Food fermentation: a safety and nutritional assessment*

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An assessment of the food-safety and nutritional aspects of lactic acid fermentation for the preparation of weaning food at the household level was carried out during a Joint FAO/WHO Workshop held in Pretoria, South Africa, in December 1995. In particular, lactic acid fermentation was evaluated as a part of food preparation processes involving other operations such as soaking, cooking, and the germination of cereal grains. The use of germinated cereals is of particular interest since they can be used to prepare semi-liquid porridges of high nutrient density. After reviewing the present state of knowledge concerning the antimicrobial effects of the lactic acid in fermented foods, and the nutritional benefits of fermentation and the use of germinated cereals, the Workshop made an inventory of gaps in current knowledge and priorities for further research. High priority areas for research include the following: the effect of lactic acid fermentation on viruses, parasites, certain bacteria, and mycotoxins; certain physiological and nutritional effects of the consumption of fermented foods; the characterization and optimization of fermentation processes and the development of appropriate fermentation starters; and risk mitigation using the Hazard Analysis Critical Control Point system, the health education of food handlers, and efforts to change the consumer perception of fermented foods.

Introduction

Diarrhoeal diseases are a major health problem for infants and children, particularly in developing countries. Annually, some 1500 million episodes of diarrhoea occur worldwide in children under the age of 5 years, and over 3 million children die as a result. Diarrhoeal diseases are also indirectly responsible for the deaths of many more children, as they are one of the major underlying causes of malnutrition. It is estimated that up to 70% of the episodes of diarrhoeal disease are foodborne in origin, i.e. caused by contaminated food, including drinking-water and water used in food preparation (*1*). Sources of food contamination are diverse and include polluted water (e.g. wastewater, irrigation and household water), dirty hands, flies, pests, domestic animals, dirty pots and cooking utensils, and human and animal excreta in the environment. Foods themselves are also frequently the source of contaminants, as some foodstuffs naturally harbour pathogens or may have been obtained from infected animals. Moreover, during food handling there is a risk of cross-contamination of foods. Epidemiological studies have shown that one of the major causes of foodborne disease worldwide is time–temperature abuse during food preparation, leading to the survival and/or growth of contaminating pathogens — or the pro-

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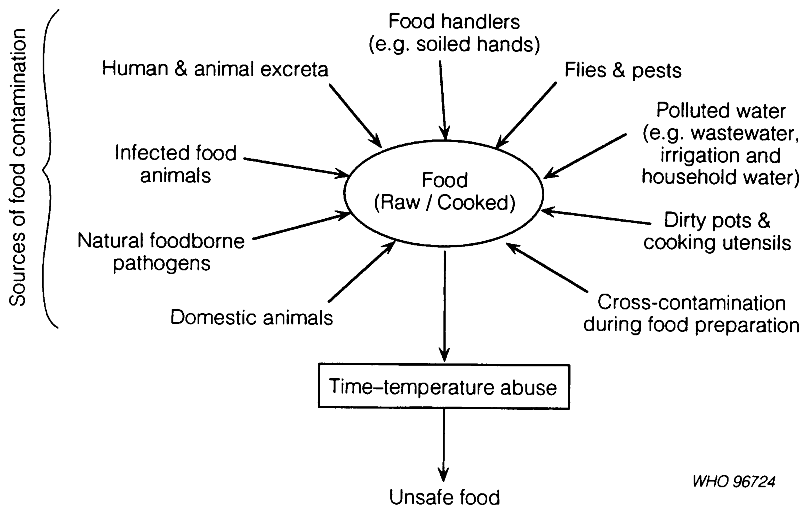
Fig. 1. **Sources of food contamination.**



duction of toxin — to disease-causing levels (Fig. 1). Two practices are typically involved in disease-causing time–temperature abuse:

— preparation of food several hours prior to consumption and its storage at temperatures that favour the growth of pathogenic bacteria and/ or the formation of toxins; and
— insufficient cooking or reheating of food to reduce or eliminate pathogens.

The education of food handlers, particularly the mothers of small children, to avoid these practices, is an essential part of the prevention of foodborne disease. Observing basic principles of food hygiene, including thorough cooking, proper storage, and thorough reheating of stored food, can prevent many cases of foodborne diarrhoea (*2*).

