EFFECT OF DRYING LACTIC ACID BACTERIA FERMENTED *UJI* ON ITS PASTING PROPERTIES AND CONTENT OF CARBOXYLIC ACIDS

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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ABSTRACT

The effect of fermentation and drying on the pasting properties and carboxylic acids of pure flours of maize, finger millet and cassava and of composite flours of maize-finger millet and cassava–finger millet were studied. The pasting properties were measured between 30^0C and 96^0C in a Brabender Amylograph while carboxylic acids from the *uji* slurries were determined on thin layer chromatography plates coated with 0.25 mm silica gel.

Irrespective of the treatment given, the cereal flours of maize, finger millet and the composite of maize-finger millet consistently had higher onset and peak gelatinization temperatures than pure cassava or the composite of cassava-finger millet. Also the latter two flours developed higher peak viscosities and disintegrated more rapidly after attaining the peak than either pure maize, finger millet or the composite of maize-finger millet. The higher viscosities of the root flours was also reflected in the higher swelling powers and solubility values at 85^0C. Fermentation increased the viscosity of the slurries. The greatest increases were recorded by maize (500BU) and the composite of maize-finger millet (780 BU). Fermentation did not affect gelatinization temperatures except for the maize-finger millet composite whose gelatinization temperature decreased by 10^0C. Fermentation and drying resulted in increased viscosity when compared to the non-fermented flours, except for the drum dried cassava-finger millet composite. For all the drum dried flours there was a spontaneous increase in viscosity at 30^0C when the Brabender Amylograph was switched on. The drum dried flours absorbed about four

times their own weight of water; and since the starch granules were pregelatinized, reconstitution in cold water was difficult, as the flour particles tended to lump together, getting wetted on the surface and inhibiting the penetration of water into the interior. In contrast, sun and cabinet dried flours absorbed about 1.9 times their own weight of water and formed smooth slurries in cold water. Fermentation increased total titratable acidity and fixed acidity of the slurries to about 3.9% and 3.6% respectively, while the pH declined from 5.5 to 3.9. On drying there were no significant changes in ($p<0.05$) total titratable acidity declined by between 20-60%; the greatest losses being experienced by cassava and cassava finger millet. Acetic, formic and hexanoic acid were present in all the fermented slurries while propionic acid was absent. Acetic and formic acids were completely lost when the fermented slurries were either sun-, cabinet-, or drum dried. Hexanoic acid declined slightly on drying but the levels were influenced by the drying system. Consumer preferences for *uji* prepared from the fermented and dried slurries did not differ significantly ($p>0.05$) from the *uji* prepared from fermented and non-dehydrated slurries.

1 INTRODUCTION

Cassava, maize and finger millet are important sources of dietary energy in Africa. Their popularity is due to their ability to grow well in arid and semi-arid lands and their high yields (Kay, 1987; BOSTID, 1988; FAO, 1995). Despite these agronomic advantages, their consumption is declining because of the rapid rate of urbanisation, poor marketing facilities, large imports of temperate crops such as wheat and rice, and inadequate processing techniques (FAO, 1990; FAO, 1992; FAO, 1995). These crops are also associated with disadvantaged groups and hence are referred to as 'poor peoples' crops'.

The market value of these crops can be improved by processing them into a wide variety of food products with good organoleptic properties and long shelf-life. Fermentation is one of the technologies where the flours could be used either singly or in various composites to make a thin gruel referred to as *uji* in Kenya. This product is popular because of its sweet sour taste and the high prices of sour milk, lemon and sugar. It is consumed across all social classes though this is declining due to availability of easier to prepare substitutes such as tea and coffee and the erratic supply of cassava and finger millet in the local market. Thus quantities produced are usually low, just enough for immediate consumption within the household.

Though fermentation enhances the shelf-life of *uji*, further advantages could be derived if the product is dehydrated and well packaged. Dehydrated foods require less labour for handling, less packaging materials, smaller packaging equipment and less storage space. Dehydration also enables foods to be preserved during periods of abundance and can therefore increase the utilisation and value of cassava and finger millet in Kenya. Sun drying or artificial solar

drying are the common modes for drying the limited commercial quantities of fermented *uji* produced in Nyanza and Western provinces of Kenya. The products are then packed in sisal bags and are usually left exposed to moisture uptake and contamination by dust during handling, transportation, storage and retailing. Their quality cannot therefore be guaranteed. The fermented dehydrated flours are mainly purchased by low income rural-to-urban migrant workers living in cosmopolitan centres such as Nairobi and Mombasa. Though drum drying is best suited for slurries and materials with high solid content (Hayashi, 1989), there is no published evidence that it has been used to produce fermented *uji*. Cabinet drying is best for granular materials such as cereal grains (Hayashi, 1989) and it simulates sun-drying, but it has the advantage that the drying conditions such as temperature and relative humidity can be closely monitored and controlled. The drier used must not impair the organoleptic attributes of the product and must be economical and adaptable to the raw material to be used. In lactic fermented *uji*, the most important organoleptic constituents associated with drying are the carbohydrates and the flavour compounds (Masha *et al.*, 1998). With increasing dehydration temperatures the former will gelatinize while the latter are carried off with moisture.

This study was designed to evaluate the influence of drying on the carboxylic acids and pasting properties of fermented maize, finger millet, cassava and composites of maize-finger millet and cassava-finger millet. Flavour losses and starch modifications occur during drying of the fermented slurries. Thus the objectives of this study were:

1. To investigate the effect of fermenting *uji* on its pasting properties, solubility and swelling power indices, acidity and carboxylic acids.
2. To investigate the effect of dehydration of lactic fermented *uji* on its pasting properties, solubility and swelling power indices, rehydration potential, acidity and carboxylic acids.

2 LITERATURE REVIEW

2.1 CASSAVA

2.1.1 Utilisation of Cassava in Africa

Cassava (*Manihot esculenta* Crantz) is a perennial shrub that produces enlarged tuberous roots. It was introduced to Africa by the Portuguese in the 16th century. Africa now produces about 40-50% of the worlds' total cassava crop (Kay, 1987; FAO, 1996). The leading producers of the crop in Africa are: The Democratic Republic of Congo, Nigeria, Tanzania and Mozambique (Rickard and Coursey, 1981; FAO, 1996). In Kenya cassava is mainly grown along the coast and western parts of the country. There is also limited cultivation in eastern and central regions of the country. Cassava is the major carbohydrate source to over 800 million people in Africa; and per capita consumption is 102 kilograms per year (Oyewole, 1992).

Cassava grows well at harsh climatic conditions in areas with poor soils though it responds well to fertilization (Kay, 1987). These growth conditions make it a suitable crop for most areas in sub-Saharan Africa. Its other important characteristics as a subsistence crop are:

1. Resistance to pests and diseases that attack many other crops;
2. High yielding;
3. Drought resistant and therefore serves as an important food security crop;
4. Relatively short growth period of 12-18 months after planting, while the early maturing varieties take as short as 9-12 months;
5. The planting material in the form of the stem is always readily available;

6. High return of food calories per unit energy input in its cultivation and per unit land area.

Proximate composition of cassava is such that it has 60-62% water, 32-35% carbohydrate; 0.7-1.2% proteins; 0.3% fat; 0.8-1.3% fibre and 0.3-1.3% ash (Rickard and Coursey, 1981; Onwueme and Charles, 1994). Its protein content is low and of poor quality. Despite its low protein content, cassava is rich in carbohydrates which provide 5000-6000 MJ of energy per 1000 g of the edible portion (Onwueme and Charles, 1994). Cassava should therefore be viewed essentially as an energy giving food. Communities that rely heavily on cassava diets as a protein source have a high incidence of protein malnutrition (Onwueme and Charles, 1994). To alleviate this problem cassava should be consumed with protein enriched foods, but this is not always possible especially among the low income earners. Attempts have been made to breed cassava with higher protein levels, but it has been noted that there is an adverse effect on the yield. Asiedu *et al.* (1992) suggest that biotechnology research on cassava with improved protein levels should be given a low rating in priority because cassava based products are usually eaten with protein sources. Fermentation is probably the best way of increasing the protein content of cassava products.

The tubers of cassava plant are the most important edible part of the plant although the leaves can also be made edible (Saka, 1993). Over 85% of cassava produced in Africa is used as human food; and of this 70% is processed before consumption while 30% is consumed in the fresh form (Bokanga and Djoussou, 1995). Consumption of the fresh tuber is not common due to the danger posed by hydrogen cyanide poisoning. It can be subjected to minor processing, where the peeled tubers are either boiled or processed into high value fermented foods such as *gari, attieke, kwanga* (*chikwanghe*) or *uji*. The processed products have lower

levels of cyanogenic glucosides than the fresh parenchyma roots (Onwueme and Charles, 1994). Despite its agronomic advantages and wide food variety cassava is still not widely consumed especially by the affluent people in sub-Saharan Africa. With increasing household incomes many families tend to consume less foods from cassava in favour of temperate crops like wheat, rice and potatoes. Poor people consume cassava because it is cheap and convenient. This psychological aversion to cassava on the basis of income has caused it to be referred to as the poor people's crop (FAO, 1990).

2.1.2 Processing of Cassava

Cassava tubers deteriorate very rapidly after harvest. The deterioration of the tubers takes place in two stages:

1. Primary or physiological deterioration is caused by enzymatic processes that lead to the production of catechins, coumarin and leucoanthocyanidins which later polymerise to form tannins (Rickard and Coursey, 1981; Kay, 1987; Onwueme and Charles, 1994). The vascular bundles of the tubers acquire a blue colour later on becoming brown; referred to as vascular streaking.
2. Secondary or microbial deterioration begins 24 hours after primary deterioration and involves microbial rotting, softening and fermentation of the tissues (Rickard and Coursey, 1981).

A number of methods have been proposed for the storage of fresh cassava roots (Rickard and Coursey, 1981), but these options are expensive and offer limited extension to the shelf-life of the produce. The most widely practised preservation technique in sub-Saharan Africa involves leaving them in the ground until when required for use but the disadvantage is that a

large portion of land is occupied by the mature crop and is unavailable for other farming activities. Furthermore, the tubers increase in size, become more fibrous and woody and their starch content declines.

To overcome the problem of rapid deterioration of the fresh tuber, it is processed into a variety of food products. Processing also improves palatability and safety and makes cassava easier to transport. The Collaborative Study of Cassava in Africa (COSCA) has reported more than 80 different cassava products from Africa (Bokanga and Djoussou, 1995). Processing of cassava results in either a fermented or non-fermented product. The fermented cassava products can be further classified as:

1. Solid state fermented cassava (or solid substrate fermented) where microbial growth occurs on the surfaces of the solid substrates. Fermentation is mainly by mould growth such as in the processing of *gari, attieke, placali*, and *agbelima*.
2. Submerged culture fermentation where lactic acid bacteria are the predominant micro-organisms that acidify the product. It is characterised by a low biomass concentration in the liquid phase (Lopez, 1992) such as in the processing of *kwanga, fufu* and *lafun*.

Cassava roots may also be peeled, sliced then sun-dried. These chips are then ground into flour which is used in the preparation of bread, biscuits and confectionery and in products such as macaroni and sphagetti (Kay, 1987). In Kenya the flour is usually composited with sorghum or finger millet then used to prepare stiff porridge *(ugali)* or thin porridge *(uji)*. The composite flours may be fermented before being used to make porridge.

Gari is the most popular form in which cassava is consumed in West Africa and is the staple food for about 80 million people in this region (Odunfa, 1985). *Attieke* is a typical cassava

product from Cote d'Ivoire while *Kwanga*, (also referred to as *chikwanghe*) is a fermented cassava product consumed in Congo, Democratic Republic of Congo and Central Africa Republic (Odunfa, 1985; Onwueme and Charles, 1994). *Boulettes, cossetes* and *miettes* are different products that may be obtained from *kwanga* (Banea *et al.*, 1992). The use of dried cassava chips and pellets as livestock feed is a common phenomenon in the European Community countries (Kay, 1987), but is not practised in Africa because of the tuber's value as a calorie rich food. The chips may also be processed into starch for use in the paper and textile industry, or further hydrolysed into glucose, but once again, this is not possible in sub-Saharan Africa since the main priority is to ensure adequate supplies to meet the energy requirements of the population.

The use of cassava leaves as a source of food is widespread in Africa, especially in Sierra Leone and in the Congo basin (FAO, 1990; Onwueme and Charles, 1994). The leaves are rich in proteins, minerals, vitamins and all the essential amino acids except methionine and phenylalanine (FAO, 1990; Onwueme and Charles, 1994). However, like the tubers, the leaves are also rich in cyanogenic glucosides which release toxic hydrogen cyanide on hydrolysis by the linamarase enzymes (FAO, 1990; Onwueme and Charles, 1994). Communities that consume cassava leaves have been able to reduce levels of the toxic constituents by different processing techniques such as chopping or crushing and cooking (Saka, 1993).

2.1.3 Cyanogenic Glucosides in Cassava

Cyanogenic glucosides (CNGs) of cassava are synthesised from the amino acids valine and isoleucine and occur in the vacuole of the cytoplasm (Bokanga, 1991). CNGs exist as:

1. The free cyanides: These constitute 25-34% of the total cyanide, and include cyanohydrins, small amounts of hydrogen cyanide and the cyanide ions (under alkaline conditions).
2. The bound cyanides: These make up 66-75% of the total cyanide of which 93% is linamarin and 7% is lotaustralin.

The bound cyanides are hydrolysed by linamarase which occurs in the cell wall. When the cell is raptured by chopping or grating the tuber, linamarase comes into contact with the substrate to give glucose and a cyanohydrin (FAO, 1990). The cyanohydrins will decompose under neutral, alkaline or slightly acidic conditions to the corresponding ketone and hydrogen cyanide (HCN); the latter is lost by volatilisation at 27°C.

The quantity of CNGs in the tubers ranges from 15 to 490 mg HCN equivalent per kg on fresh weight basis (Kay, 1987; FAO, 1990; Mlingi *et al.*, 1991). The tubers can be classified into three categories based on hydrogen cyanide content:

1. Innocuous, less than 50 mg HCN / kg of fresh peeled roots;
2. Moderately toxic, 50-100 mg HCN / kg;
3. Extremely toxic, over 100 mg HCN / kg.

The CNGs are highest in the rind and in the fibrous core but the levels also vary with the age of the plant (Gomez *et al.*, 1984). High levels also occur in tubers that have been subjected to water induced stress (Aalbersberg and Limalevu, 1991) or grown in nitrogen rich soils

(Onwueme and Charles, 1994), or in soils of low fertility, especially potassium deficient soils (Kay, 1987).

