FEMS Microbiology Reviews 46 (1987) 369–379
Published by Elsevier

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Lactic-acid fermentation as a low-cost means of food preservation in tropical countries *

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Key words: Food preservation; Lactic acid bacteria; (Fish); (Cassava); (Meat); (Tropical countries)

1. SUMMARY

The range of traditional lactic-acid-fermented foods in tropical countries is briefly reviewed. Recent studies on the lactic acid fermentation of fish and cassava products are described. Lactic-acid-fermented fish products may offer considerable scope for the development of new food products and for the use of under-utilised fish species. Lactic-acid-fermented fish products are common in parts of Asia; methods to improve the product and shelf-life quality, to reduce microbial risks and to accelerate the process are described. This work is based on fish/salt/carbohydrate model systems. The nutritional aspects of cassava fermentation are discussed with respect to factors involved in determining residual cyanide levels; the possible anti-nutritional rôle of condensed tannins is mentioned. The increasing consumption of meat products in tropical countries emphasises the need for a preservation method that does not depend on refrigeration. The possible production of sausage ingredients preserved by lactic acid fermentation, and the associated research needs are described.

2. INTRODUCTION — SURVEY OF ACID-FERMENTED FOODS IN THE TROPICS

Lactic acid fermentation of foods is common in tropical countries because the following benefits are intrinsic to this process.

(i) A low-cost method of food preservation; spoilage and pathogenic microorganisms are inhibited by a combination of pH reduction, a lowering of oxidation-reduction potential, competition for essential nutrients and the production of inhibitory compounds—antibiotic compounds and hydrogen peroxide.

(ii) Improved organoleptic qualities.

(iii) In some cases the nutritional value or the digestibility of the raw material is increased.

The cost and infrastructural requirements of many of the food preservation methods (e.g., refrigeration, freezing, canning, irradiation) used in developed countries greatly restrict their application in the developing world. The high ambient temperatures of the tropics heighten the need for low-cost preservation methods such as salting, drying and traditional fermentations. This is the primary motive for acid fermentation of the perishable substrates (vegetables, root crops, dairy products, fish and meat). The most common categories of acid-fermented foods in the tropics are indicated in Table 1.

Fermented foods produced in developed countries are produced under controlled conditions. Starter cultures are often used to achieve uniform

* Presented at the Second Symposium on Lactic Acid Bacteria —Genetics, Metabolism and Applications, 22–25 September 1987, Wageningen, The Netherlands.

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products. In the dairy industry the raw material is pasteurised prior to starter addition. In other fermentations, close control of environmental conditions achieves consistent quality (sauerkraut, olives, etc.). In the tropics production is usually home-scale; the procedures have developed from natural fermentations with traditional techniques selecting a particular lactic flora by means of substrate composition and back-slopping, i.e., inoculation from earlier batches [1–3]. The composition of the substrate mixtures and of the procedures used for apparent similar products varies considerably. Steinkraus' Handbook of Indigenous Fermented Foods [2] reviews this diversity and Stanton [4] has recently provided an historical perspective.

Improvements in acceptability (and nutritional value) rather than preservation are the principal reason for lactic acid fermentation of cereals [5]. Muller [6] reviewed several traditional African fermentations of millet, sorghum and maize. *Ogi* is one such product which is obtained as a wet corn starch cake which may be eaten as a paste or mixed with boiling water to form a porridge.