However, the implementation of the principles of food hygiene is sometimes hampered by socioeconomic constraints such as the lack of facilities for cold storage (e.g. refrigerators) or the lack of fuel for thorough cooking, hot storage, or reheating (*1*). As a result, low-income households are often not able to apply the key principles mentioned above.

Fermentation has long been used as a means of preparing and preserving food. Recently, however, the value of lactic acid fermentation has been recognized as an alternative technology when cold or hot storage is not feasible. In addition, it is considered that in some cases fermented products can be safely consumed without reheating and fuel needs can be reduced. Fermented cereal products have traditionally been used as weaning foods in some African countries, e.g. Nigeria (*ogi*) and Kenya, Uganda, and the United Republic of Tanzania (*uji*). Moreover, as certain nutritional benefits have been attributed to fermented foods, they have also been promoted for nutritional reasons (*3*).

However, the following questions arise when considering the use of fermentation at the household level. First, what kind of hazards can be controlled through the application of this technology? Second, what risks are associated with fermentation, as the result of food handlers' lack of knowledge or unhygienic food preparation conditions? Experience has shown that when fermentation has been improperly used, the resulting food products have caused illnesses. Third, what sociocultural considerations should be taken into account in order successfully to apply fermentation technology or transfer it to another region? Finally, in light of the risks and benefits, should fermentation technology be promoted for the prevention of foodborne diarrhoea or as a means of improving the nutritional value of foods?

With these considerations in mind, the Food and Agriculture Organization of the United Nations (FAO) and WHO organized a Workshop (held in Pretoria, 11–15 December 1995), in collaboration with the Department of Health of South Africa, to assess lactic acid fermentation as a household technology for improving food safety.

The objectives of the Workshop[a] were to review the current state of the art with respect to the benefits and risks of food fermentation, giving particular consideration to traditional African weaning foods; to develop practical interventions for improving the safety and nutritional quality of fermented foods; and to review gaps in current knowledge and determine where additional research is needed.

Fermentation: a description

Fermentation can be defined as the biochemical modification of primary food products brought about by the action of microorganisms and their enzymes. Fermentation is intentionally carried out to enhance the taste, aroma, shelf-life, texture, nutritional value, and other properties of food. It is often part of a sequence of food-processing operations that can include the following: cleaning, grinding, soaking, cooking, packaging, and distribution. It is used in many parts of the world, with regional differences depending on the availability of raw materials, consumption habits, the laboriousness of the processes involved, and a variety of social factors. Fermented foods intended for infants or young children are mainly lactic-acid-fermented cereals (e.g. maize, sorghum, millet), root crops (e.g. cassava), milk, and, to a lesser extent, fish, meat, or vegetables.

Lactic acid fermentation is a natural process brought about by the lactic acid bacteria (LAB) naturally present in food or derived from a starter culture. A variety of fermentation techniques are used in Africa. For example, after cleaning, cereal grains are soaked in water for a few days during which a succession of naturally occurring microorganisms results in a population dominated by LAB. Fermentation may be facilitated by grain-endogenous amylases, which generate more readily fermentable maltose from starch. The fermentation process can be accelerated by the addition of a starter culture of LAB, either by adding some already fermented material (back-slopping) or a carrier material to which LAB attach. In some fermentation techniques, germinated grains are used as source of amylase and/or starter culture. Some industrially produced starter cultures are currently used in Africa, but mainly in the fermentation of dairy products (*4*).

[a] *Report of the Joint FAO/WHO Workshop on Assessment of Fermentation as a Household Technology for Improving Food Safety.* Unpublished document WHO/FNU/FOS/96.1, 1996 (available upon request from Division of Food and Nutrition, World Health Organization, 1211 Geneva 27, Switzerland).

Assessment of benefits and risks

Fermentation is often just one step in the process of fermented food preparation. Usually other operations such as size reduction, salting, or heating are also involved. Therefore, where a change in food characteristics is observed it may be the effect of other operations or their combination with fermentation rather than the result of the fermentation step itself. Below are presented the risks and benefits associated with the fermentation step.

