified beans or insufficiently acidified soybeans for tempe production. In some cases this has led to spoilage and could lead to food poisoning.

While soybean tempe has an excellent safety record, there is a type of tempe that has a reputation for causing sickness and even death in the consumer. This is tempe bongkrek made from the coconut residue from coconut milk production. Again, if the substrate is properly acidified, it is generally safe and the mold overgrows the substrate knitting it into a compact cake. But, if the substrate is not sufficiently acidified and/or, if the fungal inoculum is insufficient, a bacterium *Burkholdaria* (*Pseudomonas*) *cocovenenans* can grow in the coconut residue producing two toxic compounds-bongkrek acid, the most lethal, and toxoflavin (Van Veen 1967; Steinkraus 1996). These toxic compounds are inhibitory to the mold and it does not overgrow the substrate properly. Bongkrek acid is colorless and it can be lethal to the consumer. Toxoflavin is yellow and so, if tempe bongkrek has a yellow color or if the mold has not overgrown the substrate properly, it should not be consumed Yet, quite a number of Indonesians in central Java die every year from consumption of improperly fermented tempe bongkrek. This is an example of a fermented food that can and does become toxic but it is amply documented and there is no good excuse for people consuming it and becoming ill or dying.

It has been a mystery why bongkrek poison appears to develop only in coconut tempeh fermented in Java. Part of the answer has been discovered by Garcia, Hotchkiss and Steinkraus (1999). Forty and fifty percent coconut fat concentrations in the substrate (coconut presscake or the residue from coconut milk production) supports production of 1.4 mg/g bongkrek acid while less than 10% coconut fat while, supporting growth of the bacterium, yields no bongkrek acid. Oleic acid was most stimulatory in production of bongkrek acid (2.62 mg/g dry substrate). Lauric, myristic and palmitic acids also stimulated production of bongkrek acid but at lower levels.

A valid concern is mycotoxins that are present in many cereal grain and legume substrates before fermentation. Aren't these dangerous to the consumer of fermented foods? Certainly they are a problem; however, it is not the fermentation that produces mycotoxins. They are produced when the cereal grains or legumes are improperly harvested or stored. It has been found that in the tempe fermentation, mycotoxin levels are reduced. Van Veen and others (1970) reported that the ontjom mold, *Neurospora* and the tempe mold *Rhizopus oligosporus* could decrease the aflatoxin content of peanut presscake 50% and 70% respectively during fermentation. And during soaking and cooking of raw substrates before fermentation, many potential toxins such as trypsin inhibitor, phytate and hemagglutinin are destroyed. So, in general, fermentation tends to detoxify the substrates.

Sudigbia and Sumantri (1990) developed an infant formula containing tempe as 39.6% of its weight. Other major ingredients were wheat flour 31.6%, sugar 23.3% and vegetable oil 2.9%. Infants suffering from acute diarrhea and consuming the formula recovered more rapidly than infants not receiving the formula and also gained weight rapidly. It would appear that inclusion of tempe in infant formulas on a broader scale would not only decrease the overall incidence of diarrhea but also improve infant/child growth rates and nutrition.

Lactic acid fermentations

A second principle is that fermentations involving production of lactic acid are generally safe. Lactic acid fermentations include those in which the fermentable sugars are converted to lactic acid by lactic acid organisms such as *Leuconostoc mesenteroides, Lactobacillus brevis, Lactobacillus plantarum, Pedioccus cerevisiae, Streptococcus thermophilus, Streptococcus lactis, Lactobacillus bulgaricus, Lactobacillus acidophilus, Lactobacillus citrovorum, Bifidobacterium bifidus*, and so on.

This single category is responsible for processing and preserving vast quantities of human food and insuring its safety. We are all aware of the excellent safety record of sour milks/yogurts, cheeses, pickles, and so on. In addition the lactic acid fermentations provide the consumer with a wide variety of flavors, aromas and textures to enrich the human diet.