The classification of cassava into sweet and bitter varieties is controversial and has led to a lot of confusion (Asiedu *et al.*, 1992; Onwueme and Charles, 1994). Akinrele (1986) refers to varieties yielding less than 50 mg of hydrocyanic acid per kilogram of fresh matter as sweet or non-toxic; while those with higher values as being poisonous or bitter. El Tinay *et al.* (1984), Gomez and Valdiviesa (1984) and Mlingi *et al.* (1991) support this classification that relates taste to the cyanogen levels in cassava. However, this is disputed by other authors (Kay, 1987; FAO, 1990; Onwueme and Charles, 1994). More research needs to be done to identify what compounds are responsible for bitterness in cassava.

2.1.4 Toxic Effects of Cyanogenic Glucosides

Since no processing method exists that can completely eliminate CNGs from cassava tubers, small amounts will always be consumed. A well nourished individual is able to detoxify and eliminate these small amounts from the body (FAO, 1990). In detoxification cyanide is converted to thiocyanate, a reaction that is catalysed by thiosulphate cyanide sulphur transferase (rhodanase) enzyme. Formation of thiocyanate requires sulphur, which is derived from cystine, cysteine or methionine (FAO, 1990). Vitamin B12 in the form of hydroxcobalamin also probably influences conversion of cyanide to thiocyanate (FAO, 1990). The thiocyanate is then excreted in the urine. A diet rich in proteins, particularly sulphur amino acids, is therefore important as an aid in the removal of cyanide from the body.

Toxicity due to the consumption of CNGs from cassava is manifested either as acute or

chronic. Acute toxicity occurs when a large amount of HCN is ingested in one meal or over a very short period of time. The symptoms appear 4-6 hours after a meal of insufficiently processed cassava and consist of vomiting and vertigo. Death may occur within one to two hours (FAO, 1990). The early stages of this form of intoxication can be reversed by giving the patient an intravenous injection of thiosulphate. Sulphur from the thiosulphate reacts with cyanide to form more thiocyanate, which is then eliminated in the urine.

Chronic toxicity occurs when small amounts of the intoxicant are consumed over a long period of time and the levels slowly accumulate in the body. Chronic cassava toxicity is recognised in populations in which cassava is always a major portion of the diet and protein supplementation is low (Kay, 1987; FAO, 1990). Chronic toxicity is manifested as goitre, cretinism and mental retardation (Mlingi *et al.,* 1991; Onwueme and Charles, 1994). These diseases are caused by the high levels (1-3 mg per 100 ml) of thiocyanate in the serum. The normal level is 0.2 mg per 100 ml (FAO, 1990). Chronic cassava toxicity may also result in neurological disorders which manifest themselves either as tropical ataxic neuropathy (FAO, 1990; Mlingi *et al.*, 1991) or epidemic spastic paraparesis (Mlingi *et al.*, 1991; Banea *et al.*, 1992)

2.1.5 Detoxification of Cassava

A number of techniques have been proposed for the reduction of cyanide content of cassava. Ejiofor and Okafor (1983), Okafor and Ejiofor (1990), Mlingi *et al.* (1991), and Banea *et al.* (1992) describe methods that involve the use of fermentation to reduce the level of CNGs in cassava tubers. Techniques that do not utilise fermentation also exist,,for instance sun drying and boiling (Nambisan and Sundaresan, 1985).

In the non-fermentation processing of cassava the tubers are peeled, grated then dried. Grating action brings linamarase enzymes into contact with the CNGs. In the course of drying the linamarase hydrolyses the CNGs. This method results in losses of more than 95% of the CNGs (Nambisan and Sundaresan, 1985). If the chips are oven dried the amount of bound cyanide that is lost decreases as oven temperature increases (FAO, 1990), but losses of free cyanide remain high. This is because as the temperature is raised linamarase gets progressively denatured with the complete loss of activity at 72°C. Although sun-drying results in a greater loss of bound cyanide; oven drying at 60°C gives chips with a lower final total cyanide content than sun drying (Gomez *et al.*, 1984). This is probably because of the higher efficiency of oven drying in removing free cyanide while at the same time allowing linamarase to degrade the bound cyanide at 60°C.

Linamarin degrades at 150°C, and hence boiling of cassava roots will not substantially reduce the levels of bound cyanide. Sokari and Wachukwu (1993) have reported losses of about 45% and 54% for linamarin and total cyanide respectively after boiling cassava chips in water for 30 minutes. These reductions could be attributed to leaching of the glucosides into the boiling water but not hydrolysis, because the linamarase enzymes are inactivated at 72°C. Higher losses of bound CNGs occur when cassava tubers are placed in cold water and the temperature is gradually raised (FAO, 1990; Sokari and Wachukwu, 1993). In this case the linamarase enzymes have sufficient time to act before they are denatured.

Detoxification of cassava can also be achieved by inoculating the mash or grated pulp with micro-organisms capable of producing linamarase enzymes or by natural fermentation. In the former case Ejiofor and Okafor (1983) have proposed the use of: *Alcaligenes faecalis*,

Leuconostoc mesenteroides, Saccharomyces cerevisiae or *Rhodotorula minuta*. All these microbes are capable of releasing more HCN per gram of the pulp than the endogenous linamarase. *Schwanniomyces alluvius*, *Saccharomyces* species or *Leuconostoc* species are suitable when it is desired that the flora produce both linamarase and amylase enzymes (Okafor and Ejiofor, 1990).

2.2 MAIZE

2.2.1 Production and Utilization of Maize in Africa

Maize (*Zea mays*) belongs to the Graminae family; it is a tall annual plant with a fibrous root system. The grain develops in the cob, each cob having 300-1000 kernels weighing 190-300 g per 1000 kernels (FAO, 1992). The kernels are either white or yellow in colour though other colours also rarely occur. The practice of maize cultivation is believed to have originated from Central America and was introduced to Africa by the Portuguese in the late 16^{th} century, and is now a vital staple food for millions of people. It spread quickly and widely due to its high yields and appropriate ecological conditions. It possesses numerous agronomic advantages (BOSTID, 1988):

1. Gives one of the highest yields per hour of labour spent;
2. Provides nutrients in a compact form;
3. Is easily transportable;
4. Is protected against rain and birds by its husks;
5. Is easy to harvest and can be shelled by hand;
6. Stores well if properly dried;
7. Is relatively free of major disease epidemics;

8. Competes with weeds better than other cereals;

9. Does not shatter and can be left standing in the field at maturity;

10. Has cultivars with different maturity periods.

Africa now produces about 7% of the worlds' total maize crop (FAO, 1996). The leading producers of the crop are Egypt, South Africa, Tanzania, Nigeria, Kenya and Ethiopia (FAO, 1996). In Kenya most of the crop is grown by small-scale subsistence farmers for household consumption and they only sell the surplus. The large scale growers are mainly in Trans Nzoia, Uasin Gishu and Nakuru Districts.

Maize is the third most important cereal crop in the world after wheat and rice. In most African countries maize is the staple food and serves as an important source of calories and proteins. The per capita consumption in Kenya, Malawi, Zambia and Zimbabwe is about 100 kg per year (BOSTID, 1988). Conversely in the developed countries maize is mainly used as animal feed and industrial raw material for the production of starch, food sweeteners and alcoholic beverages. In Asia maize is not the preferred human food due to the prodominance of rice; while in most Latin America countries the per capita consumption is about 100 kg per year, just like in Africa.

Maize can be prepared and consumed in a variety of ways. The whole ears may be boiled with or without husks, or roasted. The mature whole kernels can also be boiled with beans to make a local dish known as *githeri* in Kenya. The grains can be milled into flour to produce a thin porridge (*uji*), or a thick porridge (*ugali*). The thin porridge may or may not be fermented before cooking. The grains can also be pounded into grits then used to make an opaque maize beer called *busaa*. A similar product known as *mahewu* is brewed in South

Africa on a commercial scale (Odunfa, 1985). In West Africa *ogi* and *kenkey* are the predominant foods prepared from fermented wet-milled maize paste (Odunfa, 1985). Like cassava the consumption of maize tends to decline with rising family income, leading to increased demand for temperate crops such as wheat, rice and potatoes.

2.2.2 The Nutritional Quality of Maize

About half of the worlds' chronically undernourished people live in countries where maize is the staple food (BOSTID, 1988). The proximate composition of maize grain of 12% moisture content is 72-73% starch; 8-11% proteins; 3-18% lipids; 1-3% dietary fibre and 1% ash (FAO, 1992). Though maize is a good source of calories, it is low in protein quantity (i. e. lysine and tryptophan). Communities that rely heavily on maize as the source of calories and proteins are thus prone to protein deficiency disease, referred to as kwashiokor. Weaning age children are the most seriously affected especially when the birth of a new baby displaces the older child from the breast. Symptoms of this disease are; stunted growth, oedema in the legs and abdomen, development of a reddish colour in the hair, loss of appetite, diarrohea and vomiting, decreased resistance to disease, anaemia and accumulation of fat in the liver (FAO, 1992).

Maize is low in niacin (FAO, 1992), an essential vitamin for the synthesis of nicotinamide adenine dinucleotide and nicotinamide adenine dinucleotide phosphate. These coenzymes are hydrogen carriers and are required for generation of energy in the body. Individuals who are deficient in niacin develop pellagra. The pellagragenic properties of maize is due to the poor bio-availability of niacin and the low tryptophan content. In children growth is stunted while in people of all ages the disease is characterised by dermatitis, dementia and diarrhoea.

(FAO, 1992)

The quality and quantity of protein in maize can be improved by genetic manipulation. The levels of lysine and tryptophan in the endosperm have been raised by breeding Opaque-2 maize variety (BOSTID, 1988). This maize has been found to improve protein deficiency malnutrition as well as prevent pellagra but it has failed to get widespread acceptance because it is chalky, its ears are small, its yield is 8-15% lower than the traditional maize varieties, is more susceptible to fungi and insect attack in the field and in storage and it dries more slowly (BOSTID, 1988). It is now gradually being replaced with Quality Protein Maize which has the desirable agronomic traits of traditional maize, and yet is rich in lysine and tryptophan. The use of Quality Protein Maize can therefore improve the nutritional status of millions of people in Africa who are dependent on maize as a staple food.

The nutritional value of maize can be improved by fermentation or germination. Fermenting the cooked maize results in a higher vitamin B concentration and better protein quality (Mensah *et al.*, 1991), while germination of the grain increases levels of lysine and tryptophan. In Latin America, *tortillas* are prepared by cooking dried maize kernels in a weak solution of lime water for about 30 minutes before grinding to make the dough. This frees small amounts of niacin that is otherwise unavailable to humans (BOSTID, 1988). Maize diets can also be supplemented with protein rich foods such as beans, milk and fish flour. The supplement must have a relatively high protein content and be a good source of lysine and tryptophan.

2.3 MILLET

2.3.1 Utilization of Millet in Africa.

According to FAO (1995) there are six major genera of millet in the world. In addition Bencini (1991) and FAO (1995) have reported that the most important species in sub-Saharan Africa are:

1. *Pennisetum glaucum*: It is also referred to as *Pennisetum americanum* L. Leeke. The common names are bulrush millet, pearl millet, cat-tail millet, spiked millet and dark millet.
2. *Eleusine coracana* Gaerth: The common names are finger millet and African millet.

The other genera and species are *Sertaria italica* (foxtail millet), *Panicum miliaeceum* (Proso or common millet), *Echinochloa crus-galli* (barnyard millet) and *Paspalum scorbiculatum* (kodo millet). These genera are most common in Asia, Japan and India.

Bulrush and finger millets are native to Africa where the greatest number of wild and cultivated forms occur. Bulrush millet is most prevalent in tropical West Africa while finger millet is extensively grown in East, Central and Southern Africa. Africa produces about 40% of the world's total millet crop (FAO, 1996). The leading producers are Burkina Faso, Mali, Niger, Nigeria and Senegal all of which account for 75% of millet production in Africa (FAO, 1996). However, these figures should be viewed cautiously because most countries in Africa do not distinguish between millet and sorghum in their statistics since the crops are usually intercropped and most farmers grow the crops for subsistence. Also the production statistics do not distinguish between the different species of millet. Of the total production in Africa 77% is used as human food, 1% as animal feed and 21% for other uses (FAO, 1995).

The proximate composition of bulrush and finger millet is; 8-12% protein; 1.5-5.0% fat; 2-4% fibre and 67-73% carbohydrate at 12 % moisture content (FAO, 1995).

Bulrush and finger millet are well adapted to the arid and semi-arid regions of sub-Saharan Africa (FAO, 1995) but their yields remain low due to poor agronomic practices and the tendency for farmers to grow them only as a buffer against famine. Like cassava and maize, the consumption of bulrush and finger millet tends to decline with increasing family income (Bencini, 1991). They are associated with economically disadvantaged groups and are referred to as a 'poor people's crop'. Other factors that have caused a decline in the consumption of finger millet are (Bencini, 1991; FAO, 1995):

1. Poor marketing facilities: Finger millet is usually not traded in the international or local market in many countries and therefore the farmers do not have an assured market during periods of surplus production.
2. The national policies of many countries in sub-Saharan Africa favour production, importation and utilisation of temperate cereal grains such as wheat, maize and rice. In some cases these crops are even subsidised by national governments in order to make them available to a wider spectrum of the population.
3. Increasing urbanisation has led to changes in consumer eating habits as urban workers seek foods that require little time and energy to prepare.

In processing, after the heads have been harvested they are sun dried to a moisture content of 10-12%. The stalks are then threshed by beating them on the ground with sticks or stripping by hand. The grain may then be steamed and served with other dishes such as vegetables and stew; or it may be milled into flour. In Kenya finger millet flour is usually composited with maize or cassava to make a thin porridge (*uji*) or a thick porridge (*ugali*). Thin porridge is

prepared by mixing the flour with water in a ratio of about 1:3 and the slurry may be fermented before cooking. Thick porridges have a higher flour concentration and are prepared by kneading in boiling water till a stiff gel is obtained. In Senegal, Sudan and Burkina Faso wheat flour has been partially replaced with bulrush millet flour in bread-making (Bencini, 1991); and the product is widely accepted by consumers. This is an important technology that could have a positive socio-economic impact in many sub-Saharan Africa countries by reducing wheat imports and encouraging production of the millets. Other products from finger millet are *kisra* and *nasha* in Sudan, *couscous* in Senagal, *bousa* in Egypt, *ogi* in Nigeria and *koko* in Ghana (Andah and Muller, 1973; Odunfa, 1985). Finger millet is also the preferred grain for brewing of opaque beers. Its enzymes have a saccharifying power greater than those from sorghum, bulrush millet or maize malt (Bencini, 1991). In Kenya, *busaa* (a traditional opaque beer) is prepared using finger millet malt and maize grits as the enzyme and carbohydrate sources respectively.