Biological benefits and risks

There is considerable evidence that lactic acid fermentation inhibits the survival and multiplication of a number of bacterial pathogens. The extent to which bacterial growth is inhibited depends on the organism concerned, the ambient temperature, the amount of lactic acid and other inhibitory substances produced, and the properties of the food, i.e. its acid-buffering capacity. In cereal and vegetable products that are weakly buffering, efficient lactic acid fermentation will produce a pH of 4 or less, a level at which the growth of many bacterial pathogens is inhibited and at which many bacteria die at a rate that increases with the ambient temperature.

The potential of lactic acid fermentation to control the harmful effects of food contamination depends on factors that are difficult to quantify, such as the initial level of contamination, which in turn depends on local conditions, levels of hygiene and sanitation, and the resulting degree of acidity. It should be noted, therefore, that fermentation cannot replace observing the principles of food hygiene/food safety and minimizing the risk of contamination. This is particularly important since some pathogens may be acid resistant and may consequently survive the fermentation process: foodborne viruses such as rotavirus — a common cause of childhood diarrhoea — are relatively acid resistant; there are also emerging signs of acid resistance in some enteropathogens such as *Escherichia coli* O157:H7. While further research is needed to determine the effect of acidity on parasites such as *Cryptosporidium* spp., *Giardia lamblia*, and foodborne trematodes, these organisms often show resistance to adverse conditions.

Chemical benefits and risks

Lactic acid fermentation has been associated with the reduction of certain naturally occurring toxins in plant foods. For example, cyanide levels in cassava are found to be reduced in several traditional fermented cassava products, although this reduction may be principally the consequence of endogenous enzymes rather than microbial activity. However, microorganisms may play an important role in softening the plant tissue and facilitating the reduction in cyanides.

There are a number of toxins produced by moulds (e.g. *Aspergillus flavus* and *Fusarium moniliforme*) or bacteria (e.g. *Staphylococcus aureus*, *Bacillus cereus*, *Clostridium botulinum*). The results of studies are contradictory regarding the role of fermentation in reducing the level of mycotoxins in food. Moreover, there is no evidence to suggest that fermentation will reduce the level of preformed bacterial toxin. Therefore, fermentation alone cannot be relied upon to reduce levels of mycotoxins or bacterial toxins in food.

Physical benefits and risks

While fermentation does not reduce the level of contamination due to extraneous matter in food, other operations that typically precede fermentation, e.g. washing, may contribute to its removal.

Nutritional benefits and risks

Fermentation has various effects on the nutritional quality of food. Microbial fermentation leads to a decrease in the level of carbohydrates and indigestible oligosaccharides in legumes. A decrease in levels of the latter reduces abdominal distention and flatulence. Moreover, certain amino acids may be synthesized, and the availability of B-group vitamins may be increased by fermentation. Fermentation techniques involving the addition of amylase-rich flour and a small amount of lactic acid starter culture provide a considerable increase in the nutrient density of the resulting food. The decrease in the viscosity of starchy foods mixed with water (porridges) after fermentation enables an increase in the concentration of dry matter while maintaining the desirable semi-liquid consistency.

Fermentation, by lowering pH, also provides more optimal conditions for enzymatic degradation of the phytate present in cereals in the form of complexes with proteins or polyvalent cations such as iron, zinc, calcium, and magnesium. This degradation occurs during the soaking of cereal grains in water for 12–14 hours. Such a reduction in phytate may increase the amount of soluble iron, zinc, and calcium severalfold. Similarly, as a result of lactic acid fermentation, the tannin content may be reduced in some cereals, leading to the increased absorption of iron. Vitamin C is better preserved in lactic-acid-fermented vegetables, which also facilitates the absorption of iron in a phytate-rich diet. There are indications for the presence of other iron-promoting factors in fermented vegetables as well.

On the other hand, compared with cooking, lactic acid fermentation has a minimal effect on reducing the negative nutritional impact of protease inhibitors and the toxic effects of lectins. Moreover, microbially produced lactic acid is usually a mixture of the L-(+) and D-(−) isomers of lactic acid. As the latter cannot be metabolized by humans, excessive intake can result in acidosis, which is a disturbance in the acid–alkali balance in the blood. The potential toxicity of D-(−) lactic acid is of particular concern for malnourished and sick children. Further research is needed with regard to the content of D-(−) lactic acid in lactic-acid-fermented foods.