The most ancient lactic fermentation, likely, is fermented/sour milk. Raw, unpasteurized milk will rapidly sour because the lactic acid bacteria present in the milk ferment milk sugar, lactose to lactic acid. In the presence of acid and a low pH, other microorganisms that might invade the milk and transmit disease-producing organisms are less able to do so.

If the whey is allowed to escape or evaporate, the residual curd becomes a primitive cheese. Fermented cheeses and milks are an extensive topic on their own (Kosikowski 1977; Wood, 1998). The readers are referred to Dr. Kosikowski's classic book "Cheese and Fermented Milk Foods" for details.

Vegetable foods and vegetable/fish/shrimp mixtures are preserved around the world by lactic acid fermentation (Steinkraus 1983a,c; 1996). The classic lactic acid/vegetable fermentation is sauerkraut (Pederson and Albury 1969; Pederson 1979). Fresh cabbage is shredded and 2.25% salt is added. There is a sequence of lactic acid bacteria that develop. First, *Leuconostoc mesenteroides* grows producing lactic acid, acetic acid and CO_2 which flushes out any residual oxygen making the fermentation anaerobic. Then *Lactobacillus brevis* grows producing more acid. Finally *Lactobacillus plantarum* grows producing still more lactic acid and lowering the pH to below 4.0. At this pH and under anaerobic conditions, the cabbage or other vegetables will be preserved for long periods of time.

Korean kimchi is a fermentation similar to sauerkraut but it includes not only Chinese cabbage but radishes, red pepper, ginger and garlic. It is less acid than sauerkraut and is consumed while still carbonated. It is a staple and makes a major contribution to the Korean diet in which consumption of 100 g or more/capita/day is not uncommon (Mheen and others 1977; Steinkraus 1983 a,c). Kimchi is still a household fermentation in Korea although it can be purchased commercially.

Pickled vegetables, cucumbers, radishes, carrots and very nearly all vegetables and even some green fruits such as olives, papaya and mango are acid fermented in the presence of salt around the world. Mukerjee (1987) demonstrated that Indian farmers can safely preserve their surplus vegetables by lactic acid fermentation on the farm. This improves the supply and availability of vegetable foods throughout the year and improves the nutrition of the Indian population.

Pit fermentations

Lactic acid fermentations include the "pit" fermentations in the South Pacific Islands. They have been used for centuries by the Polynesians to store and preserve breadfruit, taro, banana and cassava tubers (Steinkraus 1986; Aalbersberg and others 1988). The fermented pastes or whole fruits, sometimes punctured, are placed in leaf-lined pits. The pits are covered with leaves and the pits are sealed. It has recently been found that pit fermentations are lactic acid fermentations (Aalbersberg and others 1988) The low pH and anaerobic conditions account for the stability of the foods. An abandoned pit estimated to be about 300 years old contained breadfruit still in edible condition.

In Ethiopia, pulp of the false banana (*Ensete ventricosum*) is also fermented in pits (Steinkraus 1983a). It undergoes lactic acid fermentation and is preserved until the pit is opened. Then the mash is used to prepare a flat bread kocho-a staple in the diet of millions of Ethiopians.

Lactic acid fermented rice/shrimp/fish mixtures

Philippine balao balao is a lactic acid fermented rice/shrimp mixture prepared by mixing boiled rice, raw shrimp and solar salt (about 3% w/w), packing in an anaerobic container and allowing the mixture to ferment over several days or weeks (Arroya and others 1977); Steinkraus 1883a,c). The chitinous shell of the shrimp becomes soft and when the product is cooked, the whole shrimp can be eaten. The process provides a method of preserving raw shrimp or pieces of raw fish (burong dalog) (Orillo and Pederson 1968). The products are well-preserved by the low pH and anaerobiosis until the containers are opened. Then they must be cooked and consumed.