2.3.2 Anti-nutrients in Millet: Polyphenols

The predominant anti-nutrients in finger millet are the polyphenolic compounds, the phytates, digestive enzyme inhibitors and the goitrogens. The main polyphenols in finger millet are tannins (FAO, 1995). These polyphenolic compounds are secondary metabolites that act as defense chemicals that protect the plant from predatory attacks of birds, herbivores, pathogenic fungi, parasitic weeds and insect attack. In storage the polyphenols also prevent grain losses by premature germination and damage due to mould. Among the finger millet, the brown varieties have 351-2392 mg tannins per 100 g of dry material while the white varieties have no detectable tannins (FAO, 1995). The tannins bind to enzymes of the digestive tract adversely affecting the utilisation of proteins and carbohydrates. This results

in reduced growth, feeding efficiency, metabolizable energy and bioavailability of amino acids. Tannins also complex with iron making it unavailable (Khetarpaul and Chauhan, 1990a; Khetarpaul and Chauhan, 1990b).

Traditional household techniques such as decortication, soaking, germination and lactic acid fermentation of millets can be used to reduce the levels of polyphenols (Lorri, 1993). Germination alone does not contribute much to lowering the polyphenol content of millet grains and it must be preferably combined with fermentation (Khetarpaul and Chauhan, 1990a). However, even in fermentation, the importance of desirable cultures developing in the substrate cannot be overstated. Mixed pure cultures of *Saccharomyces diastaticus* and *Lactobacillus fermentum* can lower the polyphenol content; while mixed cultures of *Saccharomyces diastaticus* and *Lactobacillus bulgaricus* or *Saccharomyces cerevisiae* and *Lactobacillus fermentum* increase the polyphenol content (Khetarpaul and Chauhan, 1990a). From the above it can be concluded that spontaneous fermentation may not necessarily lower the polyphenol content in millets unless the desired microflora outgrows its competitors.

2.3.3 Anti-Nutrients in Millet: Phytic Acid

Phytic acid is a phosphorous based compound and is the main phosphorous store in mature millet grains. The acid readily forms complexes with metal ions and proteins making these to be biologically unavailable to humans. In bulrush millet the levels of phytin phosphorous ranges from 170-330 mg per 100 g of dry material (FAO, 1995). The phytates mainly occur on the bran of millet; and most seriously affect absorption of iron, zinc and calcium.

Fermentation significantly reduces the levels of phytic acid and improves the availability of

minerals. Khetarpaul and Chauhan (1990a) have reported that mixed cultures of either *Saccharomyces diastaticus* and *Lactobacillus fermentum* or *Saccharomyces diastaticus* and *Lactobacillus brevis* or *Saccharomyces cerevisiae* and *Lactobacillus fermentum* are effective in reducing levels of phytic acid in bulrush millet. The optimum natural fermentation conditions are 40-50^{0}C for about 72 hours (Mahajan and Chauhan, 1987). In these conditions the phytic acid was almost completely eliminated and the changes in concentration of extractable phosphorus was attributed to phytase activity in pearl millet flour.

Germination can reduce the phytin phosphorous content of both bulrush and finger millet by up to 50% (Khetarpaul and Chauhan, 1990a; FAO, 1995). The reduction of phytin phosphorous is accompanied by increases in ionizable iron and soluble zinc. The problem with germination is that it is not a very hygienic process when done at the household level and could result in proliferation of pathogenic and toxigenic micro-organisms in the food (Nout, 1993). It is therefore advisable to supplement it with fermentation or decontaminate the product by some other physical process such as heating.

2.4 FERMENTATION OF CEREALS AND ROOT CROPS

2.4.1 Fermentation and Processing Outline for *Uji*

Uji is a thin porridge made from maize, sorghum, cassava or finger millet flours. The flours may be used singly or in various composites and may or may not be fermented. Maize is most commonly used alone, while the popular composites are cassava-finger millet, sorghum-maize, maize-finger millet and cassava-sorghum all in 1:1 ratios. *Uji* processors in Nairobi prefer to use finely sifted maize flour (*Unga baridi*) which they buy from commercial millers. This porridge has a smooth consistency unlike porridge from hammer-milled maize that causes a gritty sensation in the mouth during consumption.

The flours are then made into slurries of 30-40% w/v and allowed to ferment for 24-48 hours. Traditionally the fermentation takes place in earthenware pots at room temperature or close to a wood or charcoal fire. This process can be hastened by using uncleaned vessels that contain some previously fermented *uji* (Mbugua, 1984) or by backslopping (Lorri and Svanberg, 1993). In the latter method a small amount of previously fermented batch is added to the fresh slurry. When the fermentation is complete the slurry is diluted with water to 10% w/v and cooked for 20-30 minutes. It may then be sweetened with sugar and served warm or cold. Figure 1 shows the steps involved in the traditional preparation of *uji* from a composite of cassava and finger millet flours. Technological improvements to this traditional technique involves an amylase digestion step, to reduce the bulk density of porridge (Lorri and Svanberg 1993), and sun-drying. Reduction of viscosity is not as popular as dehydration. The latter method is employed by small and medium size enterprises especially in Nyanza and Western provinces of Kenya and the dried product is sold in cosmopolitan centers such as Nairobi and Mombasa.

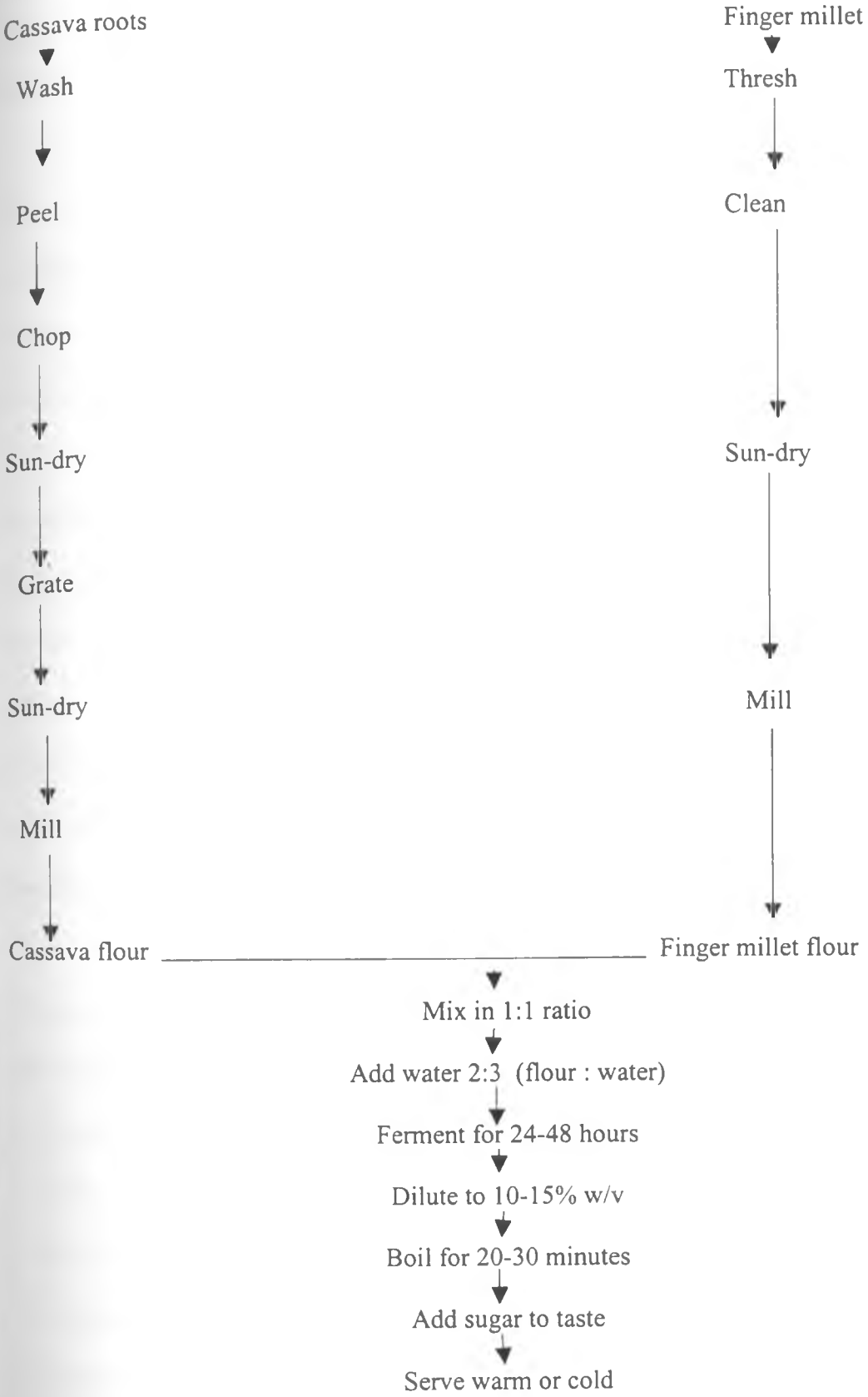

Figure 1: Traditional preparation of fermented *uji* from a composite of cassava and finger millet flours

2.4.2 Fermentation Micro-organisms in Cereals and Root Crops

The microflora responsible for fermentation of cereal and root crops are usually mixed cultures. In mixed culture fermentation the inoculum always consists of two or more organisms. These cultures may be all of one microbial group, as in bacteria, or they may consist of a mixture of organisms as in fungi and bacteria (Hesseltine, 1991). Lactic acid bacteria and yeasts have been identified as the most predominant flora in cereal and root crops fermentations (Mbugua, 1984; Mensah *et al.*, 1991; Svanberg *et al.*, 1992). The lactic acid bacteria preserve the food products, enhance the nutritional value, destroy anti-nutrients, reduce the energy required for cooking, improve the appearance and taste of the foods and salvage material that is otherwise not suitable for human consumption (Steinkraus, 1992; Lopez, 1992). The yeasts that have been identified in non-alcoholic fermented foods supply vitamins, peptides and other micro-nutrients that may be required by the fastidious lactic acid bacteria (Nout, 1993) and also degrade stachyose and raffinose (Akobundu, 1981).

The currently employed starter preparation and inoculation methods can be broadly divided into three approaches:

1. The natural flora on the flour is allowed to establish itself, hence no external inoculum is added. This method is applied in both solid substrate and submerged culture fermentation but is more common in the former. Solid substrate fermentation occurs at low moisture contents of 10-20%, conditions which favour the development of filamentous fungi (Lopez, 1992). In Tanzania, cassava fermented by the solid substrate fermentation gives a flour known as *makopa* (Lorri and Svanberg, 1993). Cassava tubers are peeled then stacked and covered with banana leaves and left to ferment for 2-3 days until moulds

appear. The tubers are then sun dried and milled into flour.

2. The use of an uncleaned container that had fermented a previous batch. Fresh substrate is added into this container and fermentation is allowed to proceed (Mbugua, 1985). This method is commonly applied in submerged culture fermentations, as in the preparation of fermented *uji*.

3. The backslopping method; where a small amount of a previously fermented batch is added into the fresh slurry (Bokanga, 1992; Lorri and Svanberg, 1993). The advantage of backslopping is that there is natural selection of a stable mixture of lactic acid bacteria, the fermentation process is accelerated and consumption of fermentable carbohydrates by aerobes and Enterobacteriaceae is inhibited by the immediate dominance of lactic acid bacteria. As a result more carbohydrate is available for lactic acid fermentation (Mbugua, 1986; Nout *et al.*, 1989; Nout, 1992). Backslopping is suitable for household and small scale commercial fermentation operations that require simple low technology investments (Nout, 1992; Nout, 1993).

All the above inoculation methods differ from those employed in conventional fermentations as described by Tamime (1981). In the traditional methods there is no control over the fermentation flora and this causes variations in flavour, aroma and texture of the fermented foods. However, the use of mixed undefined starter cultures also offers a number of advantages (Pulusani *et al.*, 1979; Ngaba and Lee, 1979; Mbugua, 1985; Mensah *et al.*, 1991; Hesseltine, 1991; Bokanga, 1992; Oyewole, 1992).

Fermentation of *uji* is by a flora of mixed cultures; and due to the variety of substrates that

can be used either singly or in different combinations the flavour also differs. This is because different substrates influence the growth of flora utilising different metabolic pathways. The main metabolizable substrate is glucose although fatty acids, proteins and amino acids are also acted upon and contribute to the flavour. The main group of micro-organisms involved in fermentation of *uji* are the lactic acid bacteria. Mbugua (1984) isolated *Lactobacillus plantarum, Lactobacillus fermentum, Lactobacillus cellobiosus, Lactobacillus buchneri, Pediococcus acidilactici* and *Pediococcus pentocaceus* from fermented *uji* prepared from maize-sorghum and maize-finger millet composites. Unpublished results of work done at Kenya Industrial Research and Development Institute (1996) identified *Lactobacillus plantarum, Lactobacillus brevis, Lactobacillus buchneri, Lactobacillus paracasei* sub sp. *paracasei* and *Pedioccocus pentocaceus* in maize-finger millet composites. In both studies *Lactobacillus plantarum* was the predominant microbe. The metabolic activities of these organisms result in production of fatty acids (e.g. lactic, acetic, butyric, formic and propionic acids), and ethanol, which contribute to the safety and acceptable flavour of fermented *uji*. The reported final pH ranged from 3.5 to 4.0 with a titratable acidity of 0.6% as lactic acid (Mensah *et al.*, 1991).

Even though most of the micro-organisms involved in cereal and cassava based fermentations have been identified (Okafor, 1992; Mensah *et al.*, 1991); most are not of any significance to the fermentation process and could even be harmful. Bokanga (1992) identified 15 microbial species belonging to 10 genera in *kwanga* (*chikwanghe*). Of these, only two were essential to the fermentation process and when these were aseptically inoculated into cassava they gave a product with similar characteristics as the traditionally prepared *kwanga*. Three of the identified species were human pathogens, while the other ten species did not contribute to the fermentation process.