Table 1

Traditional fermented foods in the tropics

Categories of acid-fermented products with representative examples

(I) Starchy substrates (cereals and root crops)		
(A) Porridges and gruels		
(i) maize (also millet, sorghum)	Nigeria	ogi
	Kenya	uji
	Ghana	kenkey
	S. Africa	mahewu
	Mexico	pozol
(ii) cassava and root crops	W. Africa and Central Africa	gari
	N. Brazil	farinha de mandioca
	Hawaii and Pacific Islands	poi (from taro)
(B) Acid-leavened breads and similar products		
(i) rice	Philippines	puto
	Sri Lanka	appa
(ii) rice-legume mixtures	India	idli, dosai
(iii) tef (Eragrostis tef)	Ethiopia	enjera
(iv) sorghum	Sudan	kisra
(II) Vegetables		
(i) leafy vegetables	Korea	kimchi
	Thailand	pak-sian
	China	hum-choy
(ii) vegetables/unripe fruit	Malaysia	(pickles, etc.)
	Egypt	(pickles, etc.)
(III) Dairy products		
(i) milk	India/Pakistan	dahi, yoghurts
	Egypt	leban rayeb, yoghurt
	Malaysia	yoghurt
(ii) milk-cereal mixtures	Egypt/Middle East	kishk
	Greece/Turkey	tarhana
	India	rabdi
(IV) Fish and meat		
(i) fish	Philippines	burong isda
	Thailand	pla-som, som-fak
(ii) meat	Thailand	nham
	Mexico	chorizo

Lactic acid bacteria (LAB) and *Saccharomyces rouxii* are reported as the key micro-flora. *Pozol* is a similar Latin American product made of fermented maize which is previously cooked with lime. Viniegra-Gonzalez [8] recently reviewed the rôle of LAB in this process which is associated with an improvement in nutritional value. *Poi* is prepared by the lactic acid fermentation of taro (*Colocasia esculenta* C.) and is an important food in the South Pacific. *Idli* is a protein-rich steamed bread common in India [2]. Rice and black gram *dhal* (usually in a mixture of 3 : 1) are soaked separately in water for 3–10 h before grinding into a paste. The two pastes are mixed with salt (1%) and water to make a batter (2 : 1, water : paste) and allowed to ferment at 25–30 °C for 14–16 h. *Lactobacillus mesenteroides* is the dominant organism; in the later stages of fermentation *Streptococcus faecalis* and still later *Pediococcus cerevisiae* become significant. Other workers have isolated yeasts which they claim are necessary for effective fermentation (*Torulopsis candida* and *Trichosporon pullulans*), although they would not cause the observed pH change.

Puto is similar to *idli* except that it does not contain legume. *Puto* is consumed daily in many parts of the Philippines as a breakfast or snack food. The predominant microorganisms are reported [2] to be *L. mesenteroides* followed by *S. faecalis* and then *Saccharomyces cerevisiae.* A small amount of sugar is added during the fermentation. This and the yeast interaction is the major difference between *puto* and *idli. Enjera,* i.e., fermented tef is a staple food in Ethiopia. Little work has been done on the microbiology of fermentation which is thought to involve a bacterial-yeast combination. *Kisra,* the most popular bread in Sudan, appears to depend for its successful fermentation on a combination of lactobacilli, *Acetobacter* and *S. cerevisiae* [2].

The processing of cassava into fermented, dried products (e.g., gari and farinha) has the benefit of improved nutritional value i.e., reduced cyanide content (see section 4) and improved acceptability, and also generates a stable product from the perishable roots. Lactic acid fermentation as a low-cost preservation method is also the principal reason for the development of the food categories II to IV of Table 1. The fermented vegetables of category II are similar to the European sauerkraut and pickles [3] except that the substrates used are more diverse. For example the Korean *kimchi* is based on cabbage or radish but includes garlic, onion, ginger, pickled fish and condiment spices as minor components [2]. It usually has a lower acidity than sauerkraut.

In the developing world refrigeration facilities are usually limited and milk stored for any length of time is fermented. Indian *dahi,* Egyptian *laban rayeb* and Malaysian *tairu* are all types of sour milks or yoghurts. The milk-cereal combinations are highly nutritious foods. *Kishk* is a popular food among the rural populations of the Middle East, based on milk-wheat mixtures. The boiled grain is dried and mixed with lactic acid-fermenting milk (usually 2 : 1 by weight) and sun-dried. *Tarhana* is similar but based on crushed wheat and sheep's milk, whereas Indian *rabdi* derives from cooked maize flour combined with buttermilk [9].

Fish and meat products are discussed in the following sections.

3. LACTIC-ACID-FERMENTED FISH

3.1. Significance of acid-fermented fish foods

A key limitation to fish utilisation is its extreme perishability, since fish flesh offers microorganisms conditions of good nutrient availability coupled with a high water activity (a_w) and moderate pH [10]. In tropical countries the problem posed by the intrinsic suitability of fish flesh as a medium for microbial growth is further compounded by a high ambient temperature. Fish stored under these conditions is considered spoiled within 12 h [11].

