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PAPER

Review of the effect of fermentation on naturally occurring toxins*

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INTRODUCTION

Lesser developed countries require food processing technologies that are technologically appropriate, suitable for tropical regions and that are affordable in rural and urban economies. Household-level fermentation is one such technology that has been developed indigenously for a wide range of food commodities. These include cereals and legumes, root crops, fruit and vegetables, dairy products, fish and meat (Steinkraus, 1983, 1989; Campbell-Platt, 1987, 1994). As a unit operation in food processing, fermentation offers a large number of advantages, including: food preservation, improved food safety, enhanced flavour and acceptability, increased variety in the diet, improved nutritional value, reduction in anti-nutritional compounds and in some cases, improved functional properties.

Fermentation is a very important low-cost food processing technique and a common means of preservation in lesser developed tropical countries (Cooke *et al.*, 1987) where preservation techniques such as refrigeration, freezing, canning or modified atmosphere packaging are prohibitively expensive. Problems are compounded in communities with low levels of disposable incomes and where limited infrastructure available in the food processing industry greatly restricts the use of more advanced technologies.

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This paper considers the appropriateness of fermentation as a food processing operation in improving food safety, particularly the effect on naturally occurring toxins in raw materials. A wide range of toxic compounds is considered, but specific attention is given to cyanogens (cyanide containing compounds) in cassava as an example of the complexity of the role of fermentation in reducing toxic compounds.

Food safety is an important issue in developing countries. Processing techniques that ensure food safety are required at both the rural and urban levels, particularly in view of the frequently poor sanitary conditions and high ambient temperatures. This review focuses specifically on two sources of toxic compounds: those inherent in the commodity and those of microbial origin. The key research issues and the prospects for the future use of the technology are discussed.

HOUSEHOLD LEVEL FERMENTATION

The term fermentation is often used with imprecision when referring to foods (Adams, 1990). For the purpose of this paper, the term is used in a more general sense to cover any foods that have been subjected to the action of microorganisms or enzymes so that desirable biochemical changes cause significant modification of the food (Campbell-Platt, 1987). Several excellent reviews exist which describe and catalogue the production and use of fermented foods worldwide (Steinkraus, 1983, 1989; Wood, 1985; Campbell-Platt, 1987; Lee *et al.*, 1991). This review will focus primarily on the fermentation of staple food crops since such fermentations have the greatest

potential for contributing towards food safety and food security.

NATURALLY OCCURRING TOXINS OF MICROBIAL ORIGIN

Mycotoxins

The most commonly occurring toxins of microbial origin in cereals and legumes used as raw materials for fermented foods are mycotoxins. These are toxic secondary metabolites that are formed during growth of certain fungi and are some of the most potent toxic compounds known to man (Coker, 1995). The preferred method of controlling the presence of mycotoxins in these foods is to prevent their formation, either in the field or during storage (Coker, 1995). However, this is not always feasible, particularly when mycotoxins are produced by field fungi or during storage in uncontrolled, hot and humid environments. The risk of contamination by mycotoxins of raw materials used in fermented foods is a serious food safety hazard. The production of fermented foods usually involves other processing steps, such as cleaning, soaking, milling, dehusking and cooking. These can contribute to the reduction in contamination of final products and should not be ignored when considering the efficiency of a whole processing procedure.

Aflatoxins

There have been a number of reports (*Table 1*) of the effects of fermentation on the aflatoxin content of contaminated raw materials. Nout (1994) summarised the effect of fermentation on aflatoxin B_1. Fungi involved in food fermentations such as *Rhizopus oryzae* (*R. arrhizus*) and *Rhizopus oligosporus* are able to reduce the cyclopentanon moiety which results in aflatoxicol A. This is a reversible reaction. However, under certain conditions (for example the presence of organic acids) aflatoxicol A is irreversibly converted into the stereoisomer aflatoxicol B. The latter is about 18 times less toxic than aflatoxin B_1. Under the conditions created in a lactic fermentation (pH ≤ 4.0), aflatoxin B_1 is readily converted to aflatoxin B_{2a}, which is also less toxic.