2.4.3 Bulk Density of Fermented Gruels

The role of fermented gruels as weaning foods is limited by their high bulk density. Gruels prepared from 30% w/v flour concentration have a thick consistency and is rejected by children because it is difficult to swallow. Though this gruel has an energy density of 1.2 Kcal/g, which is higher than 0.75 Kcal/g in breast-milk (Lorri and Svanberg, 1993), it is not able to meet the energy needs of children because of the limited amounts that can be consumed. An alternative is to dilute the gruel to a flour concentration of about 5% w/v. This gruel is less viscous and is easier to swallow, but provides only 0.2 Kcal/g (Lorri and Svanberg, 1993). The weaning age child must then consume large quantities in order to meet its daily energy needs, but this is not practical because of its limited stomach capacity.

A proper balance between the energy density and consistency of the gruel can be achieved by adding malted flours to the gruel during cooking (Mensah *et al.*, 1991; Mbugua *et al.*, 1992; Lorri and Svanberg, 1993). Enzymes in the malt flour act by hydrolysing starch into simple sugars and limit dextrins, releasing bound water and thus reducing the viscosity. Grains that are rich in polyphenols can be treated with formaldehyde to increase the solubility of diastase, improve lactic acid fermentation and soften the proteins (Holzapfel, 1991). Microbial amylases can also be used to reduce the bulk density in gruels prepared from cereals and root crops; but these are expensive and cannot be afforded at the household level or by small scale entrepreneurs. Addition of germinated malt is most preferred, and at low concentrations of about 15% w/v the viscosity of the gruels reduces from about 10000 cP to 1600-4000 cP (Lorri and Svanberg, 1993). Nout (1993) suggests that for a weaning child who must consume about 3000 KJ of energy in four feedings of 250 ml each; then at a flour

concentration of 20% w/v, the viscosity should be between 1000-3000 cP. This gruel is easy to swallow and has a semi-liquid consistency. Some micro-organisms such as *Bacillus cereus* are also capable of producing limited quantities of the saccharifying enzymes during fermentation but the resultant porridge has an unpleasant odour and could be harzadous to health (Westby and Gallat, 1991).

2.4.4 Control of Pathogenic Bacteria in Fermented Gruels

Developing countries experience high incidences of child mortality and morbidity during the transition of feeding from breast milk to the family pot (Nout *et al.*, 1989; Svanberg *et al.*, 1992). The illness and deaths are caused by the high microbial load, including pathogens, in the infant food formulations. The incidence of diarrhoea peaks between the ages of six months and three years (Svanberg *et al.*, 1992), and therefore most seriously affects weaning age children who can no longer rely on breast-milk alone for their energy requirements. The proliferation of pathogenic micro-organisms in infant food formulations is caused by unhygienic practices in the preparation, handling and storage of the foods. The almost neutral pH of these foods and lack of cooling facilities in many rural households provides a good environment for rapid growth and multiplication of diarrhoea causing pathogens. The condition in which the mother has to decide between continued exclusive breast feeding versus feeding the child with contaminated food is described as the weanling's or suckling's dilemma (Mensah *et al.*, 1991). The mortality rate due to the weanling's dilemma is estimated at more than 15 million children per year in tropical developing countries (Nout, 1993).

The most common aetiological agents that cause infantile diarrhoea are enterotoxigenic

Escherichia coli, Campylobacter, Shigella, Vibrio cholerae, Salmonella and *Yersinia* (Nout *et al.*, 1989; Svanberg *et al.*, 1992; Lorri and Svanberg, 1994). Other enterotoxigenic bacteria genera that have been implicated as causative agents of diarrhoea are *Pseudomonas, Enterobacter, Klebsiella, Serratia, Proteus, Providencia, Aeromonas, Achromobacter* and *Flavobacterium* (Nout *et al.*, 1989). Among the viruses, the rotavirus is most frequently implicated (Svanberg *et al.*, 1992; Lorri and Svanberg, 1994).

Fermentation of gruels is a convenient option for solving the weanling's dilemma. The fermentation micro-organisms are thought to suppress pathogenic flora by production of organic acids (lactic, propionic and acetic acid), competition for nutrients, hydroperoxide formation and production of bacteriocins and antibiotic like substances (Svanberg *et al.*, 1992; Lorri and Svanberg, 1994; Mensah *et al.*, 1995). Lorri and Svanberg (1994) conducted a study in Tanzania where they found that children who are regularly fed on fermented gruels experience fewer and less severe episodes of diarrhoea than those who are fed on non-fermented gruels. Fermented gruels are also thought to have some health promoting effects, such as increased appetite of the children when they are sick, increased production of breast-milk by the lactating mothers, replacement of lost fluids during diarrhoea, and faster recovery of children suffering from measles (Lorri and Svanberg, 1993).

2.5 DRYING OF FOODS

2.5.1 Drying Characteristics of Foods

Drying is one of the oldest food preservation techniques known to man. Apart from extending the shelf-life of foods, drying also reduces costs of storage and transportation and retains the organoleptic properties of the food. In most of the sub-Saharan Africa foods prepared by submerged culture fermentation such as *uji, togwa, obusera* and *ogi* are usually consumed after the fermentation process (Akinrele, 1970; Odunfa, 1985; Lorri and Svanberg, 1993). Foods prepared by solid substrate fermentation, such as *kwanga*, *boulettes, cosettes* and *miettes* are usually further preserved by sun-drying (FAO, 1990; Onwueme and Charles, 1994). However, submerged culture fermented foods can also be preserved by drying because of their high solids content. Traditionally when fermented foods are dehydrated they still often deteriorate rapidly because of their high final moisture content of about 13-14%, and poor packaging. Proper drying and packaging of these foods could result in increased food self-sufficiency and also make the foods available to a wider cross-section of the population.

Water loss from food materials can take place by various mechanisms (Sodha *et al.*, 1987). The most important mass transfer mechanism in *uji* is by capillary action and vapour flow due to the granular solids that have high porosity and high critical moisture content; characteristics that make them have a long falling rate period. The limitation is that increase in temperature of the product leads to nutrient degradation, loss of flavour compounds and undesirable chemical reactions. Therefore when choosing a drier and drying conditions (i.e. suitable time and temperature), the food constituents must be considered. Hayashi (1989)

suggests the use of drum, flush and agitated conduction driers for paste foods (e.g. mashed potatoes), and spray, freeze and foam-mat driers for liquid foods (e.g. coffee and milk)

Drying of porous granular solids involves two distinct stages:

1. A constant rate period: This is the period when internal resistance to moisture transport is less than external resistance to water vapour removal from the product surface (Sodha *et al.*, 1987). There is no increase in temperature of the material being dried because of its high moisture content. Only latent heat of vapourisation is required and the temperature does not exceed the wet bulb temperature. The drying rate in this period is governed by the following equation (Sodha *et al.*, 1987):

$$dM / dt = h_c A(T_a - T_w) / l \qquad \text{Equation 1}$$

where;

dM / dt = drying rate, kg water evaporated / second;

h_c = thermal conductance of air film, W / m^2K;

T_a = temperature of hot air, ^oC ;

T_w = temperature of wet surface, ^oC;

l = latent heat of vapourisation, J / kg;

A = drying surface area, m^2.

2. Falling rate period: In this period internal resistance to moisture transport exceeds external resistance, and movement of moisture through the porous granular solids is by capillary action. When all the unbound moisture has been removed, drying should be stopped to avoid damaging the product. Loss of moisture in the falling rate period for

thin layer drying is represented by the Henderson-Pabis equation:

$$dM / dt = -k (M-M_e)$$

which on integration gives:

$$M(t)-M_e / M_{in}-M_e = \exp (-kt) \qquad \text{Equation 2}$$

where;

t = drying time;

M(t) = product moisture at time, t;

M_e = equilibrium moisture content;

M_{in} = initial (t=0) moisture content at the start of falling rate period, or at the beginning of the experiment if there is no constant rate period;

k = the drying constant, h^{-1}.

The thin layer drying constant can be related to the temperature by the Arrhenius equation i.e.

$$k = p \exp (-q / T) \qquad \text{Equation 3}$$

where p and q are constants determined by the material and T is temperature in Kelvin. The value k depends on the moisture content, temperature and relative humidity.

Page equation which uses purely empirical relationships is more widely used for a variety of materials instead of the Henderson-Pabis equation (Hutchinson and Otten, 1983)

$$MR = \exp (-Kt^N) \qquad \text{Equation 4}$$

where;

$MR = M-M_e / M_{in}-M_e$;

K and N are constants;

t = time, minutes.

2.5.2 Sun and Solar Drying

Sun drying has been used by man since time immemorial to preserve food and is still widely used in Kenya to dry products like fish and coffee beans. Kenya, which lies across the equator receives an abundant supply of solar energy all year round. The country is situated between latitudes 3°S and 4°N and longitude 35°E and 41°E. Almost the whole country receives more than 18 MJm^{-2} per day, on average (Okoth, 1983).

Okoth (1983) and Shakya and Flink (1986) have reported several advantages of sun drying foods:

1. The energy is free, non-polluting and readily available in tropical and sub-tropical countries and can be used in areas without electricity;
2. The energy is renewable and non-depleting;
3. It requires low capital investment;
4. The high quality of the product is maintained since there is no over drying or over heating.

Despite these advantages there are also some limitations to the use of solar energy (Okoth, 1983):

1. It is intermittent in nature and is not available throughout the period of processing i.e. during cloudy spells and at night. Auxillary drying systems must therefore be provided when solar energy cannot be utilised, but this has the effect of increasing the operating cost;
2. Product is exposed to environmental contamination from insects, dust and rodents;
3. Drying material occupies a very large area;
4. Process is relatively slow as compared to the techniques that use other forms of energy;
5. Increased chances of product spoilage due to slow drying.

Sun-drying of *uji* has been reported to reduce the moisture content to about 15% (KIRDI unpublished). This high moisture value together with poor packaging promotes further uptake of moisture and can lead to colonization of the food by undesirable flora. Though there is not yet an acceptable moisture content, a value of 6.5-8.5% as recommended for *gari, lafun, eluko* and *yam* flours (Onayemi and Oluwamukami, 1987) can also be considered acceptable for *uji*.

Solar driers are improvements on the traditional sun drying technique. In operation, solar radiation is captured and used to heat air, increasing its ability to hold and carry water vapour. The heated air then warms up and extracts moisture from the product. The solar driers must be able to harness the sun's energy and convert it into heat energy, which is then used for drying. Their effectiveness is therefore dependent on factors such as area, colour and material of the surface and the angle of the incoming radiation. According to Sodha *et al.* (1987) solar driers can be classified as:

1. Natural convection driers: These do not require any mechanical or electrical power to

operate as they rely on natural circulation of air (i.e. hot or warm air rises and cooler air is sucked in to take its place). Examples are solar cabinet driers, solar tent driers and chimney type solar driers. Their main limitation is low air flow rates.

2. Forced convection driers: These require the use of a fan or blower to pump air through both the solar collector and the product. Their use is not common in developing countries because of the need for supplemental power supply to operate the fans.

In the design of solar driers, the aim is to overcome the problems posed by sun drying. Apart from the intermittent nature of sunshine, solar driers do not have the disadvantages of sun drying. According to the Brace Research Institute (1986) solar driers:

1. Make better use of the available solar radiation and other climatological factors;
2. Produce a more even dried product of higher quality;
3. Reduce the noxious effect caused by dust, dirt and insect infestation;
4. Reduce the dangers of incomplete drying caused by sudden rainfall and high humidities;
5. Reduce, wherever possible, the time taken to dry the agricultural product.

2.5.3 Drum Drying

Drum driers (also known as roller driers) are hot cylinder driers that are used to dry solutions (e.g. milk) and slurries (e.g. potato puree). A drum drier may have one or two rollers and is referred to as single or double drum drier respectively (Karuri, 1978). In operation heat is transferred by conduction from the condensing steam within the drum through its wall to the thin layer of feedstock on its outer surface. The material is either fed in from the top at one end of the drum or dip-fed as the drum submerges into a feed trough. As the drum rotates,

the material is dehydrated and is peeled off by the scraper knives once it has covered about 75% of the drum. The main advantage of the drum drier is its high thermal efficiency (Karuri, 1978), however its use is limited by the high initial costs, need for auxilliary installations such as boilers and ventilated hoods to collect the moisture, reconstitution difficulties, loss of nutritive and organoleptic qualities. Karuri (1978) performed drying studies on purees prepared from bananas, cassava and horsebean and was able to predict the optimum drum operating conditions as shown in Table 1.

Table 1: Optimum conditions for drum drying of some tropical food purees

Variable	Cassava puree	Banana puree	Horsebean puree
Feed gap (mm)	0.4-0.6	0.2	0.6
Feed solids (% dwb)	30-40.5	26	24
Drum speed (rpm)	1.5-4.5	2.5-5.0	1.5-5.0
Steam pressure (bars)	2.8-4.8	2.5-3.5	1.8-4.8
Flake moisture (% dwb)	3.0-4.5	nd	3.0-6.5

nd: data not given

Source: Karuri (1978)

Though there seems to be no published work on the effect of drum drying on *uji*, high losses of volatile flavour compounds have been reported for *koko* (*akasa*), a Ghanaian fermented maize porridge (Andah and Muller, 1973).

2.5.4 Cabinet Drying

The material is loaded on trays and hot air is blown across them. Drying occurs as hot air is transferred to the surface of the moist product. It supersedes sun and solar drying because all the essential drying parameters (i.e. air velocity, temperature and relative humidity) can be determined and controlled (Hayashi, 1989). Heat is transferred to the drying materials by radiation from the heated surfaces and by convection from the hot air. The rate and completeness of the drying process depends on moisture content of the product, air temperature and humidity, surface area of the material and air flow rate. The main limitations to cabinet drying are:

1. Wastage of exhaust air especially if it is still hot and saturated;
2. The product has a high chance of case hardening especially if the loading rate is too high;
3. It is relatively expensive when compared to sun and solar drying techniques.

2.5.5 Other Drying Techniques

Advanced drying techniques at low temperature (e.g. freeze drying and vacuum freeze drying) are expensive in capital cost, operation and maintenance. Even in developed countries, like Japan, their use is limited to production of instant coffee and instant foods in which excellent quality and aromatic elements should be naturally maintained (Hayashi, 1989). The use of these techniques in sub-Saharan Africa would make the products unaffordable to low income earners. The advantages of freezing and subsequent sublimation are that there is excellent retention of flavour, colour, aroma and nutrients and reconstitution is easy to achieve. Nabors and Salunkhe (1969) have reported that there are no significant losses of volatile constituents, ascorbic and lactic acid from freeze-dried sauerkraut.