The necessity in developing countries for methods of fish preservation that are low-cost has reduced the applicability of technologies such as chilling, freezing and canning. Traditional curing processes that depend upon the reduction of a_w as the principal preservative factor [12] are important, e.g., salting, drying, smoking. Traditional fermented fish products are also particularly popular in S.E. Asia. As commonly applied, the term fermented fish covers two categories of product [13]: (i) fish/salt formulations, e.g., fish sauce; and (ii) fish/salt/carbohydrate mixtures, e.g., *pla-ra* in Thailand and *burong-isda* in the Philippines.

These categories do not, however, comprise a series of well-defined products with precise and generally accepted compositions. A single title can encompass a wide range of recipes. This reflects the fact that, apart from the fish sauces, they are usually produced on a small scale by numerous individuals.

Fermented fish products have been reviewed periodically, the focus usually being on the first category of product, i.e., the more widely used fish sauces and pastes [14,15]. In the second category lactic acid fermentation occurs and contributes to the extended shelf-life. There are many examples of this type of fermentation common in S.E. Asia [13,16]. This category may offer considerable scope for the introduction of new products and for the use of under-utilised fish species. Lactic-acid-fermented products can be prepared in a shorter time (and hence more cheaply) than the fish/salt products which depend primarily on autolytic processes. Their lower salt contents also permit them to be consumed as a main course, rather than in the condiment rôle of the high-salt fish sauces and pastes. This suggests that the lactic-acid-fermented products offer greater scope for low-cost fish preservation in S.E. Asia than the simply low a_w products. However, this potential is limited by the currently variable organoleptic quality and shelf-life of these products. The principal carbohydrate source used in these traditional lactic-acid-fermented products [13] is cooked rice, although in some products partially saccharified rice (mouldy rice: *ang-kak,* or prefermented rice) is used or, on occasion, small amounts of cassava flour, or cooked millet, e.g., *sikhae* in Korea [17].

Table 2 summarises the fish/salt/carbohydrate derived foods common in Thailand. *Pla-ra* is the most popular of the lactic-acid-fermented fish products of Thailand, and can be consumed as a condiment or side dish. In appearance it ranges from a dark brown, turbid liquid to partly dried, brown fish pieces and there is a marked regional variation in the preferred type. In N.E. Thailand a more liquid product is preferred and brine rather than dry-salting is often used in its preparation. The liquid is used as a flavouring agent in dishes such as *tam-som* where it is mixed with raw papaya. In Central Thailand a drier product is sold and it is the fish pieces that are eaten.

Analysis of *pla-ra* samples from different parts of Thailand showed that the pH and titratable acidity (expressed as lactic acid) ranged between 4.7–6.2 and 0.4–3.2%, respectively. This indicates one of the problems of this type of product, i.e., variable quality. This, together with occasional spoilage problems are thought likely to be responsible for the currently less important economic rôle of the lactic-acid-fermented fish products (Table 2) compared with the salt-preserved products referred to above.

Som-fak is different to most of the other Thai fermented fish products in that minced fish is

Table 2

Fish/salt/carbohydrate products of Thailand [a] (from [13])

No.	Name	Composition	Preparation time	Shelf-life
(1)	Pla-ra	Fish (whole or pieces) : salt : roasted rice, 3 : 1 : 0.2–4	6–12 months	1–3 years
(2)	Pla-jao	Fish (pieces) : salt : khao-mark (fermented rice), 3 : 1 : 1–3	10–20 days	2–3 months
(3)	Pla-som	Fish : salt : boiled rice : garlic, 10 : 2 : 1 : 0.25–1	5–12 days	3 weeks
(4)	Pla-jom	Fish : salt : roasted rice : garlic, 10 : 1 : 3 : 1	3– 7 days	2 weeks
(5)	Som-fak	Fish (minced) : salt : rice : garlic, 10 : 0.5–1.5 : 2–3 : 1	5–10 days	2 weeks
(6)	Pla-paeng-daeng	Fish : salt : boiled rice : ang-kak [b], 3 : 1 : 3 : 0.03	5 days	6–12 months