Interventions for improving the safety and nutritional value of fermented foods

Since fermentation is typically one part of a multistep food-processing operation, assessing the safety and nutritional value of fermented foods and determining appropriate interventions to improve these should be considered in the context of the entire process transforming foodstuffs from raw materials to end-products. In the light of present practices for the preparation of fermented weaning foods, three areas of concern can be identified: safety, nutrition, and sociocultural factors.

The time necessary for food processing in traditional household fermentation processes is a constraint on the hours available to food preparers who may also be engaged in child care and other household activities. The lack of sufficient time can have significant implications for the safety and nutritional quality of fermented foods, as any time saved by shortening the period of fermentation can jeopardize the effectiveness of acidification or the degradation of anti-nutritional factors. Some reduction in time expenditure may however be acceptably achieved by accelerating the fermentation process (e.g. through the use of starter culture) or by a different distribution of labour (e.g. through food production by an entrepreneur). Care should in any case be taken that no short cuts making the food unsafe are used. Food safety problems can also arise from processing or handling food under unhygienic conditions. Improvement in food quality and safety can be achieved by implementing or promoting principles of good manufacturing and good hygienic practice, and by using the Hazard Analysis Critical Control Point system (HACCP). The HACCP system constitutes a food-safety assurance tool that can be used for the identification, assessment, and control of hazards at all points in the process from raw material to packaging and consumption. The application of the HACCP system to several fermented African foods was carried out during the Workshop to illustrate the use of this approach to identify the necessary measures to improve the safety of fermented foods and to determine the practices and behaviours that should be the subject of health education for food handlers. Application of the HACCP system also demonstrated the relatively high risks associated with the preparation of certain fermented foods and the importance of assessing the safety of each product and each preparation individually.[b]

From a nutritional point of view, it is possible to improve the nutrient density of fermented foods while maintaining their desirable semi-liquid consistency by the addition of amylase-rich flour, provided that the starchy cereal or root-crop intended for fermentation is cooked. Likewise, it is possible to improve the protein content of fermented porridges by enriching them with legumes, e.g. soybeans or cowpeas.

A major constraint associated with the use of fermented foods for weaning is that of their poor image compared with commercial weaning preparations which, in some countries, are considered superior and are associated with progressiveness. The education of consumers and food handlers in this regard is essential.

Research needs

An extensive amount of research on food fermentation has been carried out throughout the world. The current status of that research — with particular emphasis on the needs of developing countries and the level of understanding of the potential of the use of fermentation to prevent foodborne diarrhoea and the improvement of nutritional status — was assessed during the Workshop. Areas for research that could increase the understanding of policy-makers, food scientists, and food technologists with regard to the safety, nutritional value, and socio-economic and cultural aspects of fermented foods were identified.

Some of the priority areas recommended by the Workshop for further research are shown below:

— the effect of lactic acid fermentation on parasites, viruses, and sublethally injured pathogenic bacteria, as well acid-resistant bacteria;

— the effect of lactic acid fermentation on mycotoxins and the toxicity of their degradation products;

— the effect of the consumption of fermented foods on the incidence of diarrhoea, and the mechanism through which it has this effect;

— the significance of D-(−) lactic acid acidosis associated with the consumption of fermented foods;

— the effect of fermentation on the bioavailability of nutrients, especially iron, zinc, calcium, and protein;

— the development of appropriate starter cultures for lactic acid fermentation;

— the assessment of risks associated with the household preparation of fermented weaning foods and the identification of critical processing points (through the application of the HACCP system) that should be the subject of health education for food handlers; and

— the perception of fermented foods held by consumers and food handlers, and identification of appropriate mechanisms for their education.

Conclusions

The single most effective way of controlling microbial hazards in food is to cook it thoroughly and eat it promptly. On its own, fermentation cannot eliminate all food-related health risks, and it should not be seen as a replacement for observing the principles of food hygiene.