Spray drying would be inappropriate for *uji* because of the nature of the material. Fluidized bed drying would also not be suitable due to the high initial moisture content of *uji*. Moisture content of materials for fluidized bed drying should be in the range of 10-20% (Hayashi, 1989). Fluidized bed drying is therefore suitable in a two-stage drying operation where the fermented slurry is first dried in a cabinet, tunnel or continuous belt drier. Microwave drying has the disadvantage of high initial costs, and it cannot be applied to foods with moisture content of 50% or more because of improper ebullition for the drying process.

2.5.6 Loss of Flavour Compounds on Drying

Flavour has been defined as a mingled sensation of smell and taste. The taste buds of the mouth however can only distinguish between acidity, bitterness, saltiness and sweetness; and more subtle stimuli are obtained by volatile constituents diffusing into the nose (Greenshields, 1974). These volatile compounds constitute the aroma, and this is the major contributor flavour perception. In some foods, such as coffee and tea, flavour is critical to overall acceptability. In other foods such as meat and cheese, flavour is important but is not the dominant quality characteristic that will determine acceptance. Other attributes such as texture, mouthfeel and appearance also become important.

The volatiles in foods represent a large variety of functional groups and chemical classes of compounds. In meat, for example, in excess of 700 volatile components contribute to flavour (Reineccius, 1984). Advanced analytical methods such as gas-liquid chromatography and high pressure liquid chromatography have been developed to identify these compounds; but these instruments have limited levels of detection and will only analyse single components.

In contrast flavour perception by the nose and the mouth will give a total impression of aroma and taste of the food; and humans have lower limits of detection than machines. The main limitation of using human beings in flavour analysis is that they are subjective (Greenshields, 1974). Thus, as a compromise, optimal information on flavour of a food is only possible by a combination of the sensory and instrumental analysis.

Aroma compounds in fermented foods are the result of metabolic activities of the micro-organisms involved in fermentation. As already discussed in section 2.4.2 not all the micro-organisms found in fermented foods will contribute towards flavour development. Unpublished results of research conducted at Kenya Industrial Research and Development Institute (1996) indicate a wide variety of aldehydes, alcohols, fatty acids and esters from *uji* fermented from maize-finger millet composites contribute to the flavour (Table 2). Table 2 also shows the flavour compounds found in other fermented African foods.

As water is evaporated from a food product, it carries with it some volatile constituents leading to a loss of the characteristic flavour. The relative volatilities of the different odorous compounds are affected by changes in temperature or pressure and on their solubilities in water (Flink and Karel, 1970). Most African fermented foods (e.g. *gari, togwa, attieke, uji, kwanga* and *kawal*) that are dehydrated are usually sun-dried (Dirar *et al.*, 1985; Odunfa, 1985; Onayemi and Oluwamukami, 1987). Though little work has been done to establish the effect of dehydration on the flavour of African fermented foods, it is most likely that the drying conditions and systems used can have a marked influence on the organoleptic properties of *uji.*

Table 2: Flavour compounds produced from the fermentation of some African foods

Product	Raw material	Flavour compounds	Reference
Uji	maize-finger millet	Ethanol, pentanol, acetic, hexanoic, octanoic, hexenal, 1-propanol, 1-pentanol, 1-hexanol, 1-octanol, 1-nonanol	KIRDI (unpublished)
Ogi	maize	Lactic, acetic, butyric	Akinrele (1970), Banigo and Muller (1972)
Gari	cassava	Lactic, succinic, pyruvic, acetic, propionate, aldehydes, ethyl ketone	Ofuya and Nnanjiofor (1989)
Foofoo	cassava	Acetic, butyric, lactic, ethanol, isobutyric.	Blanshard *et al.* (1994)

Andah and Muller (1973) have reported high losses of flavour compouds when *koko* (a Ghanian fermented maize porridge) is either drum or spray-dried. In contrast Nout *et al.* (1989) reported minimal losses of organic acids from fermented drum-dried porridge. In these two studies the raw material, processing methods and microbial flora were not similar. All these are factors that could determine the extent of retention of flavour compounds. For *kawal* (a meat substitute derived from fermentation of *Cassia obtusifolia* leaves in Sudan), the level of volatile fatty acids declined by 5% on sun-drying (Dirar *et al.*, 1985), while significant losses of volatile compounds and lactic acid have been reported when sauerkraut (a European fermented vegetable) is either oven or microwave dried (Nabors and Salunkhe,

1969). From these studies it can be inferred that different drying systems and temperatures have a major influence on the retention of flavour compounds in fermented foods. Since fermented *uji* is normally cooked at about 100°C for 20-30 minutes before consumption, it is possible to determine appropriate drying conditions that would not adversely affect flavour.

Of all the drying methods, freeze drying gives the highest retention of volatile flavour and aroma compounds in foods (King, 1973; Flink and Karel, 1970). This could be explained by the slower rates of diffusion to the evaporation or sublimation interface, by the morphology and molecular aggregations and degree of crystallinity in the material during freeze drying or subsequent treatment (King, 1973). The hypothesis that volatiles are adsorbed onto the dried material has been discounted by Flink and Karel (1970). Other closely associated methods that preserve food flavours on drying are vacuum drying, vacuum belt drying and atmospheric spray drying.

Various methods have been developed to improve retention of flavour in dried foods (Joslyn and Heid, 1963):

1. Drying under conditions such that flavour loss during dehydration is reduced by reducing temperature or pressure of the product being dried, as in vacuum drying.
2. By recovery of the volatile essences and returning them to the product during the drying process.
3. By recovery of volatile flavours and their combinations with flavour fixing or holding substances resulting in solid flavour sealed products that can be granulated and added back to the finished product.
4. By development of flavour from flavour precursors by the activity of naturally occurring or added enzymes.

2.5.7 Effect of Drying on the Physico-chemical Properties of Foods

Starch is the main component of cereal seeds and certain roots and tubers and its values range from 74-85%, 72-73% and 67-72% on dry weight basis for cassava, maize and finger millet respectively (FAO, 1990; FAO, 1992; FAO, 1995). The starch granules are composed of amylose and amylopectin. Amylose is a linear polymer consisting of (1-4)-linked alpha-D-glucopyranosyl units; while amylopectin is a highly branched polymer of alpha-D-glucopyranosyl units linked by (1-4) bonds with branches resulting from (1-6) linkages. This basic difference in the structures of amylose and amylopectin cause them to have different physico-chemical properties which have been summarized by Shannon and Garwood (1984).

The amylose content of cassava starch is in the range of 13.6-23.8% (Kay, 1987; Rickard *et al.*, 1991) and 20-30% for maize (Penfield and Campbell, 1990). The amylose and amylopectin polymers are found within the starch granules. The maize starch granules are either angular with dimpled surfaces or rounded with smooth surfaces (Penfield and Campbell, 1990). Cassava starch granules have diameters ranging from 5-20 μm and are either round, cylindrical, spherical, oval, polygonal or truncated (Rickard *et al.*, 1991).

Table 3: Properties of amylose and amylopectin components of starch

Property	Amylose	Amylopectin
General stucture	Essentially linear	Branched
Colour with iodine	Dark blue	Purple
Maximum of iodine complex	~650 nm	~540 nm
Iodine affinity	19-20%	1%
Average chain length) (glucose residues)	100-10000	20-30
Degree of polymerisation (glucose residues)	100-10000	10000-100000
Solubilty in water	Variable	Soluble
Stability in aqueous solution	Retrogrades	Stable
Conversion to maltose by crystalline beta-amylase	~70%	~55%

Source: Shannon and Garwood, 1984.

Drying of lactic acid fermented cereal and root crops changes the starch granules and this subsequently affects the behaviour of the flours during processing (Westby and Cereda 1994). The changes are thought to be brought about by enzymes and acids in the fermented slurry (Camargo *et al.*, 1988).

On rehydration of lactic fermented and dehydrated cereal flours, the rate of absorption of water is affected by the size and shape of the particles and by the physical and chemical changes that occurred during drying and storage. For example, when a slurry of starch is drum-dried it gets pregelatinized. This process damages the granules and the dry product

readily takes up water when dispersed (Penfield and Campbell, 1991). Proteins are denatured, but this change is of little consequence to the subsequent behaviour of the flour due to the low protein levels in cassava, maize and finger millet flours. Other factors that may affect the rate of reconstitution are: nature of water (i.e. is it hard or soft, distilled or tap water), presence of other soluble materials such as salt, temperature of the water, process of manufacture of the substrate and the time period for the reconstitution process.

Gelatinization and pasting have been used interchangeably in the past, but now they refer to certain specific stages as the starch suspension is heated (Penfield and Campbell, 1990). Gelatinization includes the early changes and is manifested as irreversible changes in properties such as granular swelling, native crystallite melting, loss of birefringence and starch solubilization. Gelatinization begins in the intercellular areas where hydrogen bonds are weakest (Glicksman, 1969). It involves disruption of hydrogen bonds within the starch granules causing water molecules to become attached to the liberated hydroxyl groups as the granules continue to swell irreversibly. Birefringence is lost when the granules are disrupted, a phenomenon that takes place between the gelatinization and pasting temperature (Rickard *et al.*, 1991). Pasting occurs after gelatinization and involves granular swelling, exudation of amylose and amylopectin polymers from the granules and eventually total disruption of the granules. The temperature at which rapid swelling of the granule begins depends on the type of starch and added ingredients but falls in the range of 62-75°C for maize (Penfield and Campbell, 1990) and 56-66°C for cassava (Rickard *et al.*, 1991). The collapse of the granule increases the viscosity of the suspension due to exudation of molecular components from it. Maximum viscosity is normally achieved at about 90°C. This behaviour of starch suspension on heating is best observed in a Brabender Amylograph, which gives temperature at which pasting begins, peak viscosity, stability of the cooking starch at 95°C for one hour,

postheating thickening referred to as setback, and stability of the paste after one hour at 50°C. The completeness of gelatinization and pasting depends on a number of factors:

1. Concentration of the starch;
2. Rate and extent of heating;
3. Type and size of the starch granules;
4. Presence of any added ingredients such as sugars, acids, lipids and surfactants;
5. Ratio of amylose to amylopectin;
6. Rate of shear.

Cassava starch do not form gels on cooling, while maize starch form rigid gels. This difference could be attributed to the different ratios of amylopectin and amylose polymers in these starches, the latter being higher in maize than in cassava. The amylose fraction is considered to be primarily responsible for gel formation and is able to form gels at a concentration as low as 1.5% (Olkku and Rha, 1978)

3 MATERIALS AND METHODS

3.1 PREPARATION OF MATERIALS AND EXPERIMENTAL DESIGNS

3.1.1 Preparation of Raw Materials

Fresh cassava roots (20 months old) were harvested from a farm in Migori District, Nyanza Province of Kenya. The tubers were then washed to remove any adhering soil, and an incision made on the surface with a knife followed by removal of the peel by hand. The roots were then cut into cubes of about 2x2x2 cm and sun-dried for 48 hours. The dried chips were then finely milled in a hammer-mill. Maize and finger millet grains were purchased from a local wholesale market in Nairobi. They were cleaned to remove broken seeds, dust and other extraneous material, dried and finely milled in a hammer-mill. Proximate analysis was done on the maize, cassava and finger millet flours. Crude protein (Nx6.25), ether extract, crude fibre, ash and moisture contents of the flours were determined by the AOAC methods (1975). Soluble carbohydrate (nitrogen free extract) was estimated by difference.

3.1.2 Preparation of Inoculum

Maize, finger millet, cassava, and 1:1 composites of maize-finger millet and cassava-finger millet were each mixed with tap water that had been boiled then cooled to 45°C; in ratios of 2:3 (flour to water). The slurries were allowed to ferment spontaneously in a water bath (Blue M Electric company, USA) set at 45°C. After 24 hours, 10 g of the slurries were sampled under hygienic conditions. The samples were homogenized with 90 ml sterile buffered (pH 5.7) peptone water (Hi Media Mumbai, India) and decimal dilutions prepared. The dilutions

were made into pour plates with MRS agar (10 g bacteriological peptone, 8 g meat extract, 4 g yeast extract, 20 g D(+) glucose, 1 ml tween 80, 2 g diammonium hydrogen acetate, 5 g sodium acetate, 0.2 g magnesium sulphate, 0.04 g manganese sulphate, 1000 ml distilled water). Incubation was carried out at 30°C for 4 days. Plates with 30-300 colonies were used to determine the microbial population. Between six and eight colonies were randomly selected from plates obtained from the highest dilution. The selected colonies were isolated by streaking on MRS agar and incubated at 30°C for 4 days. The purity of the isolated organisms was checked by streaking again on MRS agar plates followed by microscopic examinations and catalase reaction as described by Harrigan and McCance (1976). Gram positive and catalase negative rods and cocci were selected and labelled. Stock cultures were subcultured in MRS broth before further tests could be performed. The test on homo- and heterofermentative assimilation of glucose were assessed using MRS broth with durham tubes inserted. Growth at 15°C was tested in MRS broth incubated in a Memmert incubator (854 Schwabach West Germany) while at 45 and 50°C incubation was done in a Blue M water bath for 10 days. Production of ammonia from arginine was done by inoculating MRS broth containing 0.3% arginine. Ammonium production was tested by addition of Nesslers reagent.

3.1.3 Fermentation of the Flours

Maize, finger millet, maize-finger millet, cassava and cassava-finger millet flours were separately mixed with water in a ratio of 2:3 (flour to water) in 500 ml round bottomed flasks. Backslopping was done by adding 15 g of the inoculum prepared above. Fermentation was then allowed to proceed at 45°C for 24 hours. The variables measured were acidity, carboxylic acids, pasting and viscosity properties. The experiment was set up as a completely

randomized design with three replicates. The data were analysed by a one-way analysis of variance and further analysis by use of non-orthogonal contrasts. The following contrasts were considered:

L1 : Maize vs Finger millet

L2 : Maize vs Cassava

L3 : Cassava vs Finger millet

L4 : Maize vs Maize-Finger millet

L5 : Cassava vs Cassava-Finger millet

L6 :.Maize-Finger millet vs Cassava-Finger millet

L7 : Finger millet vs Maize-Finger millet

L8 : Cassava vs Cassava-Finger millet

3.1.4 Fermentation and Drying of the Flours

The fermented slurries were thinly spread on trays at a loading rate of 13 kg/m^2. Sun-drying was done over a period of two days starting approximately 8.00 am to 5.00 pm each day. At night the trays were stored in a cabinet drier set at 30°C. A single drum-drier (APV-Mitchell Dryers Ltd. Carlisle, England) was also used to dry the slurries. The roller drier has dimensions of 0.3048 m diameter; 0.2797 m total surface area and 0.2921 m length. The effective drying surface of the drum is 79.3% and the product contact surface is chromium plated. The drum was set to rotate at two revolutions per minute at a steam pressure of 2 bars and 0.4 mm feed gap. A laboratory cabinet drier (Type U40 Memmert 854 Schwabach, West Germany) was also used. The trays were placed in the drier at 55°C. Temperatures were kept to an accuracy of plus or minus 0.5°C and drying was done for 24 hours. The dried samples were then ground in a food drink blender (Sanyo model) for two minutes. The experiment

was set up as a 5 x 3 factorial in a completely randomized design with three replications. The drying systems were sun-, cabinet-, and drum-drying while the substrates were maize, cassava, finger millet, cassava-finger millet and maize-finger millet. The analysed variables were acidity, flavour retention, viscosity, rehydration and pasting behaviour. Data was entered into Microsoft Excel spread sheets and then analyzed using the statistical package Genstat 3.2 as described by Payne (1994). Testing for significance between means was done by Least Significant Difference (LSD) at $p<0.05$.