[a] Products 1–4 are also produced using shrimps. In these cases the prefix 'pla' is replaced by 'kung'.
[b] Ang-kak, red mould rice obtained by fermenting rice with *Monascus purpureus.*

used, rather than fish pieces or whole fish. The fish is minced into a sticky paste with salt (estimates of the salt addition vary from around 1–3% up to 15%), cooked rice (2–20%), garlic (4–10%) and sometimes cassava flour. The mixture is squeezed into polythene bags (traditionally banana leaves are used) and wrapped tightly. The product is at its best after about 5 days, but can be kept up to 10 days under refrigeration.

The pH of *som-fak* ranges from 4.0–5.0, the titratable acidity from 1.1–2.8%, and the salt content from 2.5–4.8%. The latter figure suggests that the salt addition most commonly used is nearer the bottom of the range quoted above. The bacterial count was 1.3×10^7–2.8×10^9 cfu/g, *Pediococcus cerevisiae, Lactobacillus brevis,* a *Staphylococcus* sp. and a *Bacillus* sp. being isolated [18].

The lactic-acid-fermented fish in the Phillippines are known collectively as *burong-isda.* A survey of *burong-isda* products [19] showed that white products had pH values of 4.1–4.5 whereas red types were in the range 3.0–3.9. This may be due to amylolytic enzymes in *ang-kak* (see footnote to Table 2) increasing the extent of the lactic acid fermentation by increasing the availability of readily fermented sugars. The counts of acid-producing bacteria and yeasts, 10^8 and 10^7 cfu/g, respectively, were similar for both types of product. The salt contents ranged from 2.5–4.8% for white *burong-isda* and from 1.4–4.4% for the red variety.

Laboratory studies of red *burong-isda* fermentation by Orillo and Pederson [2] showed one sample to have a microbial succession similar to that reported to occur in some vegetable fermentations. A more recent study of *burong-isda* also showed a similar progression of a *Streptococcus* followed by a *Leuconostoc* and *Pediococcus* [21].

A similar sequence was noted in the case of *balao-balao* (a fermented shrimp product) by Solidum [22] although there was some doubt about the species involved.

There are many traditional fermented fish products in Korea of both the high and low salt types [17]. *Sikhae* is an example of a low salt product in which lactic acid fermentation is involved. The formulation [17] is based on flat fish (80%), cooked millet (7.5%), red pepper (9%) and garlic (3.5%). The pH decreases to 4.5 within the first 2–3 days of storage at 20 °C.

3.2. Preliminary study of parameters involved in the production of lactic-acid-fermented fish

The variable organoleptic quality and shelf-life of traditional fermented fish products (section 3.1) indicated the need to study the key fermentation parameters with the objective of improving the product and shelf-life quality, reducing the microbial risks and accelerating the process.

A minced-fish formulation analogous to the Thai product *som-fak* [13] was studied at TDRI to avoid the sampling difficulties associated with fish-piece type formulations. The addition of carbohydrate is necessary to promote a satisfactory fermentation since fish flesh is very low in free carbohydrate. Most of the traditional products use a starch-derived carbohydrate source at different (and uncertain) degrees of gelatinization and degradation. Relatively few LAB have been reported to produce amylases and it is not known whether such bacteria are involved in these traditional starch-based fermentations [16]. Consequently these preliminary studies used a fermentable carbohydrate source (glucose or sucrose) in order to permit a defined substrate availability.

3.2.1. Studies of fish-salt-glucose model system [23]

The speed and efficiency of the lactic acid fermentation was monitored by the rate of pH decrease and the balance between LAB counts and total spoiler (bacterial) counts (on Plate Count Agar). The objective was to optimise the rate of lactic acid fermentation, i.e., a rapid decrease in pH (< 4.5) within the first 48 h; a rapid proliferation of LAB with concomitant decrease in spoilage microorganism count.