Although the above reactions reduce toxicity, they do not provide complete detoxification (Nout, 1994). Complete detoxification is only achieved when the lactone ring is broken. This corresponds to a loss in fluorescence at 366 nm. This has been used as a screening tool. Bol and Smith (1989) used the technique to identify certain *Rhizopus* spp. that are able to degrade greater than 85% of aflatoxin B_1 present into non-fluorescent substances. The toxicity of these substances is unknown. Similar results on the selection of *Rhizopus* strains with the ability to degrade aflatoxin B_1 has also been reported by Kanittha (1990). This identified ability of certain strains to degrade aflatoxin offers the potential to develop defined starter cultures.

The reports in *Table 1* give a range of conflicting pictures as to the effects of fermentation on aflatoxins. Although some authors report very efficient aflatoxin reductions associated with fermentation, others show no effect. From this data, it is clear that fermentation cannot be relied upon as a means of detoxifying raw materials contaminated with aflatoxins. However, the potential contribution of fermentation to the safety of some products should not be ignored.

Table 1 Examples of the reported effects of fermentation on mycotoxins in raw materials

Toxin	Raw material/ product	Type of fermentation	Naturally contaminated/ spiked	Extent of reduction	Reference
Aflatoxin	Maize/*kenkey*	Lactic acid		None	Jesperson *et al.* (1994)
Aflatoxin	Sorghum/*ogi*	Lactic acid	Natural with B_1	12–16%	Dada and Muller (1983)
Aflatoxin	Wheat/bread	Yeast (dough)	Spiked with B_1	19%	El Banna and Scott (1983)
Aflatoxin	Milk/yoghurt	Lactic acid	Natural with M_1	None	Wiseman and Marth (1983)
Aflatoxin	Milk/kefir Milk/yoghurt	Lactic acid Lactic acid	As above Spiked with B_1, B_2, G_1, G_2 and M_1	Decreased None	Blanco *et al.* (1993)
Aflatoxin	Melon seed/*ogiri*	*Bacillus* spp.	Natural with B_1 and G_1	Complete removal after 4 days	Ogunsanwo *et al.* (1989)
Aflatoxin	Peanut press cake/ pure mould cultures	*Neurospora sitophila* and *Rhizopus oligosporus*	Not stated	50% and 70% respectively	Steinkraus (1983)
Aflatoxin	Maize/*ogi* Sorghum/ *ogi*	Lactic fermentation	Natural with B_1	Greater than 70%	Adegoke *et al.* (1994)
Alternariol and Alternaniolmono- methylether	Pure culture isolates from *kenkey*	Lactic acid bacteria	Spiked laboratory media	Reduction greater than 50% by all tested strains	Holzapfel (1995)

Other mycotoxins

The biological detoxification of several other myco-toxins has been demonstrated, in particular, sterig-matocystin, ochratoxin A, patulin, rubratoxin, zearlenone, T-2 toxin, deoxynivalenol and diacetoxy-scirpenol (Smith *et al.*, 1994). However, detailed studies have only been carried out with aflatoxins.

Patulin and ochratoxin A have been reported to be reduced during the fermentation of cider and beer. A number of mycotoxins have been shown to be degraded significantly by rumen organisms. These include zearalenone, ochratoxin A, T-2 toxin, deoxy-nivalenol and diacetoxyscirpenol (Smith *et al.*, 1994). Such observations demonstrate that desirable enzyme systems exist in certain rumen organisms that could, if justifiable, be cloned into microorganisms respon-sible for other fermentations.

In conclusion, there are clearly some fermentations where the action of microorganisms can contribute to the reduction of mycotoxins from some raw materials. The mechanisms are currently not very well under-stood, but there may be some circumstances where the optimisation of these processes would be justified. However, the prevention of the contamination of the raw materials should be viewed as the best long term approach (Smith *et al.*, 1994).

NATURALLY OCCURRING TOXINS OF PLANT ORIGIN

Cyanogenic compounds in cassava

Cassava is an important staple food crop, especially in Africa. Cassava roots contain the cyanogenic glucosides linamarin and lotaustralin. These cyano-genic glucosides can be hydrolysed to the corre-sponding ketone and glucose by the endogenous enzyme linamarase when cellular damage occurs (de Bruijn, 1973; Nartey, 1978). Cyanohydrins break down nonenzymically at a rate dependent upon pH and temperature (Cooke, 1978), with their stability increasing at acidic pH values. A second enzyme, hydroxynitrile lyase, may also contribute to cyanohy-drin breakdown (Conn, 1969).