Yogurt/cereal mixtures

Another household lactic acid fermentation of considerable nutritional importance includes Egyptian kishk, Greek trahanas and Turkish tarhanas. These products are basically parboiled wheat/yogurt mixtures that combine the high nutritional value of wheat and milks while attaining excellent keeping qualities. The processes are rather simple. Milk is fermented to yogurt and the yogurt and wheat are mixed and boiled together until the mixture is highly viscous. The mixture is than allowed to cool, formed into biscuits by hand and sun-dried. Trahanas can be stored on the kitchen shelf for years and used as a base for highly nutritional soups. In the Egyptian kishk process, tomatoes, onions and other vegetables are sometimes combined with the yogurt and wheat in the biscuits (Abd-el-Malek and Demerdash 1977; Steinkraus 1983a;1996).

Cereal/legume sour gruels/porridges/beverages

Cereal/legume sour gruels/porridges/beverages include Nigerian ogi, Kenyan uji, South African mahewu/magou, and Malaysian soybean milk yogurt (tairu). In Nigerian ogi, maize, millet or sorghum grains are washed and steeped for 24 to 72 h during which time they undergo lactic acid fermentation. They are drained, wet milled and finally wet-sieved to yield a fine, smooth slurry with about 8% solids content. The boiled slurry called "pap", is a porridge. Pap is a very important traditional food for weaning infants and a major breakfast food for adults. Infants 9 months old are introduced to ogi by feeding once a day as a supplement to breast milk (Steinkraus 1983a; Banigo 1969; Banigo and Muller 1972). Unfortunately the nutritional value of ogi is poor. It is vastly improved by the addition of soybean to produce a soy-ogi (Akinrele and others 1970).

Kenyan uji is a related product except that the grains are ground to a flour before mixing with water and fermenting. The initial slurry is 30% solids. This is fermented for 2 to 5 days yielding 0.3 to 0.5% lactic acid. The slurry is then diluted to 10% solids and boiled. It is then diluted to 4 to 5% solids and 6% sucrose is added for consumption (Dirar 1993; Steinkraus 1983a; Gatumbi and Muriru 1987; Mbugua 1981)).

South African mageu/mahewu/magou is a traditional sour, nonalcoholic maize beverage popular among the Bantu people of Africa (Holzapfel 1989). Corn flour is slurried with water (8 to 10% solids), boiled, cooled and inoculated with 5% w/w wheat flour (household fermentation) which serves as a source of microorganisms and incubated at ambient temperature or the boiled slurry is inoculated with *Lactobacillus delbrueckii* (industrial process) and incubated at 45 C. The slurries are fermented to a pH of 3.5 to 3.9 and then are ready for consumption.

Lorri (1993) and Svanberg and others (1992) reported that lactic acid-fermented gruels inhibited the proliferation of Gram-negative pathogenic bacteria including toxicogenic *Escherichia coli, Campylobacter jejuni, Shigella flexneri* and *Salmonella typhimurium*. The mean number of diarrhea episodes in preschool children over a 9 month period was 2.1 per child using fermented gruels compared with 3.5 per child using non-fermented gruels. Lorri also reported that using a natural lactic acid culture and flour of germinated seeds (power flour), it was possible to prepare liquid cereal gruels from maize, white sorghum, bulrush millet and finger millet with a 30 to 35% flour concentration. The energy density of such a lactic acid-fermented gruel was about 1.2 kcal/g, as compared with 0.4 kcal/g in a non-fermented gruel prepared to the same consistency. This is a 3-fold increase in energy density. Also, the in vitro protein digestibility of high-tannin cereal varieties was significantly increased from a range of 32 to 40% before fermentation to a range of 41 to 60% after lactic acid-fermentation. Lactic acid fermentation of non-tannin cereals with added flour of germinated sorghum grain or wheat phytase increased iron solubility from about 4% to 9% and 50% respectively. Thus lactic acid fermentation has very profound effects on the nutritive value of cereal gruels for feeding infants and children in the developing world.

Ingestion of foods containing live lactic acid bacteria is likely to improve the resistance of the gastrointestinal tracts of infants and children to invasion by organisms causing diarrhea.