Studies with *L. plantarum* and *P. pentosaceus* indicated that fermentation rates increase in the range of 0–5% w/w (of fish mince) of glucose or sucrose, whereas increasing the salt concentration from 0–6% slows the rate of pH decrease (Fig. 1). The nature of the gas atmosphere during incubation had little effect on fermentation rate. Chemical modification of the initial substrate pH with

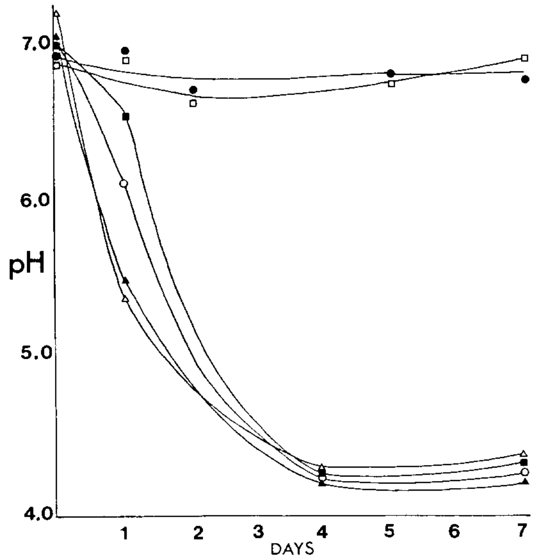

Fig. 1. Effect of sodium chloride concentration on rate of lactic fermentation of a mixture containing minced whiting, 4% w/w glucose and 0.05% w/w Lactostart (*L. plantarum*); 0% w/w NaCl (△), 1% w/w NaCl (▲), 2% w/w NaCl (○), 3% w/w NaCl (■), 4% w/w NaCl (●) and 6% w/w NaCl (□). Quantities are expressed on a w/w basis with respect to quantity of fish mince used.

lactic, acetic or citric acid did not assist the lactic acid fermentation. Incubation temperatures of 15, 24, 30 and 37°C were evaluated. The rate of pH decrease was lower at lower temperatures, but little variation was encountered in the LAB: spoiler ratio during a 7-day incubation period. The LAB count rarely exceeded the total spoiler count by more than 10-fold during the first 2 days (although it subsequently increased). The use of cooked fish minces gave only slight changes in the fermentation rate. Consequently the objective of reducing the pH to below 4.5 within the first 2 days was difficult to achieve.

One factor in this difficulty may be the balance between the initial number of competing spoilage microorganisms and the LAB inoculum. Several of the traditional lactic-acid-fermented fish products involve an initial storage of the fish in high salt concentrations [16], prior to lactic acid fermentation. This preliminary salting may promote a more rapid inhibition of spoilage microorganisms than would the immediate fermentation of fresh fish. Similarly, many starchy carbohydrate sources are good LAB substrates and use of this type of material may promote a large initial LAB inoculum. Lindgren and Pleje [24] studied the fermentation of a fish-waste cereal mixture with a high initial inoculum of LAB and obtained a rapid lactic acid fermentation. Consequently further studies involved the use of starchy substrates.

3.2.2. Studies of fish / salt / starchy substrate model system [25]

The use of rice or cassava was evaluated with or without a one-day prefermentation (prior to admixing with the fish). The use of prefermented cassava (20% w/w of fish) gave rapid reproducible fermentations; the pH decreasing to less than 4.5 and the LAB : spoiler ratio exceeding 4 log cycles within 2 days (Fig. 2).

Cassava is an excellent substrate for LAB growth and consequently cassava fermentation (which increases the initial LAB count of the mixture by about 10^2) has only a small effect on the rate of pH decrease in the fish/cassava minces. The addition of fermentable sugar (2% glucose; Fig. 2) is essential to maintain a low pH during fermentation. This is depicted in Fig. 3 which shows the effect of using a different cassava : fish mince ratio, but in the absence of added glucose. Inoculation studies with *Staphylococcus aureus* (ATCC9144), *Salmonella typhimurium* (ATCC1311), *Clostridium sporogenes* (ATCC7955) and *Escherichia coli* (ATCC11775) showed that these pathogens rapidly disappear during the fermentation [25].

3.2.3. Concluding remarks

These studies indicate methods of fish fermentation that will produce a stable, low-salt, safe product using a cheap carbohydrate source. Further work is required on the pattern of starch utilization and the fermentable sugar requirement, and about the factors determining the organoleptic properties of these products (especially the rôle of fish enzymes and autolytic changes) in the context of traditional products.