Dietary cyanide from cassava has been implicated with a number of health problems. Although there are few reports, it is reasonable to consider that cyanide exposure from insufficiently processed cassava can cause acute poisoning (Bokanga *et al.*, 1994). Such poisoning occurs when food shortage and social instability induce shortcuts in established processing methods or when high cyanogen varieties are introduced into an area lacking appropriate processing techniques (Bokanga *et al.*, 1994). It is well established that thiocyanate resulting from dietary cyanide exposure can aggravate iodine expo-sure deficiency expressed as goitre and cretinism. There is also strong evidence for a causal link between cyanide and the paralytic disease konzo

(Tylleskar, 1994) and tropical ataxic neuropathy (Osuntokun, 1994a).

Many different fermented foods can be produced from cassava (Westby, 1991), but in Sub-Saharan Africa there are only three main types of fermenta-tion (Westby and Twiddy, 1992a; Essers, 1994): acidic fermentation of grated roots; acidic fermentation of soaked roots; and solid substrate (mould) fermentation.

Acidic fermentation of grated roots

Products from acidic fermented grated cassava roots include roasted granules such as West African *gari*, steamed products such as Ivorian *attieke* and Ghanaian *yakayake*, and fermented pastes such as Ghanaian *agbelima*. The first stages in the prepara-tion of these products involve peeling roots and grating them. The grated material is then typically placed in a jute or polythene sack for a number of days. The role of microbial growth in the *gari* fermentation was investigated by Vasconcelos *et al.* (1990). Plant and microbial enzymic activities were distinguished by comparing a natural fermentation with irradiated grated root incubated under the same conditions (30°C, 96 h). In both cases, more than 95% of the initial linamarin content was hydrolysed within 3 h of grating (*Figure 1*). It was considered that cellular damage due to grating was responsible for bringing the substrate, linamarin, into contact with the endogenous enzyme, linamarase. Linamarin and linamarase have been reported to be physically sepa-rated in cassava tissues (Mkpong *et al.*, 1990).

Significant concentrations of cyanohydrin and free HCN (43% of initial total cyanogen content on dry weight basis for natural fermentation) were left in the paste after fermentation (Vasconcelos *et al.*, 1990). The processing operations that follow fermentation then become important for determining the residual level of cyanogens in the final product. Assuming efficient grating and an acceptable level of endo-genous enzymic activity, linamarin reduction is not an issue and so processing has to be geared to reducing the concentrations of cyanohydrin and free HCN. In the case of *gari* processing (Vasconcelos *et al.*, 1990), roasting is efficient at volatilizing HCN and cyano-hydrin, leaving low residual concentrations (HCN 3.4 mg/kg and cyanohydrin 2.2 mg/kg on a dry weight basis in the natural fermentation). The efficiency of other post-fermentation operations (boiling and steaming) needs to be fully investigated, particularly as cyanohydrins have been reported to be stable at acidic pH values (Cooke, 1978).

As microorganisms are not directly involved in linamarin hydrolysis, there would appear to be no advantage in developing starter cultures with lina-marase activity for grated root fermentations (Westby and Twiddy, 1992b). This has been confirmed by the work of Giraud (1993) where a *Lactobacillus plan-tarum* isolate with high linamarase activity was inocu-lated into a grated root fermentation and there was
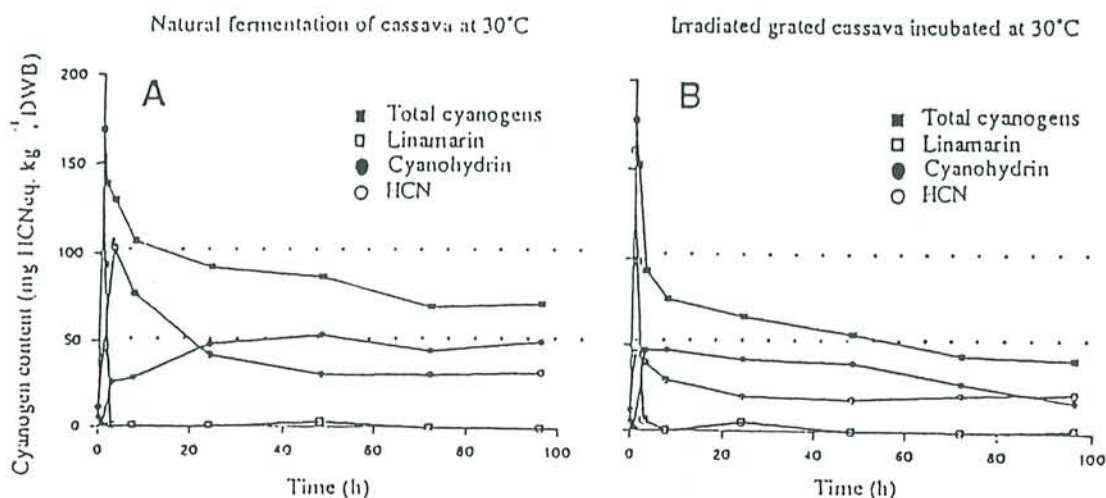
Figure 1 Changes in cyanogens during the fermentation of grated cassava and incubation of grated irradiated cassava at 30°C