However, particularly when combined with other processing techniques, fermentation can contribute to the safety, nutritional value, shelf-life, and palatability of foods. From the food-safety point of view the benefits of fermentation include the inhibition of the growth of most pathogenic bacteria and the formation of bacterial toxins. Where refrigeration or hot storage is not possible, fermentation can provide an affordable method to keep food safe until it is consumed, provided that rapid and adequate acidification is attained. Nutritional benefits may also result. Fermentation is associated with the degradation of anti-nutritional factors, the increased bioavailability of minerals, the improvement of the digestibility of proteins in tannin-rich cereals, and the degradation of indigestible oligosaccharides. The reduced viscosity of fermented foods may be used to advantage through the addition of germinated cereal grains (amylase-rich flour), yielding porridges with an increased nutrient density.

[b] See footnote *a*, p. 555.

While the advantages of fermentation, particularly when associated with other operations, were recognized, its improper application is a matter of concern. It was therefore recommended that in communities where lactic acid fermentation is used, it should be encouraged, but food handlers need to be educated to control adequately the safety of the resulting products through good food hygiene.[c] Existing socioeconomic and cultural factors should be examined, and the type of support needed to improve the safety and nutritional value of fermented foods identified. Appropriate strategies and means of communication should be developed and applied to inform households about safe and nutritionally sound fermentation techniques. Where lactic acid fermentation is not known or used, an assessment should be made of the appropriateness and feasibility of the practice of fermentation for that community, as well as of its safety and nutritional implications, prior to any formal attempt to introduce fermentation technology. Multidisciplinary and collaborative research is essential for improving knowledge concerning this technology and its use for health promotion. The coordination of research, for instance through a network of scientists, would ensure methodical and steady progress towards reaching the research objectives identified above.

Résumé

Fermentation des aliments: évaluation de la salubrité et des aspects nutritionnels

Une évaluation de la salubrité et des aspects nutritionnels de la fermentation lactique pour la préparation domestique des aliments de sevrage dans les pays tropicaux a été réalisée au cours d'un atelier mixte FAO/OMS qui s'est tenu à Pretoria (Afrique du Sud) en décembre 1995. La fermentation lactique a été en particulier évaluée en tant qu'élément des procédés traditionnels de préparation des aliments dont font partie d'autres opérations comme le trempage, la cuisson, et la germination des céréales.

Les maladies diarrhéiques posent un problème majeur de santé publique chez le nourrisson et l'enfant, notamment dans les pays en développement. On estime que 70% des épisodes diarrhéiques sont d'origine alimentaire, c'est-à-dire qu'ils sont provoqués par des aliments contaminés, par l'eau de boisson ou par l'eau utilisée dans la préparation des aliments. Il a été démontré que l'un des principaux facteurs est le non-respect des délais et des températures de conservation, qui favorise la survie et/ou le développement d'agents pathogènes ou la production de toxines jusqu'à des niveaux provoquant une toxi-infection. Il s'agit essentiellement de deux pratiques:

- préparation des aliments plusieurs heures avant leur consommation et conservation à des températures qui favorisent la croissance des bactéries pathogènes et/ou la formation de toxines;
- cuisson ou réchauffage insuffisants pour réduire ou éliminer les agents pathogènes.

Les scientifiques et les autorités de santé publique reconnaissent maintenant l'intérêt de la fermentation lactique lorsque des contraintes économiques ou autres empêchent la conservation des aliments au froid ou au chaud. Cette fermentation est un processus naturel dû aux bacilles lactiques présents dans les aliments ou provenant d'une culture. Elle est depuis longtemps pratiquée dans de nombreuses régions comme méthode de préparation et de conservation domestiques des aliments. Les aliments fermentés destinés aux nourrissons et aux jeunes enfants sont principalement des céréales (maïs, sorgho, millet), des racines (par exemple le manioc), du lait et, dans une moindre mesure, du poisson, de la viande et des légumes.

Il a été largement démontré que la fermentation lactique inhibe la croissance, la survie et la reproduction de nombreux germes pathogènes, en abaissant le pH des aliments à un niveau incompatible avec la survie bactérienne. La fermentation lactique est également associée à une réduction des toxines naturellement présentes dans certaines denrées alimentaires, comme les cyanures dans le manioc, probablement en facilitant l'action de certaines enzymes endogènes.