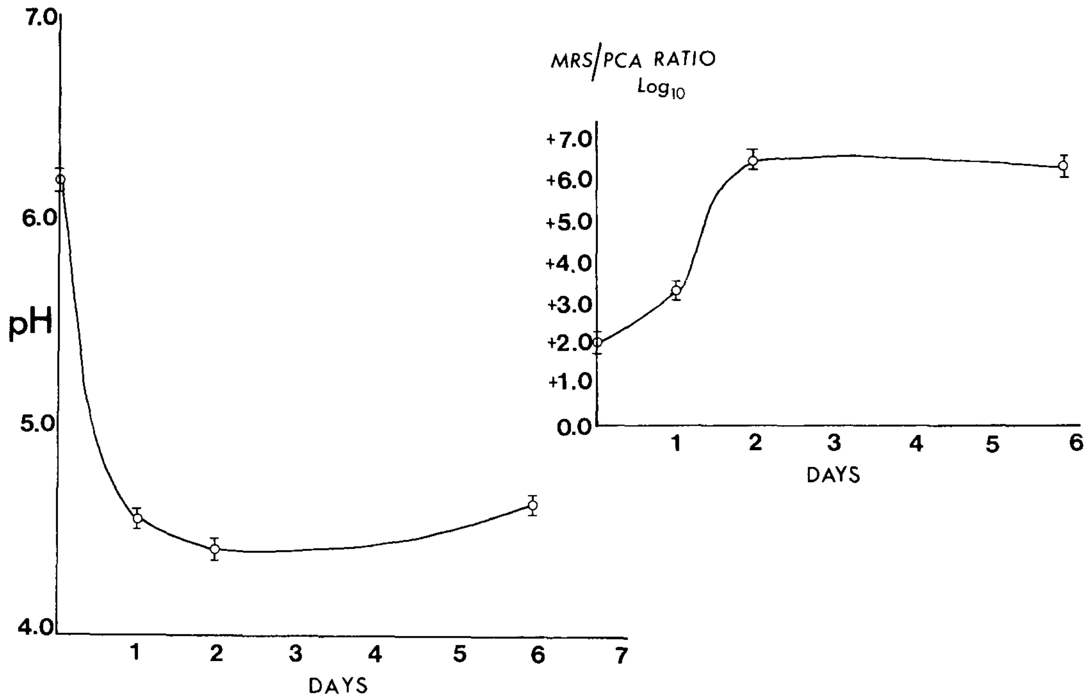

Fig. 2. Lactic acid fermentation of an 80% haddock mince:20% prefermented cassava (fresh weight basis) mix, as described in [25]. Data points are means of 6 replicate determinations; bar indicates range.