3.2 ANALYSIS OF THE PASTING PROPERTIES AND CARBOXYLIC ACIDS

3.2.1 Determination of Gelatinization and Pasting Characteristics of the Slurries

The cooked paste viscosity of a 14% (dry matter basis) slurry of sample was determined with a Brabender Amylograph (Brabender Instruments, Inc, Duisburg) equipped with 700-cmg sensitivity cartridge. The samples were heated at 1.5°C per minute to 96°C. Gelatinization and pasting temperature, peak viscosity and viscosity at 96°C were determined from the amylograph.

3.2.2 Determination of Swelling Power and Solubility of the Slurries

A modified method as described by Schoch (1964) was used. Moisture content of the fermented and dried flours and of the fermented sluries were first determined. The substrates were then weighed (2.5 g) into 100 ml pre-weighed centrifuge bottles. Distilled water was added to give a total volume of 90 ml. The suspension was then stirred to keep it completely and uniformly suspended. The bottle was placed in a water bath maintained at 85^0C, while

stirring at regular intervals. Heating was continued for 30 minutes, then the bottle removed and wiped dry on the outside. The bottle was then centrifuged at 2200 x g rpm (Beckman, model TJ-6). A 25 ml portion of the supernatant was transferred to a tared 100 ml nickel evaporating dish and evaporated to dryness on a steam bath. The dish was then dried for 2 hours in a cabinet drier (Type U40 Memmert 854 Schwabach, West Germany) at 55^0C. The dish was then cooled in a dessicator and weighed. The soluble materials were determined using the following equation:

$$\% \text{ solubles (on dry basis)} = \frac{\text{Weight of soluble starch x 400 x 2}}{\text{Weight of sample on dry basis}}$$

To obtain the swelling power, the remaining supernatant in the centrifuge bottle was withdrawn and discarded. The bottle and contents were then weighed and the swelling power determined by the following formula:

$$\text{Swelling power} = \frac{\text{Weight of sedimented paste x 100}}{\text{Weight of sample on dry basis x (100 - \% solubles, dry basis)}}$$

3.2.3 Rehydration Test

Ten grammes of the sample was added back into 40 ml distilled water in a centrifuge tube and allowed to stand for 30 minutes in a water bath at 30°C. The mixture was centrifuged at 3000 x g rpm (Beckman, Model TJ-6) for 20 minutes. Excess water was drained out and the sample weighed again. Rehydration ratio was calculated as ratio of the drained weight after rehydration to weight of the sample taken.

3.2.4 Determination of Total Titratable Acidity and Fixed Acidity

Ten grammes of sample was mixed with 90 ml distilled water and the pH measured. (Model 290 MK, Pye Unicam). To the slurry 0.1 M sodium hydroxide was added up to pH 8.5 while stirring continuously. Acidity was reported as follows :

$$\text{ml NaOH} \times 10^{-3} \times 90 = \%\ \text{w/w}$$

Fixed acidity was determined by weighing 10 g of sample to a dish, adding 10 ml distilled water and evaporating to dryness in a boiling water bath. This was repeated three times after which 90 ml distilled water was added and the slurry titrated with 0.1 M sodium hydroxide as described above. The acidity values were reported on a dry weight basis.

3.2.5 Determination of Carboxylic Acids by Thin Layer Chromatography

Twenty grammes of the fermented and dehydrated samples was extracted with 160 ml of petroleum ether (40-60°C B.pt.) in a soxhlet extractor for three hours. Excess of the solvent was then evaporated with minimum heat in a steam bath. This was done by placing the round bottomed flasks on aluminium trays suspended over a boiling water bath. The extract was then converted into its ammonium salt by dropwise addition of ammonium hydroxide (1:1 v/v) until just alkaline. The ammonium salts of the fatty acids were spotted on thin layer chromatography plates (20x20 cm), coated with 0.25 mm silica gel with fluorescent indicator UV_{254} (Machery Nagel GmbH and Co. KG, Germany). The sheets were then stood in a 0.5-0.7 cm layer of butanol in a chromatography tank. Neutral red 0.05% w/v, used as the indicator, was added to this mobile phase. An equal volume of 1.5 N aqueous ammonia was transferred to beakers which were then stood in the butanol phase. A predetermined solvent front of 15 cm was marked on the spotted plates before dipping them in the chromatography

tanks. When development was complete, the plates were removed and exposed to air for 15 minutes. The acids were identified as magenta spots on an orange background. The spot areas given by the standards were used to plot regression lines (figure 8) for each acid, from which the acid content of unknown spots were read directly. (Akinrele, 1970; Banigo and Muller, 1970)

3.3 SENSORY EVALUATION OF DEHYDRATED LACTIC FERMENTED *UJI*

Dehydrated *uji* flour (100 g) was weighed and added to 500 ml of cold tap water and the temperature allowed to slowly rise as the slurry was heated to boiling. It was then kept boiling for 20 minutes and sweetened with 50 g sugar, then cooled to about 40°C before serving to 10 panelists with sensory evaluation experience of fermented *uji.* The multiple comparison test was used and the sensory attribute to be evaluated was flavour. The fermented non-dehydrated *uji* was the reference sample (R) and it was compared against the sun-, cabinet-, and drum-dried samples for *uji* fermented from maize, finger millet and cassava flours and composites of maize-finger millet and cassava-finger millet.

Each of the test samples was coded with 3-digit random numbers while the reference sample was marked R. Each sample was tested to determine if it was better than, comparable to or inferior to the reference and the scores recorded on a five point hedonic scale as shown below:

1 Extremely better than R;

2 Better than R;

3 No difference;

4 Inferior to R;

5 Extremely inferior to R;

The results were analyzed by a two way analysis of variance (ANOVA) with the different drying systems and panelists as sources of variation. The means were compared by the Least Significant Difference Test ($p<0.05$).

4 RESULTS AND DISCUSSION

4.1 PROXIMATE COMPOSITION OF MAIZE, FINGER MILLET AND CASSAVA FLOURS

The proximate composition of the maize, finger millet and cassava flours used in this study are presented in Table 4. The flours differed widely in their contents of crude protein, ether extract and soluble carbohydrate. Maize flour had the highest protein and fat contents, whereas cassava flour had the least. Conversely the carbohydrate content was highest in cassava and lowest in maize. The ash contents in cassava and finger millet flours were quite similar, while the levels were lower in maize. Crude fibre and moisture content in all three flours did not differ much.

The flour proximate composition results were found to agree with published values (Onwueme and Charles, 1994; FAO, 1995). The high fat content in maize flour was attributed to the grain having not been degermed before milling. The fibre contents of the cereal flours correspond to values reported in literature for hulled grains (FAO, 1992). The high carbohydrate content in the flours indicated their importance as sources of energy. However, due to their poor protein quantity and quality (FAO, 1990; Onwueme and Charles, 1994) excessive reliance on these flours as predominant food sources can result to protein malnutrition.

Attempts have been made to breed cassava varieties with improved protein levels (Asiedu *et al.*, 1992), but this has met with little success, especially due to the reduction in the amount of carbohydrates. Quality Protein Maize and its predecessor Opaque–2 Maize varieties have

been developed to improve on the protein quantity and quality in maize but these developments have met with little success (BOSTID, 1988). These genetically improved maize varieties have lower yields, are more susceptible to insect and fungal attacks and have poor storage qualities. The protein values of these staple flours could also be increased by supplementing them with protein rich foods from plant (Akpapunum and Sefa-Dedeh, 1995) or animal sources; or by a combination of fermentation and germination treatments (Mensah *et al.*, 1991; Nout, 1993).

Table 4: Proximate composition of maize, finger millet and cassava flours[a]

Substrate	Crude protein[b]	Ether Extract	Ash	Crude fibre	Carbohydrate	Moisture
Maize	9.97± 0.24	9.23 ± 0.06	1.23 ± 0.07	2.88 ± 0.02	6.64 ± 2.16	11.12 ± 0.02
Finger millet	5.55 ± 0.16	1.50 ± 0.01	2.33 ± 0.15	2.88 ± 0.04	87.75 ± 0.11	12.13 ± 0.06
Cassava	2.83 ± 0.03	0.63 ± 0.01	2.24 ± 0.11	2.69 ± 0.03	91.63 ± 1.08	11.65 ± 0.18

a : Mean ± standard deviation (n =3)

b : N x 6.25

All data are expressed on a percent dry-matter basis except for moisture

4.2 FERMENTATION MICRO-ORGANISMS IN THE FLOURS

The total viable counts and percentages of betabacterium group isolated from the slurries fermented at 45^0C for 24 hours are shown in Table 5. The total viable count on MRS agar was about 10^8 cfu/g in all the slurries. Thirty-six LAB strains were isolated and classified according to the Orla Jensen system. The obligately heterofermentative betabacterium group constituted majority of LAB in all slurries. The distribution of other microbial isolates were as follows:-

1. Streptobacterium group, 16.7%, isolated from cassava-finger millet slurry;
2. *Leuconostoc* spp, 12.5%, isolated from cassava slurry;
3. Thermobacterium group, 12.5% and 16.5% isolated from cassava and cassava–finger millet slurries respectively;
4. *Pediococcus* spp, 12.5% and 50%, isolated from cassava and maize slurries respectively.

The betabacterium group and leuconostocs follow the hexose monophospahste pathway when they metabolize substrates in the flours to give lactic acid, ethanol and carbon dioxide; all in almost equal proportions. Carbon dioxide production was identified by bubbling on the surface of the slurries; and because of its low volatility, together with ethanol, are lost during cooking of the slurries. Streptobacterium, thermobacterium and pediococci follow the hexose diphosphate metabolic pathway and lactic acid is the predominant by-product. It is this lactic acid produced by both the homo-, and heterofermentative LABs that is responsible for the sour taste of fermented and cooked *uji* slurries.

Table 5: Microbial count and distribution of betabacterium group of LABs isolated from slurries fermented at 45°C for 24 hours

Substrate	Total viable count (cfu/gm)	Betabacterium group (% isolated)
Maize	8.0×10^7	100.0 (n=6)
Finger millet	1.0×10^7	75.0 (n=8)
Cassava	1.1×10^8	62.5 (n=8)
Maize-finger millet	3.6×10^7	50.0 (n=8)
Cassava-finger millet	1.6×10^8	66.7 (n=6)

a : Mean of two samples of each flour type, each plated in duplicate

n : Number of isolates from the highest dilution of each substrate

The predominance of betabacterium group has also been reported in cereal flours fermented at 45°C (Mbugua, 1984); but homofermentative streptobacterium has been found to dominate at lower temperatures (Akinrele, 1970; Mbugua, 1984). Inspite of these conflicting reports, which seem to indicate that temperature of fermentation will influence the group of LAB microflora, the data still indicated that LAB were the majority micro-organisms involved in submerged culture fermentation of cereal and root flours, confirming results in literature (Mensah *et al.*, 1991; Svanberg *et al.*, 1992). A few yeast cells were also identified in the fermented slurries. These yeasts are responsible for non-bacterial metabolism of the flour constituents (Akobundu, 1981; Nout, 1993) and also contribute to flavour development.

The pH of all the flour slurries had dropped to about 4.0 after fermentation at 45°C for 24 hours. The observation that the isolated micro-organisms consisted of a mixed culture agrees with published information (Steinkraus, 1992); the LAB grow on such substrates lowering the pH to 3.5 before inhibiting their own growth. The results obtained were therefore found to be representative of what would be expected during fermentation of cereals and root flours. Fermentation of the substrates at 45°C enabled rapid acidification within 24 hours as opposed to the traditional method where the process is done at room temperature or close to a charcoal or wood fire, a process that takes at least two days before the desired sourness is attained. The critical role of fermentation temperature in rapid acidification and flavour development of fermented cereal and root crops has also been shown by Akinrele (1970) and Blanshard *et al.* (1994).

The fresh slurries were inoculated with enriched native *uji* cultures in a process referred to as backslopping. Though the use of mixed cultures in fermentation has several disadvantages (Hesseltine, 1991); backslopping was essential in this study in order to rapidly lower the pH

of the slurries from about 6.0 to 4.0. This procedure has previously been employed in the fermentation of cereal and root flours (Mbugua, 1985; Bokanga, 1992; Lorri and Svanberg, 1993). It enables rapid acidification of the slurries by eliminating the lag phase of LAB and promoting growth of strong acidulating lactobacilli and pediococci (Mbugua, 1984). This enhanced acidity suppresses coliforms and pathogenic gram-positive and gram-negative bacteria (Svanberg *et al.*, 1992) thus ensuring a product with greater flavour stability.

4.3 PASTING CHARACTERISTICS OF THE FLOURS

4.3.1 Percent Solubility and Swelling Power of the Flours at 85°C

The results on flour solubility and swelling power at 85°C are presented in Table 6 and Table 7. The results showed that granule swelling preceded starch solubility. The latter resulted from the leaching of low molecular weight amylose from the granules into the solution which then became sticky and viscous. The solubility and swelling power indices of the flours were lower than values reported in literature (Rickard *et al.*, 1991; FAO, 1995) probably due to lipids and proteins in the flours which inhibited swelling and exudation by forming complexes with amylose in the granules (Olkku and Rha, 1978; Penfield and Campbell, 1990). Cultivar differences could also have been responsible for the differences of solubility and swelling power from published values (Rickard *et al.*, 1991).

