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.

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 Kanitha (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       | Natural with B$_1$                  | None                        | Jesperson et al. (1994) |
| Aflatoxin                                    | Sorghum/ogi      | Lactic acid       | Spiked with B$_1$                   | 12–16%                      | Dada and Muller (1983) |
| Aflatoxin                                    | Wheat/bread      | Yeast (dough)     | Natural with M$_1$                  | 19%                         | El Banna and Scott (1983) |
| Aflatoxin                                    | Milk/yoghurt     | Lactic acid       | As above                           | None                        | Wiseman and Marth (1983) |
| Aflatoxin                                    | Milk/kefir       | Lactic acid       | Spiked with D$_1$, D$_2$, G$_3$, G$_4$, M$_1$, and G$_1$ | Decreased                   | Blanco et al. (1993) |
| Aflatoxin                                    | Milk/yoghurt     | Lactic acid       | Natural with B$_1$, and G$_1$      | Complete removal after 4 days | Ogunsanwo et al. (1989) |
| Aflatoxin                                    | Melon seed/ogiri | Bacillus spp.     | Not stated                          | 50% and 70% respectively    | Steinkraus (1983) |
| Aflatoxin                                    | Peanut press cake/ pure mould cultures | Neurospora sitophila and Rhizopus oligosporus | Not stated | Greater than 70% | Adegoke et al. (1994) |
| Aflatoxin                                    | Maize/ogi Sorghum/ogi | Lactic fermentation | Natural with B$_1$ | Reduction greater than 50% by all tested strains | Holzapfel (1995) |
| Alternariol and Alternariemrnono- methylether | Pure culture isolates from kenkey | Lactic acid bacteria | Spiked laboratory media | | |
Other mycotoxins

The biological detoxification of several other mycotoxins has been demonstrated, in particular, sterigmatocystin, ochratoxin A, patulin, rubratoxin, zearalenone, T-2 toxin, deoxynivalenol and diacetoxyscirpenol (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, deoxynivalenol 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 responsible 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 understood, 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 cyanogenic glucosides can be hydrolysed to the corresponding ketone and glucose by the endogenous enzyme linamarase when cellular damage occurs (de Bruijn, 1973; Narrey, 1978). Cyanohydrins break down non-enzymically 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 cyanohydrin 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 exposure 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 fermentation (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 preparation 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 separated 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 endogenous 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 cyanohydrin, 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 linamarase activity for grated root fermentations (Westby and Twiddy, 1992b). This has been confirmed by the work of Giraud (1993) where a Lactobacillus plantarum isolate with high linamarase activity was inoculated into a grated root fermentation and there was...
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Natural fermentation of cassava at 30°C

Irradiated grated cassava incubated at 30°C

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 jüji (Westby and Twiddy, 1992b) and konدولоле 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 cyanohydrin and the subsequent decomposition of the cyanohydrin to HCN at neutral pH values. The mechanisms of cyanogen loss during soaking cassava roots under water are therefore complex, but clearly microbial growth is important: contributing to leaching through cellular breakdown and releasing cellular contents facilitating hydrolytic breakdown of linamarin. 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 conditions to promote the growth of desirable microorganisms 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 flavus and Mucor racemosus (Essers, 1994). Green spots of Penicillium spp. and Aspergillus spp. only occur occasionally. 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 equivalents/kg dry weight in the final flour.

Essers (1995) was able to demonstrate in laboratory 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, Neurospora sitophila caused significant root softening and cyanogen reduction, but had no linamarase activity. In contrast, Mucor racemosus 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 linamarin and endogenous linamarse, is therefore the key role of microorganisms. Provision of the conditions which favour the growth of the desired microorganisms 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
### Table 2 Summary of mechanisms of cyanogen reduction during fermentation of cassava

<table>
<thead>
<tr>
<th>Type of fermentation</th>
<th>Role of fermentation on reducing cyanogens</th>
<th>Mechanism of cyanogen reduction</th>
<th>Potential improvements to fermentation</th>
<th>Other potential improvements</th>
</tr>
</thead>
</table>
| Acidic fermentation of grated roots | None | - Mechanical grating brings linamarase into contact with linamarin  
- Acid stabilises cyanohydrin | - 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 hydroxynitrile lyase activity | - Ensure varieties have high linamarase activity  
- Develop suitable post fermentation processing techniques to remove cyanohydrins plus HCN  
- Ensure sufficient time is left for leaching |
| Acidic fermentation of soaked roots | Major | Microorganisms cause cellular breakdown which facilitates contact between linamarin and endogenous linamarase | - Ensure varieties have high linamarase activity  
- Ensure sufficient time for diffusion of HCN |
| 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 |