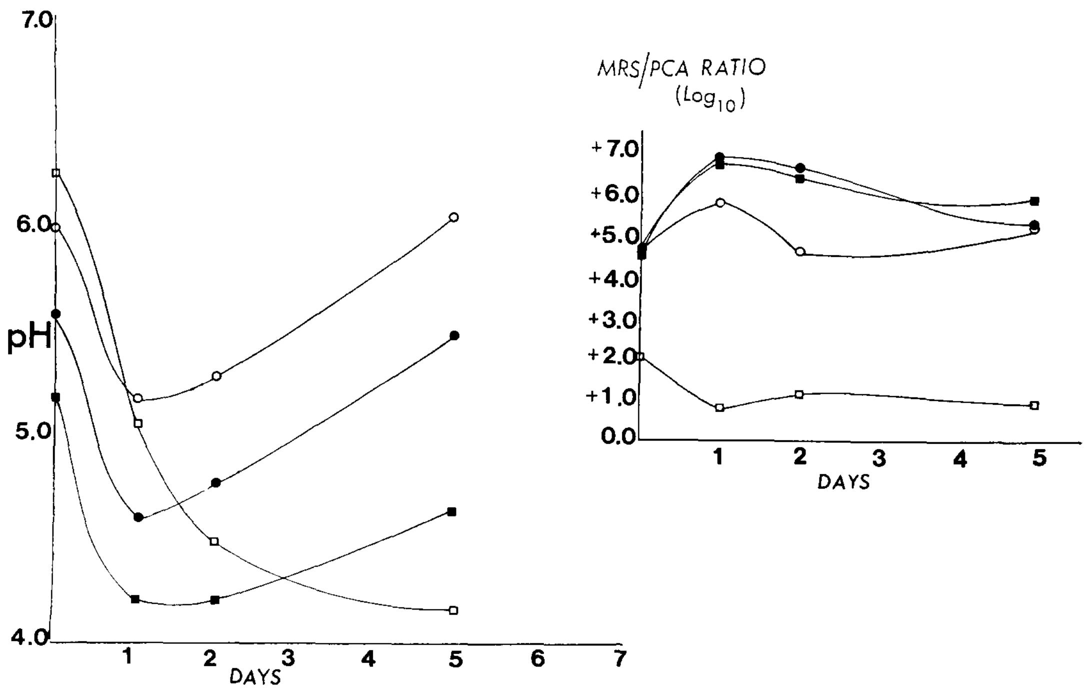

Fig. 3. Effect of different fish:cassava preparations on the rate of lactic acid fermentation, using prefermented cassava. Prefermented cassava was incorporated at 25% (○), 50% (●) and 100% (■) w/w of the haddock mince, and compared with a reference haddock mince, glucose (4%), salt (1%) mix (□).

4. LACTIC-ACID-FERMENTED CASSAVA

4.1. Introduction

The tropical root crops are important staple foods; cassava alone provides the major source of dietary calories for about 500 million people, many of them in Africa. Cassava's important rôle is a reflection of its agronomic advantages: relatively drought- and disease-resistant, ability to yield on poor soils with minimal inputs, etc. However, the perishability of this root crop (and to a lesser extent the other tropical roots and tubers) limits its utilisation and hence the realisation of its agronomic and acceptability advantages.

Lactic acid fermentation is one low-cost method of root preservation for food that has been applied in several regions, e.g., farinha de mandioca (Brazil) and gari (W. Africa, and related products in Central Africa). Commercial cassava utilisation as animal feed is based on dried cassava chips. The application of lactic acid fermentation for cassava silage as a possible alternative preservation method has been noted [8] in Mexico. Okafor [27] and Ngaba and Lee [28] have studied the LAB involved in this type of fermentation. TDRI studies have involved nutritional aspects of cassava fermentation.

4.2. Nutritional aspects of cassava fermentation

All the cassava lines and cultivars studied [26] contain the cyanogenic glucosides linamarin and lotaustralin which are hydrolysed to the corresponding cyanohydrins by linamarase when the tissue is damaged. These cyanohydrins decompose to HCN and the corresponding ketone, the decomposition rate depending on pH and temperature [29]. Recent medical studies have stressed the need for the screening of cassava to locate low cyanide lines and for extended studies of the effects of processing on residual cyanide contents, since traditional processing does not remove all the cyanide.

Earlier studies [31] showed that with simple processing involving root pieces (in which the proportion of damaged tissue is small), the hydrolysis of cyanogenic glucosides determines the total cyanide loss. In the disintegrated cassava tissues involved in many fermentation processes, the breakdown of the non-volatile cyanohydrins to the volatile HCN appears to be a limiting factor [32]. This is especially important in lactic-acid-fermented products since the rapid pH decrease at the start of the process will inhibit cyanohydrin breakdown [33]. Studies to further define the kinetics of these processes are planned.

The traditional cassava starch extraction process common in Latin America involves lactic acid fermentation during the starch separation and sedimentation stages. The product contains less than 1% of the quantity of cyanide present in the raw material [34]. A key step in obtaining these very low residual cyanide levels is the conversion of most of the bound cyanide to free cyanide in the initial process stage (homogenisation—hammer milling in excess water). The free (non-glucosidic) cyanide is much easier to remove than bound cyanide [31] and the extended mixing with water, soaking in water (with associated fermentation) and slow sun-drying constitute an efficient process for removing this residual cyanide. Other traditional food processes, as distinct from starch extraction, do not involve such complete rapid tissue disintegration in water (which facilitates linamarase action) and are associated with higher levels of residual cyanide.