Table 6: Solubility indices[a] of uji slurries at 85°C

Subtrate	Flour	Fermented slurries	Fermented and sun dried	Fermented and Cabinet dried
Maize	8.30 ± 2.04	15.67 ± 1.94	9.82 ± 0.75	8.14 ± 1.75
Finger Millet	7.13 ± 2.70	7.30 ± 0.32	5.63 ± 1.23	7.01± 2.24
Cassava	9.70 ± 1.53	13.48 ± 3.56	10.30 ± 2.72	8.39 ± 2.43
Maize-Finger Millet	11.28 ± 1.02	10.48 ± 0.65	9.34 ± 2.00	9.89 ± 1.77
Cassava-Finger Millet	9.09 ± 1.65	7.02 ± 0.96	6.44 ± 0.37	9.87 ± 2.15

[a]Expressed on a percentage dry matter basis

Table 7: Swelling Power indices [a,b] of *uji* slurries at 85°C

Substrate	Flour	Fermented slurries	Fermented and sun dried	Fermented and Cabinet dried
Maize	1.82 ± 0.48	2.27 ± 0.02	1.70 ± 0.18	1.56 ± 0.26
Finger Millet	1.89 ± 0.58	1.60 ± 0.29	2.08 ± 0.49	2.30 ± 0.39
Cassava	2.70± 0.58	3.82 ± 0.71	2.76 ± 0.84	3.06 ± 0.58
Maize-Finger Millet	2.23± 0.11	1.71 ± 0.08	1.68 ± 0.05	2.02 ± 0.13
Cassava-Finger Millet	1.94 ± 0.44	2.23 ± 0.08	2.59 ± 0.84	2.46 ± 0.13

[a]Expressed on a percentage dry matter basis

[b]Ratio of sedimented paste to sample on dry matter basis

Combination of fermentation and cabinet drying did not cause any significant changes ($P<0.05$) in the solubilities and swelling powers of all the flours. This could be due to the fact that cabinet drying at 55°C is more effective, than sun-drying, in removing moisture from slurries and therefore reverting them closer to the original moisture content of the non-fermented flours. However, the fermented and dried flours could not behave in an exactly similar manner as their non-fermented counterparts due to the presence of acids and other metabolic by-products produced during the fermentation. The method was not applicable to fermented and drum-dried flours because these samples had pre-gelatinized starches (Schoch, 1964).

It was generally observed that fermentation had a greater influence on flour solubility and swelling power than the nature of drying. Maize and cassava flours solubilized and swelled more readily after fermentation than after fermentation and drying; while finger millet granules were hardly affected by either of the treatments.

4.3.2 Rehydration of Fermented and Dried Flours at 30°C for 30 Minutes

The results of effect of fermentation and drying on the water absorption capacity of the flours are given in Table 8. It was observed that sun and cabinet dried flours absorbed about 1.8 - 1.9 times their own weight of water while drum dried flours absorbed about four times their own weight of water. In the latter case the slurries were not only dried, but also cooked; a process that caused the starch granules to burst and enabled the hydroxyl groups of the exposed amylose and amylopectin polymers to form numerous hydrogen bonds with the added water. This is advantageous because the drum dried flour can be readily reconstituted in cold or warm water to make ready-to-eat porridge, as opposed to the cabinet or sun dried flours which must be cooked for about 20 minutes before they are ready for consumption. However the extensive damage caused to starch in the drum dried slurries present formidable reconstitution difficulties. When these flours are added to water they tend to lump together inhibiting formation of smooth slurries, an important characteristic of *uji*.

Table 8: Rehydration ratios of fermented and dried flours at 30^{0}C for 30 minutes

Drying condition	Maize	Finger millet	Cassava	Maize-Finger millet	Cassava-Finger millet
Sun	1.788 ± 0.05	1.847 ± 0.03	1.943 ± 0.01	1.874 ± 0.07	1.884 ± 0.02
Cabinet	1.845 ± 0.03	1.915 ± 0.04	1.907 ± 0.05	1.808 ± 0.03	1.945 ± 0.09
Drum	4.446 ± 0.13	4.467 ± 0.23	4.277 ± 0.37	4.450 ± 0.17	4.417 ± 0.22

$$\text{Rehydration ratio} = \frac{\text{Drained weight after rehydration}}{\text{Weight of sample taken}}$$

4.3.3 Amylographic Properties of the Flours

The cooking and textural characteristics of the flours were investigated using a Brabender Amylograph; and the results are presented in Tables 9–11 and Figures 2–6. The amylograms provide useful information on hot paste viscosity characteristics of the flours at 14% concentration (dry-weight basis) after being subjected to various treatments.

All the three non-composited, non-fermented flours differed in their peak and the 96°C viscosities ($p<0.05$, Table 9). Among the composites, cassava-finger millet flour had significantly higher peak and the 96°C viscosities than the maize-finger millet composite ($p<0.05$). Composited maize-finger millet flour gave a lower peak than either of the pure flours. On the other hand cassava-finger millet composite had a peak viscosity that was not significantly different from finger millet but was lower than the pure cassava flours ($p<0.05$). In all these observations the root flour slurries (i.e. cassava and cassava-finger millet) gelatinized at lower temperatures than their cereal flour counterparts (i.e. maize, finger millet and maize-finger millet composite). Maize flour had a higher onset gelatinization temperature than either cassava or finger millet flours, whereas the latter two were not significantly different ($p<0.05$). On further heating, cassava maintained a lower peak gelatinization temperature than the cereal flours ($p<0.05$). Among the composites, maize–finger millet exhibited higher onset and peak gelatinization temperatures than cassava-finger millet flour ($p<0.05$).

Table 9: Amylographic indices of non-fermented flours

Flour	Gelatinization Temperature (°C)		Viscosity (BU)	
	Onset	Peak	Peak	96°C
Maize	57.00 ± 0.00	63.25 ± 0.43	800.00 ± 52.92	773.33 ± 41.63
Finger millet	52.75 ± 1.89	60.00 ± 3.97	1393.33 ± 5.77	1190.00 ± 196.72
Cassava	52.25 ± 2.41	54.00 ± 1.98	1763.33 ± 30.55	1463.33 ± 37.86
Maize-Finger millet	57.75 ± 1.98	69.00 ± 1.30	670.00 ± 0.00	630.00 ± 10.00
Cassava-Finger millet	52.25 ± 0.43	54.50 ± 0.43	1776.67 ± 11.55	1290.00 ± 60.83

Since brabender viscosities of flours is predominantly a function of starch, the results indicated that resistance to pasting was highest in cereal flours and lowest in root flours. Meanwhile gelatinization occurred later in the cereal flours than in the root flours. These results confirm earlier findings that root starch granules swell more readily and gelatinize at lower temperatures than cereal starch granules (Pomeranz, 1987; Sefa–Dedeh, 1989). Therefore during cooking, the cassava granules tend to occupy a higher proportion of the total volume and are in close contact with their immediate neighbours resulting into much thicker pastes than the cereal flours. The delayed gelatinization and low viscosity of the cereal flours could be attributed to lipids and proteins in the starch granules, which form complexes with amylose polymers (Penfield and Campbell, 1990) and therefore inhibit swelling and release of the exudate. The high levels of amylopectin polymers in cassava and finger millet flours (Rickard *et al.,* 1991; FAO, 1995) when compared to maize flour (Penfield and Campbell, 1990) could also have been responsible for the differences in the slurry viscosities. The extensive branching of the amylopectin polymers enables it to have more exposed hydroxyl groups than amylose polymers. Extensive hydrogen bonding was therefore able to take place between the added water and amylopectin polymers, encouraging swelling of the granules and formation of more viscous pastes by cassava and finger millet slurries. Also increasing intergranular contact enabled the hot pastes of cassava and finger millet to have more cohesive and elastic characteristics than maize slurries.

The cassava containing slurries (i.e. cassava and cassava-finger millet) recorded the greatest declines in viscosity after peak viscosity had been reached. This was a reflection of the nature of weak bonding forces on cassava starch granules and inability of these granules to withstand shearing forces at high temperatures. This latter characteristic is important as it indicates the ease of cooking of cassava slurries at elevated temperatures.