Sur le plan nutritionnel, la fermentation microbienne abaisse les taux de glucides et d'oligosaccharides non digestibles dans les légumineuses. De plus, certains acides aminés peuvent être synthétisés pendant ce processus, qui augmente également les teneurs en vitamines du groupe B. Les techniques de fermentation comportant l'addition d'une farine riche en amylase, ou la germination de céréales, augmentent considérablement la valeur nutritive de l'aliment. La fermentation favorise également la dégradation enzymatique des phytates, ce qui conduit à augmenter la teneur en fer, en zinc et en calcium solubles. De même, la teneur en tanins peut être abaissée dans les céréales, et la vitamine C mieux conservée dans les légumes, deux propriétés qui facilitent l'absorption du fer.

[c] See footnote *a*, p. 555.

D'autre part, l'acide lactique d'origine microbienne contient habituellement les isomères L-(+) et D-(−) de l'acide lactique, mais comme ce dernier isomère ne peut être métabolisé chez l'homme, son absorption en quantité excessive peut entraîner une acidose lactique. La toxicité potentielle de l'isomère D-(−) pour les enfants malades ou dénutris est par conséquent préoccupante. De plus, la fermentation lactique a peu d'effet sur les conséquences nutritionnelles négatives des inhibiteurs des protéases et sur les effets toxiques des lectines, et son effet sur les parasites, les mycotoxines et les virus couramment transmis par les aliments est inconnu ou, au mieux, douteux, De plus, la fermentation lactique, comme on l'utilise dans les procédés traditionnels de préparation des aliments, peut poser des problèmes de salubrité en cas de non-respect des règles d'hygiène. L'atelier a recommandé de poursuivre les recherches sur les points suivants:

— effet de la fermentation lactique sur les parasites, les virus et les bactéries pathogènes survivants, ainsi que sur les bactéries acido-résistantes;
— effet de la fermentation lactique sur les mycotoxines et la toxicité de leurs produits de dégradation;
— effet de la consommation d'aliments fermentés sur l'incidence de la diarrhée, et mécanisme en cause;
— importance de l'acidose due à l'acide D-(−) lactique associée à la consommation d'aliments fermentés;
— effet de la fermentation sur la biodisponibilité des nutriments, notamment du fer, du zinc, du calcium et des protéines;
— mise au point de la culture de ferments appropriés;
— évaluation des risques associés à la préparation domestique d'aliments de sevrage fermentés (par l'analyse des points de contrôle critiques), et identification des points critiques qui devraient faire l'objet d'une éducation sanitaire à l'intention des personnes manipulant les aliments;
— préjugés à l'égard des aliments fermentés chez les consommateurs et les personnes manipulant les aliments, et identification des mécanismes appropriés d'éducation à l'intention de ces personnes.

Le seul moyen efficace de combattre les risques microbiens consiste à cuire complètement les aliments et à les consommer sans délai, et la fermentation ne doit pas être considérée comme un moyen de déroger aux principes de l'hygiène alimentaire. Toutefois, surtout si elle est associée à d'autres techniques de préparation, la fermentation peut contribuer à la salubrité, à la valeur nutritionnelle, à la durée de conservation et à l'agrément des aliments. Lorsqu'il n'est pas possible de réfrigérer les aliments ou de les garder au chaud, la fermentation peut constituer une méthode abordable de maintien de la salubrité des aliments jusqu'à leur consommation, à condition toutefois que l'acidification soit rapide et suffisante. Cette méthode peut également présenter quelques avantages sur le plan nutritionnel. Bien que les avantages de la fermentation soient reconnus, des pratiques incorrectes peuvent poser des problèmes.

Il a donc été recommandé que dans les communautés où la fermentation lactique est déjà utilisée, elle soit encouragée, et que les manipulateurs de denrées alimentaires reçoivent une éducation afin de garantir la salubrité des produits obtenus grâce au respect des règles d'hygiène. Lorsque cette méthode n'est pas utilisée ou est inconnue, on en évaluera l'intérêt et la faisabilité pour la communauté en question, ainsi que ses conséquences sur le plan de la salubrité et de la valeur nutritive des aliments, avant de tenter de la faire adopter. La coordination de recherches multidisciplinaires et collectives, par exemple par le biais d'un réseau de scientifiques, permettrait de parvenir de façon méthodique et régulière aux objectifs de recherche mentionnés ci-dessus et est indispensable pour améliorer l'état des connaissances concernant l'utilisation de la fermentation des aliments dans le but de promouvoir la santé.

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