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-phenylethylamine and tryptamine (Stratton et al., 1991). They are principally formed by microbial decarboxylases, enzymes possessed by the lactic acid bacteria and Enterobacteriaceae. 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 kenkey 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 citrulline, arginine or urea in the products. Fermented foods free from these compounds are unlikely to pose food safety risks from ethyl carbamate.
<table>
<thead>
<tr>
<th>Toxic component</th>
<th>Commodities in which present</th>
<th>Effect on humans</th>
<th>Mechanism of reduction during preparation of fermented foods</th>
<th>Reduced during fermentation</th>
<th>Mechanism</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phytate</td>
<td>Cereal grains, legumes and some root and tuber crops</td>
<td>Decreases bio-availability of minerals and solubility, functionality and digestibility of proteins.</td>
<td>A mixture of endogenous phytase and microbial phytase.</td>
<td>Significant reductions have been reported.</td>
<td>Hydrolysis by phytase (also role for endogenous phytases).</td>
<td></td>
</tr>
<tr>
<td>Tannins</td>
<td>Food grains and legumes</td>
<td>Interact with proteins resulting in inactivation of digestive enzymes and also decrease protein digestibility. Contribute to decreased iron absorption.</td>
<td>Main mechanism of reduction is by dehulling and cooking (for example, 100% loss during tempe preparation).</td>
<td>Small reductions associated with fermentation have been reported (for example 10% reduction during 9 h fermentation of rabadi).</td>
<td>Activity of endogenous polyphenol oxidase or fermenting microflora.</td>
<td>Role of fermentation relative to other processing techniques not considered important. Mechanisms during fermentation poorly understood.</td>
</tr>
<tr>
<td>Oxalates</td>
<td>Little known about content in many cereals, legumes and their products</td>
<td>May interfere with calcium metabolism</td>
<td>Not known. Preparation of dawadawa from locust bean resulting in a 42.9% reduction, but relative roles of soaking, dehulling, washing and fermentation unknown.</td>
<td></td>
<td></td>
<td>Antinutritional and chronic problems caused by consumption of fermented plant foods is minimal.</td>
</tr>
<tr>
<td>Lectins</td>
<td>Legumes</td>
<td>Highly toxic, binding specific sites on epithelial cells preventing nutrient uptake.</td>
<td>Heat labile and so can be detoxified by cooking prior to fermentation.</td>
<td>Where not cooked first lectin activity may remain after fermentation. May be some contribution from fermentation.</td>
<td>Strain of <em>Leuconostoc mesenteroides</em> has been isolated with a range of enzymes active in lectin hydrolysis.</td>
<td></td>
</tr>
<tr>
<td>Saponins</td>
<td>Legumes and cereals</td>
<td>Virtually non-toxic, may cause growth inhibition.</td>
<td>Fermentation reported to reduce concentration.</td>
<td>Significant reductions reported during tempe fermentation (53.8%).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enzyme inhibitors, for example trypsin inhibitors</td>
<td>Legumes</td>
<td>Cause growth inhibition by a number of methods including interfering with protein digestion.</td>
<td>A mixture of processing techniques including cooking, fermentation and steaming. Few are 100% effective.</td>
<td>Various reports exist. 47% reduction during tempe fermentation has been reported.</td>
<td>Hydrolysis is probably the main mechanism.</td>
<td></td>
</tr>
</tbody>
</table>

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; Steinkrus, 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.

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REFERENCES


Kaniththa, S. (1990) Kan khat luak chuara ti sai lai san aflatoxin (Degradation of aflatoxin by selected molds) Report, Kasetsart University, Bangkok, Thailand. [Taken from English translation of abstract]


Westby, A. and Choo, B.K. (1994) Cyanogen reduction during the

and fu-fu preparation procedures in Nigeria. *World Journal of
Microbiology and Biotechnology* **8**, 1155–1182

Westby, A. and Twiddy, D.R. (1992a) Role of microorganisms in
the reduction of cyanide during traditional processing of
African cassava products. In *Proceedings of a Regional
Workshop on Traditional African Foods – Quality and Nutrition

in yogurt, buttermilk and kefir. *Journal of Food Protection* **46**,
115–118