no apparent improvement in linamarin reduction. The efficiency of grating and the level of endogenous linamarase activity would be predicted to be important factors in the effectiveness of linamarin hydrolysis and these factors require further investigation. Fermentation is still important in the *gari* fermentation for preservation and developing the sensory attributes of the product.

Acidic fermentation of soaked roots

The soaking of roots under water is a common processing technique for several products including *foo-foo* in Sierra Leone (Blanshard *et al.*, 1994), Nigerian *fufu* (Westby and Twiddy, 1992b) and *kondowole* in Tanzania (Bainbridge *et al.*, 1994). Roots are soaked in water with or without peeling for

3–5 days, during which time they are soften sufficiently so that they can be crushed by hand.

Westby and Choo (1994) investigated the mechanisms of cyanogen reduction by comparing a natural fermentation with cassava roots soaked in a mixture of antibiotics. It was demonstrated that, in contrast to the fermentation of grated roots, microbial growth was essential for efficient cyanogen reduction. In the absence of microbial growth (*Figure 2*), there was some reduction in cyanogens (less than 50% after 4 days), whereas in the natural fermentation (*Figure 2*) less than 10% remained after 3 days. The reduction in cyanogens was strongly correlated with the softening of roots in the natural fermentation. Roots soaked in the absence of microbial growth did not soften (*Figure 2*), which implies that microbial growth
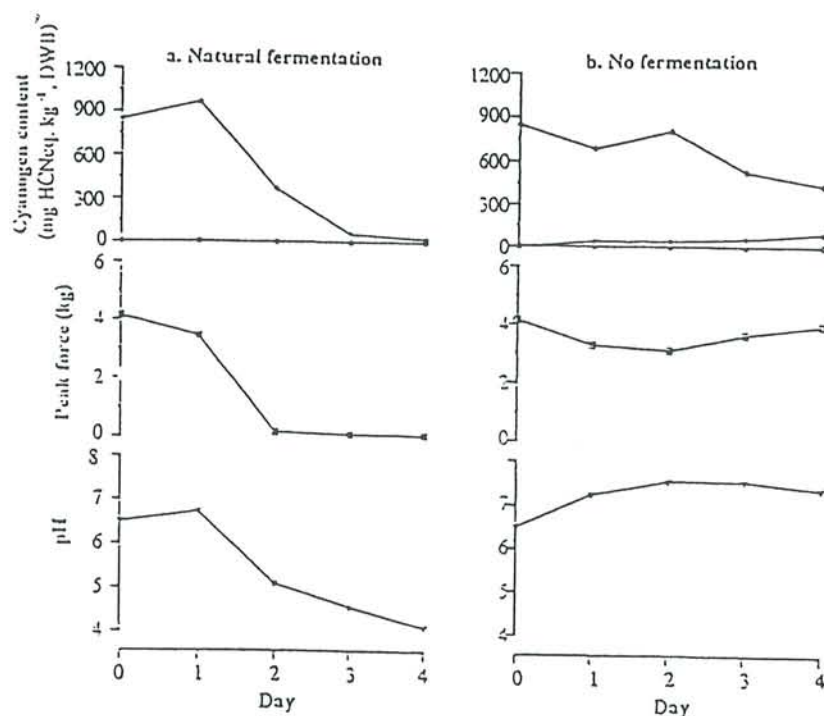

Figure 2 Changes in cyanogens, root softness and pH value during (a) the natural fermentation of cassava pieces under water at 30°C and (b) the soaking of cassava pieces in an antibiotics solution at 30°C to prevent microbial growth

is essential for root softening. This was confirmed in subsequent work using irradiated root pieces soaked in sterile water.