Another aspect under study is the rôle of condensed tannins in fermented cassava products. The initial phase of fresh cassava perishability is related to a physiological deterioration (vascular streaking) reflecting enhanced oxidative enzyme activity and condensed tannin formation (reviewed in [26,33]). In processed cassava products there are indications [35] that the levels of condensed tannins may be of nutritional significance as is the case with high tannin sorghums. This is the subject of continuing investigation.

5. LACTIC-ACID-FERMENTED MEATS

5.1. Introduction

Meat products are most commonly preserved by freezing or refrigeration. However, in tropical countries the energy cost and the lack of an established cold-chain infrastructure are major limiting factors. However, the FAO have reported that in 1978 more than 20000 tonnes of sausage products and a similar quantity of ham and bacon products were imported by developing countries at a cost of over US$100 million. A steady increase in sausage production has occurred in Africa. Asia and India in the period 1972–1981; this is commonly linked with urbanisation. Consequently, a sausage product with shelf-life comparable to the refrigerated product but which uses an alternative preservation system permitting storage at tropical ambient temperatures would have economic advantages. One such possibility is a sausage preserved by lactic acid fermentation alone or in association with other preservative mechanisms, e.g., humectants and anti-microbial additives.

Lactic-acid-fermented meat products have been known for many centuries, especially in Eastern Europe. A fermented pork product called *nham* is produced in Thailand [36]. The process is similar to that described for *som-fak* (section 3.1). The processes tend to be long and complex, and only recently (reviewed in [37]) have scientific methods been introduced to understand and control the fermentations. Furthermore such work may enable the application of simplified fermentation procedures by tropical food industries.

One aspect of TDRI's work in collaboration with Nottingham University looked at the preservation of sausages at 30 °C using a combination of reduced a_w and anti-microbial additives [38]. However, organoleptic and toxicity problems are likely to limit practical application of such methods. Current plans involve evaluation of lactic acid fermentation in combination with food additives; the temperature and a_w dependence of LAB in these environments are currently being studied.

5.2. *Survey of lactic-acid-fermented sausage products*

There are two types of fermented sausages, dry and semi-dry. Semi-dry (moisture content about 50%) differs from dry (30–40% moisture) principally in that curing involves smoking at relatively low temperatures during which active fermentation occurs. This is followed by cooking in the smoke-house and subsequent air-drying. Semi-dry sausages are subjected to a shorter drying period than dry sausages and finished at a higher drying temperatures of 59–60 °C after smoking.

The fermentation is responsible for lactic acid production and nitrate reduction. The species responsible are LAB (*Lactobacillus, Pediococcus* and *Leuconostoc*) and *Micrococcus* [39]. *Micrococcus* is responsible for reduction of nitrates to nitrites which is necessary for colour (and perhaps flavour) development. Today the cure mixture usually involves nitrite not just nitrate and the necessity for *Micrococcus* is uncertain.

The process for semi-dry sausage can potentially be reduced to 12–24 h of total processing time by the introduction of starter culture *P. cerevisiae* [37]. Dry sausages are cured in 1–2 days instead of 7–14 days by the traditional process. Because the sausages are acidified to near their isoelectric point, they can be dried more easily. Drying times for dry sausages have decreased to 25–40 days depending on sausage diameter and trichinella certification procedure (internal temp. $\geqslant$ 137 °F). The more rapid fermentation can also suppress more effectively pathogenic micro-organisms such as *Salmonella* and *S. aureus* [40].

6. CONCLUSION

Lactic acid fermentation has considerable potential as a low-cost food preservation method in the tropics. Studies to improve the product and shelf-life quality should focus initially on existing product types in developing countries. LAB's capability to inhibit the growth of spoiler micro-organisms may depend on several factors (section 2); most of the literature focusses on acid production as the key indicator of starter usefulness. Other factors such as hydrogen peroxide [41] and antibiotic [42] production may be of similar potential importance. LAB screening for spoiler growth inhibition deserves further study. Similarly, the selection of LAB with desirable nutritional effects (e.g., cyanide utilisation in cassava products) merits further consideration.

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