Cereal/legume steamed breads and pancakes

Indian idli, a sour, steamed bread, and dosa, a pancake are examples of a household fermentation that could be useful around the world. Polished rice and black gram dahl in various proportions, that is, 3:1 to 1:3 are soaked by the housewife separately during the day. In the evening, the rice and black gram are ground in a mortar and pestle with added water to yield a batter with the desired consistency. The batter is thick enough to require the use of the hand and forearm to mix it properly. A small quantity of salt is added. The batter ferments overnight during which time *Leuconostoc mesenteroides* and *Streptococcus faecalis*, naturally present on the grains/legumes/utensils grow rapidly outnumbering the initial contaminants and dominating the fermentation. The organisms produce lactic acid (total acidity as lactic can reach above 1.0%) and carbon dioxide that makes the batter anaerobic and leavens the product. In the morning, the batter is steamed to produce small white muffins or fried as a pancake. Soybean cotyledons, green gram, Bengal gram can be substituted for the black gram. Wheat, maize or kodri can be substituted for the rice to yield Indian dhokla (Ramakrishnan 1979a, 1979b; Steinkraus 1983a; 1996). A closely related fermentation is Ethiopian enjera that yields the large pancake that serves as the center of the meal.

Alcoholic fermentations

A third principle contributing to food safety is that fermentations involving production of ethanol are generally safe foods and beverages (Steinkraus 1979). These include wines, beers, Indonesian tape ketan/tape ketella, Chinese lao-chao, South African kaffir/sorghum beer and Mexican pulque. These are generally yeast fermentations but they also involve yeast-like molds such as *Amylomyces rouxii* and mold-like yeasts such as *Endomycopsis* and sometimes bacteria such *Zymomonas mobilis*. The substrates include diluted honey, sugarcane juice, palm sap, fruit juices, germinated cereal grains or hydrolyzed starch all of which contain fermentable sugars that are rapidly converted to ethanol in natural fermentations by yeasts in the environment. Nearly equal weights of ethanol and carbon dioxide are produced and the CO_2 flushes out residual oxygen and maintains the fermentation anaerobic. The yeasts multiply and ferment rapidly and other microorganisms most of which are aerobic cannot compete. The ethanol is germicidal and, as long as the fermented product remains anaerobic, the product is reasonably stable and preserved.

With starchy substrates such as cereal grains, it is necessary to convert some of the starch to fermentable sugar. This is done in a variety of ways, that is, chewing the grains to introduce ptyalin (Andes region of South America) where maize is a staple or germination (malting) of barley or the grains themselves in most of the world where beers are produced. In parts of Africa, a young lady cannot get married until she is capable of making Bantu beer for her husband.

In Asia, there are at least two additional ways of fermenting starchy rice to alcoholic foods. The first is the use of a mold such as *Amylomyces rouxii* which produces amylases converting starch to sugars and a yeast such as *Endomycopsis fibuliger* which converts the glucose/maltose to ethanol. The sweet sour/ alcoholic product of rice fermentation is called tape ketan in Indonesia. It is consumed as a dessert. When cassava is used as substrate, the product is called tape ketella (Merican and Yeoh 1989; Steinkraus 1983a). This process can also be used to produce rice wines, Chinese lao-chao and Malaysian tapuy/tapai.

Another method is the Japanese koji process used to ferment rice to rice wine (sake) (Yoshizawa and Ishikawa 1989; Steinkraus 1979b; 1983a). In this process, boiled rice is overgrown with an amylolytic mold *Aspergillus oryzae* for about 3 days at 30 C. The mold-covered rice called a "koji" is then inoculated with a culture of the yeast *Saccharomyces cerevisiae* and water is added. Saccharification by the mold amylases and alcoholic fermentation by the yeast proceed simultaneously. The result of slow fermentation is high yeast populations and ethanol contents as high as 23% v/v.

Acetic acid/vinegar fermentation

If the products of alcoholic fermentation are not kept anaerobic,