The water surrounding the roots in the natural fermentation was analysed (*Figure 3*) and, after making allowances for the samples removed and water absorbed by the cassava, it was calculated that after 3 days the linamarin concentration of the water was equivalent to more than 30% of the initial cyanogen content in the roots. A proportion of the cyanogens could not be accounted for in the water or the cassava roots and this loss was attributed to a hydrolytic breakdown of linamarin to acetone cyano-hydrin and the subsequent decomposition of the cyanohydrin to HCN at neutral pH values. The mech-anisms of cyanogen loss during soaking cassava roots under water are therefore complex, but clearly micro-bial growth is important: contributing to leaching through cellular breakdown and releasing cellular contents facilitating hydrolytic breakdown of lina-marin. There is therefore some potential for improving the fermentation to ensure efficient cyanogen reduction or speed up the process. This could include manipulation of fermentation condi-tions to promote the growth of desirable microorgan-isms or potentially some form of simple starter culture technology.

Solid substrate fermentation
Air fermented cassava products, where fresh cassava is covered with leaves for a number of days to encourage mould to grow prior to sun drying, include products such as dark moulded cassava flour (Essers and Nout, 1989) and Tanzanian *udaga* (Mlingi *et al.*, 1993). The microflora of the mould fermentation commonly include *Neurospora sitophila*, *Geotrichum candidum*, *Rhizopus oryzae*, *Aspergillus fumagatus* and *Mucor racemosis* (Essers, 1994). Green spots of *Peni-cillium* spp. and *Aspergillus* spp. only occur occasion-ally. Work in Uganda (Essers, 1994) has shown that the processing involving fermentation is able to reduce initial levels of cyanogens from 231–559 mg CN equivalents/kg dry weight to 8–41 mg CN equiva-lents/kg dry weight in the final flour.

Essers (1995) was able to demonstrate in labora-tory studies that there was a good correlation between microorganisms with good root softening capabilities and their ability to efficiently reduce cyanogens in sterile cassava pieces irrespective of the ability to hydrolyse linamarin. For example, *Neuro-spora sitophila* caused significant root softening and cyanogen reduction, but had no linamarase activity. In contrast, *Mucor racemosis* and *Bacillus* spp. had high levels of linamarase activity, but hardly softened roots and were less effective at linamarin reduction in root tissue. The ability of organisms to break down cellular structure facilitating the contact between lina-marin and endogenous linamarse, is therefore the key role of microorganisms. Provision of the conditions which favour the growth of the desired microorgan-isms or the use of starter cultures are potential approaches to ensuring the efficiency of the process.

Summary
Table 2 summarises the effects of fermentation on the cyanogens in cassava. This information will be used in the general discussion of the role of fermentation in reducing toxic compounds.

Other anti-nutritional factors

Cyanogenic glucosides are only one of many anti-nutritional compounds in foods that fermentation can have an effect upon. Lorri (1995) considers a number of these in relationship using fermentation as a means of enhancing nutritional value of raw materials. For the sake of completeness, the anti-nutritional factors are very briefly considered here.

The main anti-nutritional compounds of interest in plant foods are phytate, tannins, saponins, oxalates, lectins and enzyme inhibitors. An excellent review has also been written by Reddy and Pierson (1994). The information presented by them has been summarised in *Table 3*. The mechanisms involved in phytate reduction are well understood. The concentrations of other anti-nutritional factors are reduced during the preparation of fermented foods, but in general the mechanisms involved and the roles of microorganisms are poorly understood. Reddy and Pierson (1994) concluded their review by stating that 'Further
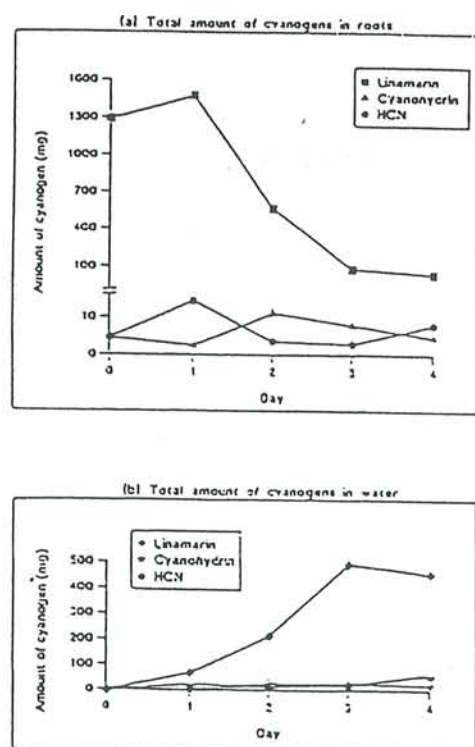

Figure 3 Changes in cyanogen levels of (a) cassava roots and (b) surrounding water during natural fermentation at 30°C. Levels of cyanogens represent HCN equivalents in the whole system (3.8 kg of roots plus water at a ratio of 1:1.38)

Table 2 Summary of mechanisms of cyanogen reduction during fermentation of cassava

Type of fermentation	Role of fermentation on reducing cyanogens	Mechanism of cyanogen reduction	Potential improvements to fermentation	Other potential improvements
Acidic fermentation of grated roots	None	– Mechanical grating brings linamarase into contact with linamarin – Acid stabilises cyanohydrin	– None required for linamarin hydrolysis – Organisms with hydroxynitrile lyase activity	– Ensure varieties have high linamarase activity – Ensure efficiency of grating – Develop suitable post fermentation processing techniques to remove cyanohydrins plus HCN
Acidic fermentation of soaked roots	Major	Microorganisms cause cellular breakdown which facilitates leeching and probably contact between linamarin and endogenous linamarase	– Use of conditions favourable to growth of microorganisms with ability to breakdown cellular structure – Potentially use of starter cultures with cell wall degrading activity – Potentially use of organisms with hydroxylnitrile lyase activity	– Ensure varieties have high linamarase activity – Ensure sufficient time is left for leaching
Solid substrate fermentation	Major	Microorganisms cause cellular breakdown which facilitates contact between linamarin and endogenous linamarase	– Use of conditions favourable to growth of microorganisms with ability to breakdown cellular structure – Potentially use of starter cultures with cell wall degrading activity	– Ensure varieties have high linamarase activity – Ensure sufficient time for diffusion of HCN

research should be directed towards the search for other strains of bacteria, moulds or yeasts that can eliminate anti-nutritional and toxic components in food during fermentation'. Perhaps this could be qualified by stating that the mechanism by which anti-nutritional factors are reduced during food processing should be better understood and the key processes involved in reducing anti-nutritional factors should be optimised. Fermentation could be improved where it plays a role. Where the other processes cannot be improved then there is some justification for trying to expand the role of fermentation to select for, or introduce microorganisms that have the ability to reduce anti-nutritional factors.

TOXINS PRODUCED DURING FERMENTATION

This review has primarily focused on the effect of fermentation on toxic compounds in foods. There are however a small number of toxins that can be produced during fermentation. These include biogenic amines and ethyl carbamate.

Biogenic amines

Biogenic amines of toxicological significance include histamine, putrescine, cadaverine, tyramine, b-phenyl-ethylamine and tryptamine (Stratton et al., 1991). They are principally formed by microbial decarboxyl-ases, enzymes possessed by the lactic acid bacteria and Enterobacteriace. The most widely studied of the biogenic amines is histamine, which is heat stable and will survive normal cooking temperatures. In a study (Nout et al., 1994) on the presence of biogenic amines in kenkey, a lactic fermented maize product from Ghana, the total amine levels were very low (60 ppm), but were increased tenfold on the addition of cowpeas. Red and white cowpeas were added to obtain products with increased protein content. The increase was attributed to the addition of precursor amino acids in cowpeas and possible presence of polyphenols in the seed coats, that could have inhibited decarboxylases. Prolonged cooking of ken-key contributes only marginally to lowering amine levels (Nout et al., 1994). Histamine toxicity has been widely reported following the consumption of poorly handled scombroid fish but has not been reported in fermented fishery products.

Ethyl carbamate

Ethyl carbamate, a carcinogen, can be produced in some fermented foods by the reaction of naturally occurring urea and carbamyl phosphate with ethanol (Ough, 1976). Their presence has been reported in such products as soy sauce (Hasegawa et al., 1990). Nout et al. (1994) studied the occurrence of ethyl carbamate in kenkey and found levels to be insignificant, concluding that the absence was most likely due to inadequate levels of ethanol and/or precursors such as citrullen, arginine or urea in the products. Fermented foods free from these compounds are unlikely to pose food safety risks from ethyl carbamate.

Table 3 Summary of the effects of fermentation on the anti-nutritional factors present in plant foods

Toxic component	Commodities in which present	Effect on humans	Mechanism of reduction during preparation of fermented foods	Reduced during fermentation	Mechanism	Comment
Phytate	Cereal grains, legumes and some root and tuber crops	Decreases bio-availability of minerals and solubility, functionality and digestibility of proteins.	A mixture of endogenous phytase activity and microbial phytase.	Significant reductions have been reported.	Hydrolysis by phytase (also role for endogenous phytases)	Role of fermentation relative to other processing techniques not considered important. Mechanisms during fermentation poorly understood.
Tannins	Food grains and legumes	Interact with proteins resulting in inactivation of digestive enzymes and also decrease protein digestibility. Contribute to decreased iron absorption.	Main mechanism of reduction is by dehulling and cooking (for example, 100% loss during tempe preparation).	Small reductions associated with fermentation have been reported (for example 10% reduction during 9 h fermentation of rabadi).	Activity of endogenous polyphenol oxidase or fermenting microflora.	
Oxalates	Little known about content in many cereals, legumes and their products	May interfere with calcium metabolism	Not known. Preparation of dawadawa from locust bean resulting in a 42.9% reduction, but relative roles of soaking, dehulling, washing and fermentation unknown.			Antinutritional and chronic problems caused by consumption of fermented plant foods is minimal.
Lectins	Legumes	Highly toxic, binding specific sites on epithelial cells preventing nutrient uptake.	Heat labile and so can be detoxified by cooking prior to fermentation.	Where not cooked first lectin activity may remain after fermentation. May be some contribution from fermentation.	Strain of *Leuconostoc mesenteroides* has been isolated with a range of enzymes active in lectin hydrolysis.	
Saponins	Legumes and cereals	Virtually non-toxic, may cause growth inhibition.	Fermentation reported to reduce concentration.	Significant reductions reported during tempe fermentation (55.8%).	Not reported.	
Enzyme inhibitors, for example trypsin inhibitors	Legumes	Cause growth inhibition by a number of methods including interfering with protein digestion.	A mixture of processing techniques including cooking, fermentation and steaming. Few are 100% effective.	Various reports exist. 47% reduction during tempe fermentation has been reported.	Hydrolysis is probably the main mechanism.	

Prepared from information presented in Reddy and Pierson (1994).

RESEARCH AND DEVELOPMENT ISSUES FOR THE FUTURE

Future research and development work should focus on several areas. These are summarised and discussed below.

Strategic research on the relationship between fermentation and the reduction in toxic compounds

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. There are many examples in the literature where microbial growth (fermentation) has been associated with a certain set of biochemical changes, but in reality there was no such relationship. For example, it was commonly assumed that the fermentation step in *gari* processing was responsible for reducing cyanogens, but in reality it played no role (Westby and Choo, 1994). To understand the mechanisms by which changes are occurring enables the rational development of improved processes and can save the misdirection of research effort. For example, there would be no advantage in developing starter cultures with linamarase activity for the fermentation of grated roots.

Research to understand the dynamics of fermentations and how they can be manipulated

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. The same principles could be employed on other aspects of food safety related to food fermentations, such as the inhibition of pathogenic bacteria (for example Westby, 1989). A simple application of this approach might be that the manipulation of moisture content during the solid substrate fermentation of cassava may promote the growth of desirable fungi able to break down the structure of cassava, thereby facilitating the hydrolysis of linamarin by endogenous linamarase.

Appropriate starter culture technologies

The provision of starter cultures is an issue commonly raised in relation to fermented foods in developing countries. There are three main simple, low-cost, technologies: natural inoculation, transfer of an old batch of fermented product to a new batch (back-slopping), and indigenously derived starter cultures (such as those for *tempe* and *tape*; Steinkraus, 1983).

The development of specific starter cultures with desirable properties needs careful consideration. The following should be considered:

- there should be good evidence that microbial activity is responsible for the desired changes (for example, there would appear to be no advantage in developing starter cultures for any of the cassava fermentations with high linamarase activity because this is not the principal mechanism by which linamarin is reduced. The action of endogenous linamarase appears sufficient).
- there should be appropriate technologies for disseminating and propagating cultures. Without these technologies, it is likely that research effort will be wasted.
- cultures should be developed for characteristics that are considered important by consumers. It is unlikely that consumers would use a starter if there was no apparent benefit to them.
- the economics of the use of the starter culture should be assessed.

Novel methods for reducing toxic compounds using fermentation

The two approaches so far described (manipulation of fermentation conditions and use of starter cultures) for the improved utilisation of fermentation have their limitations and problems. An alternative approach is to develop microorganisms with desirable properties that are very competitive in the processing environment. An example would be a specific lactic acid bacterium with the gene for hydroxynitrile lyase activity inserted, and hence with the ability to catalyse the breakdown of acetone cyanohydrin in the *gari* fermentation (see *Table 2*). Being competitive, the organism would persist in the processing environment without the need for repeated use of a starter culture.

The need to understand consumer perceptions

The ability of research and/or development programmes to improve and disseminate information on improved methods of household level fermentation to improve food safety will very much depend on consumers' perceptions of the problem. Where consumers have a good perception of the importance of fermentation the task is much easier. This is often the case with cassava cyanogens where 'bitterness' is often recognised as a problem and people treat 'bitter' (high cyanogen varieties) and 'sweet' (low cyanogen varieties) in different ways.

Where consumers have no perception of the potential hazards that might exist (or it exists sporadically), then the prospects for using household level fermentation are far more limited and rely very heavily on a supporting education programme. This is specifically the case for mycotoxins, where currently the effects of fermentation are not absolutely clear, where they may not always be present on the raw material and where consumers may not always perceive that there is a problem.

The need to consider food safety as one issue amongst others

As mentioned in the introduction to this paper and discussed elsewhere (Jones et al., 1992), there are many reasons for fermenting foods. Food safety, and specifically the reduction in toxic compounds, represents only one of the reasons why people will choose to use fermentation. The relative emphasis given to each of these different reasons by processors and consumers will vary greatly for many reasons including the product, tradition, previous experience, level of education and socio-economic circumstances. Clearly some overlap with each other, for example, some of the cassava fermentations facilitate cyanogen reduction, provide a means of food preservation and provide income generating opportunities for processors.

For the maximum impact to be made on food safety, it is important to understand the choices made by consumers and determine how food safety can be worked into the overall system.

The need to consider fermentation as one processing technique amongst others in ensuring food safety

It is important to remember that fermentation alone cannot be used to ensure food safety. The probability is that fermentation is only one technique amongst several in a processing operation. Other unit operations such as dehusking, washing, peeling, or cooking may also contribute significantly to the overall safety of a food. An example of this is in gari processing where the final roasting step ensures microbiological safety and stability and also volatalizes a high proportion of the remaining cyanogens.

The need to consider how food fermentations will develop in the future

The nature of food processing and marketing chains in rural and urban populations in developing countries is related to the stage of development, levels of income and socio-cultural characteristics of different population groups. It is therefore difficult to make generalisations on the future role of fermented foods in development. Many issues affect the uptake of new technologies within this vast diversity of situations.

Rural–urban migration is one of the major problems facing many countries, particularly in Africa. Over 40% of the world's population will live in urban environments by the end of the century. Traditional food processing systems will have to adapt to the consequences of urbanisation. The type of adaptation necessary will be dictated by the nature of the food raw material; for example commodities that can be stored, such as maize and rice, can be transported to urban centres and processed, whereas root crops, such as cassava, are difficult to transport and store poorly, and as such are better processed close to the area of production.

People in urban centres still demand traditional foods made from locally grown crops. Such consumption patterns should be encouraged as they are sustainable and avoid dependence on imported materials. The processing of many traditional foods involves fermentation and urban demand may result in increased industrialisation of traditional food processing. Industrialisation has many advantages such as standardised products, safer foods, longer storage life due to packaging, and convenience foods. Some indigenous fermented foods such as soy sauce, fish sauce, gari and sorghum beer are produced on an industrial scale. With increased urbanisation, consumer demand will probably result in a requirement for foods of a consistent quality that are more convenient to use in the home. Food safety in the widest sense, including the absence of toxic compounds, will become a more important issue as commercial producers compete for market share.

In cases where rural production of traditional food supplies urban areas, the income generated may help stem migration to urban centres. In such cases, the needs of rural processors who are predominantly women, need to be addressed. This may involve reducing their workload or increasing turnover of materials and releasing finance by, for example, speeding up fermentations. Food safety will become increasingly important in these scenarios.

CONCLUSION

Fermentation currently plays a major role in improving food safety with respect to toxic compounds in raw materials. It has the potential to play a much greater role and a number of opportunities are identified in this review. However there are a number of issues to be considered to ensure that research and development effort is not wasted whilst the real opportunities are identified and capitalised upon.

ACKNOWLEDGEMENTS

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