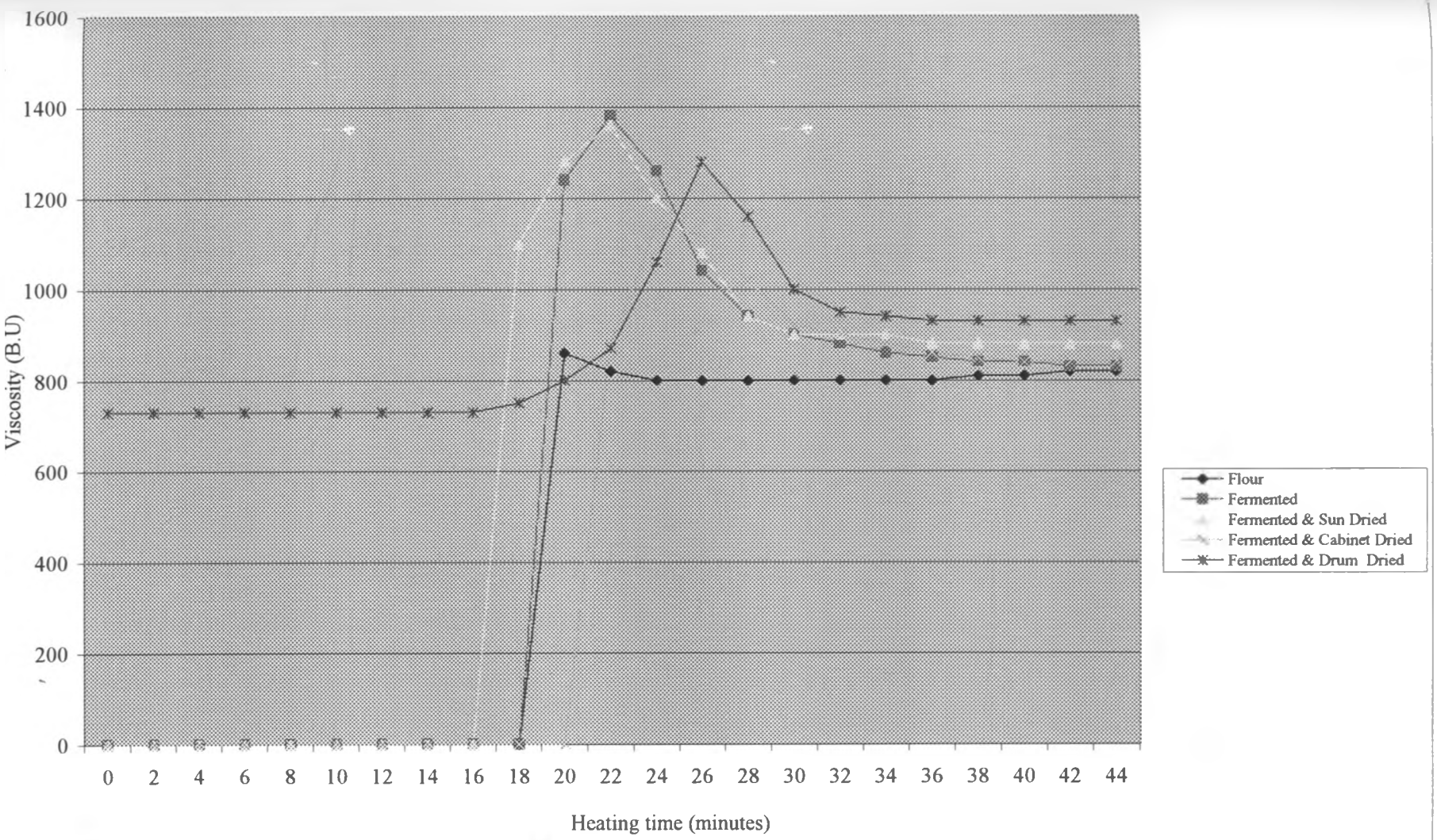

Figure 2: Amylograms of *uji* slurries made from maize

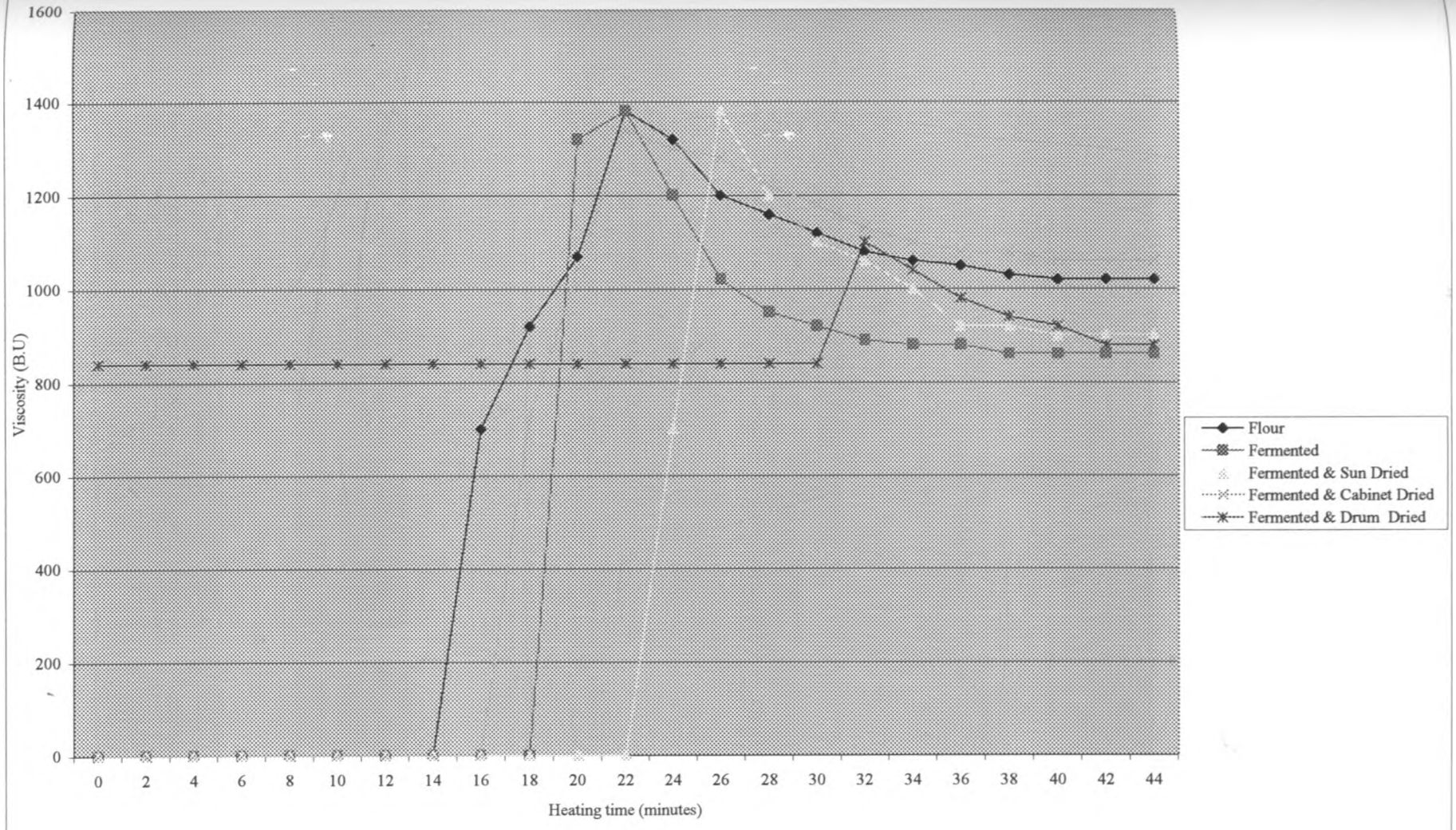

Figure 3: Amylograms of *uji* slurries made from finger millet

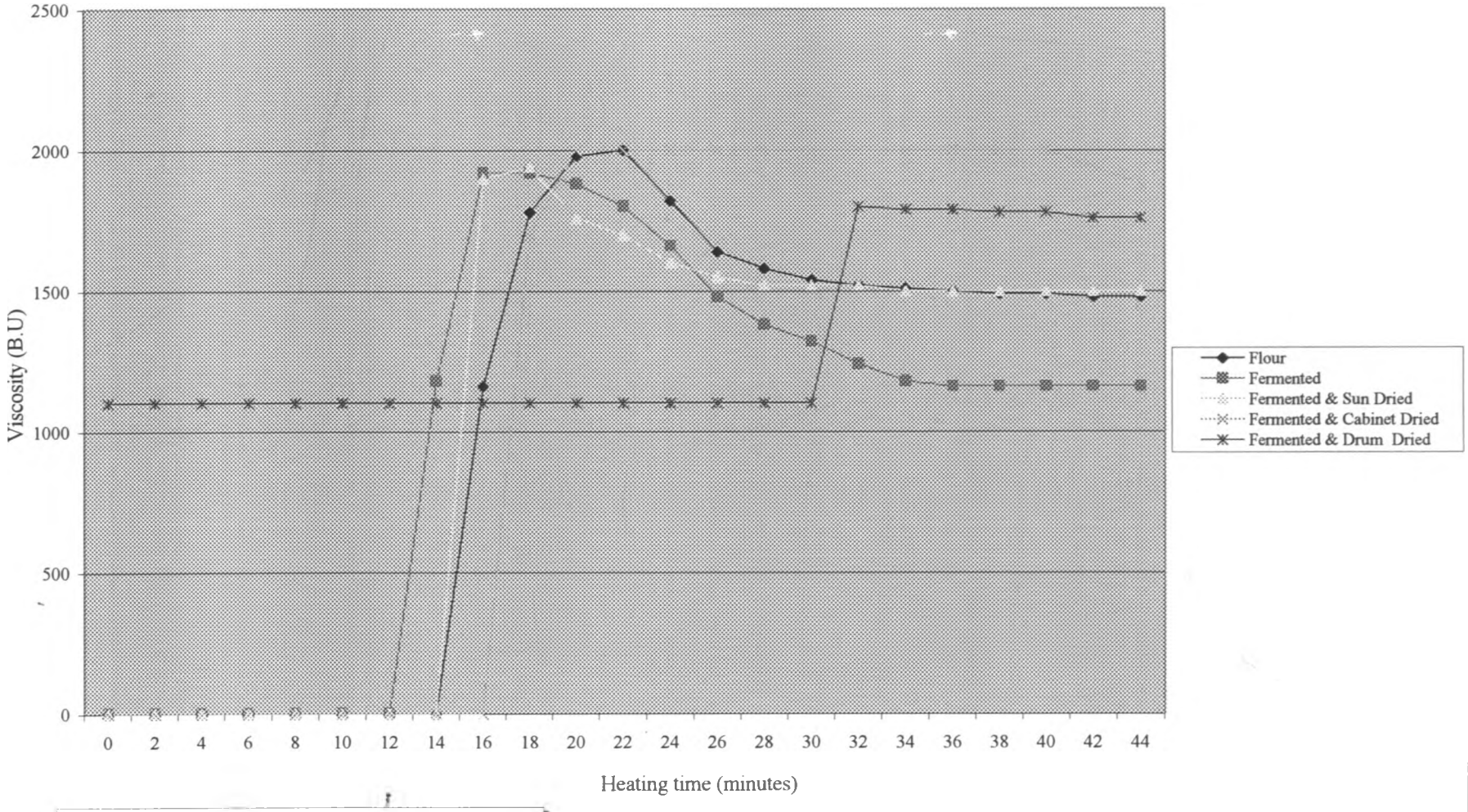

Figure 4: Amylograms of *uji* slurries made from cassava

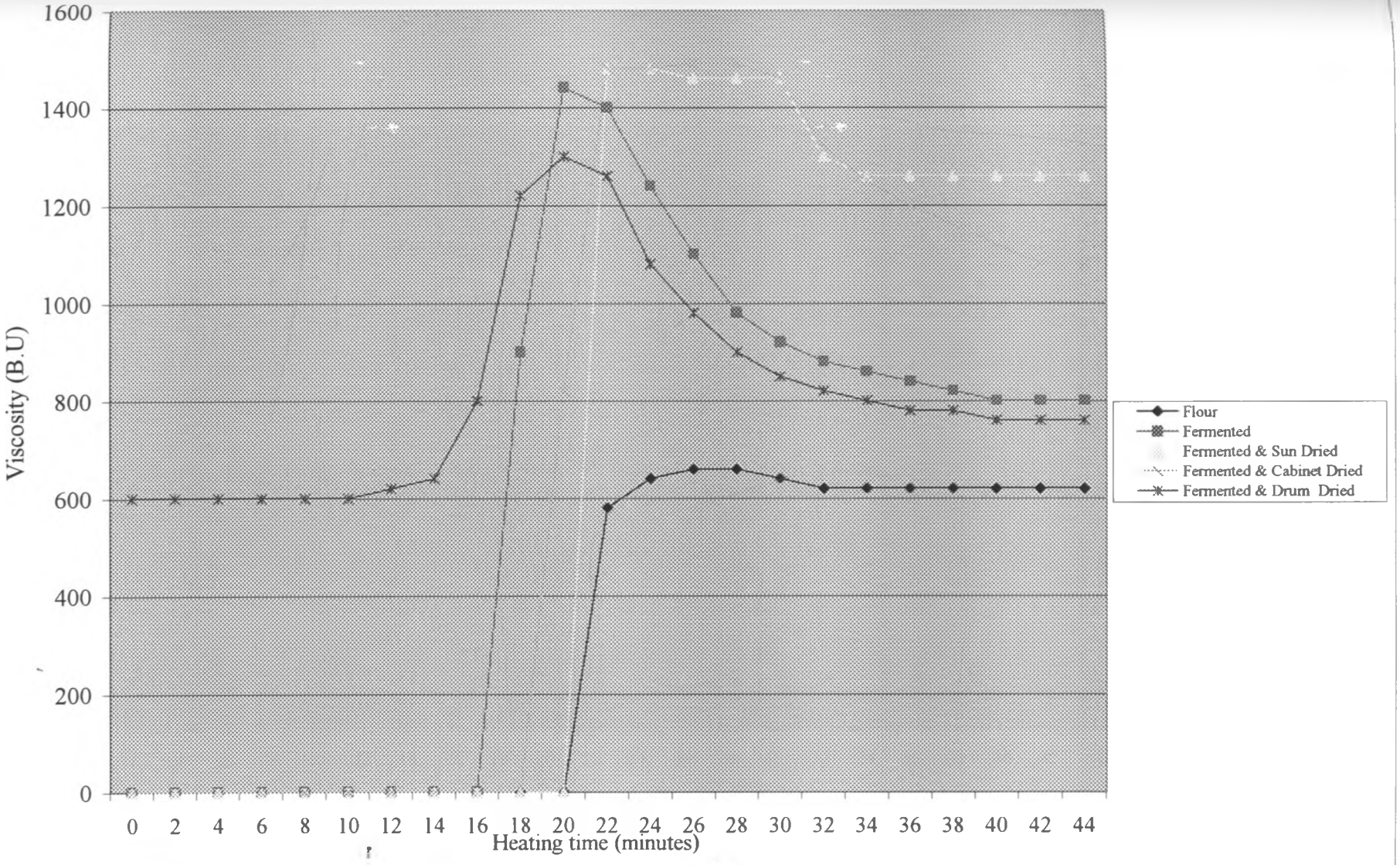

Figure 5: Amylograms of *uji* slurries made from maize-finger millet blends

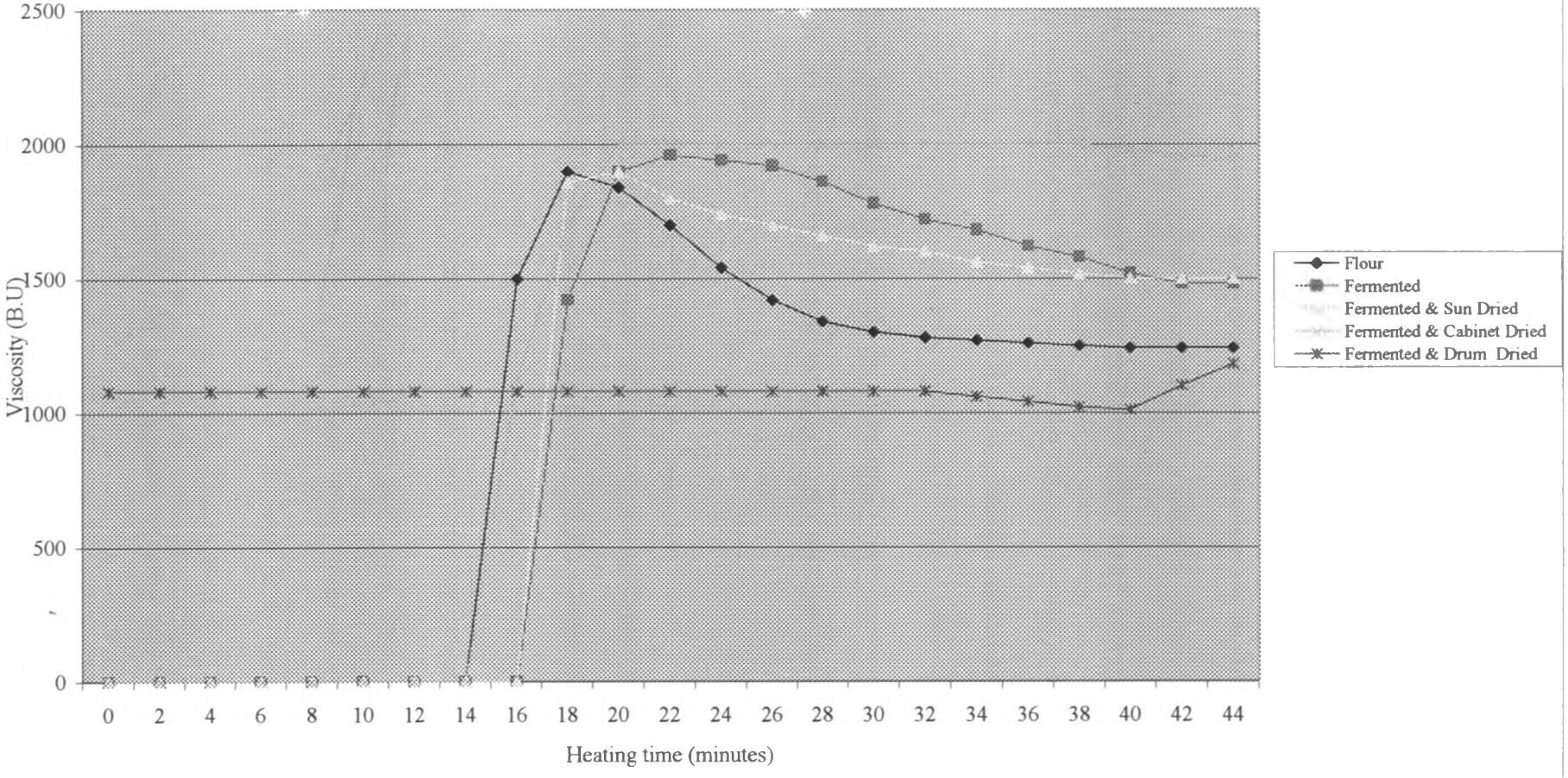

Figure 6: Amylograms of *uji* slurries made from cassava-finger millet blend

4.3.4 Effect of Fermentation on the Pasting Properties of the Flours

Fermentation resulted in increased viscosity for all the flours; maize (500 BU) and maize–finger millet composite (780 BU) recorded the largest increases. The fermented slurries did not differ much from the non-fermented slurries in their gelatinization temperatures except for maize-finger millet composite in which the peak gelatinization temperature declined by 10°C. Among the non-composited fermented slurries cassava maintained a higher peak viscosity at a lower gelatinization temperature than either maize or finger millet ($p<0.05$, Table 10). However on further heating to 96°C, the viscosity of cassava did not differ from that of finger millet ($p<0.05$) although these flours recorded the greatest and least declines in viscosity respectively. Maize maintained a significantly lower viscosity at 96°C than either cassava or finger millet ($p<0.05$). Among the composited flours, cassava-finger millet had a significantly higher peak and 96°C viscosities but at lower gelatinization temperatures than the maize-finger millet composites ($p<0.05$).

Though fermentation did not have much influence on the gelatinization temperatures, it significantly increased the viscosity of all the flours.($p<0.05$) Similar findings have been reported (Banigo *et al.*, 1979; Akpapunum and Sefa-Dedeh, 1995) but other authors (Mbugua, 1986; Sefa-Dedeh, 1989) have found that fermentation actually reduces the viscosity of cereal slurries. These different responses could have arisen from the different processing techniques that the flours may have been subjected prior to viscosity determination in the Brabender Amylographs. In this study it is hypothesised that the increased viscosities were influenced by the soaking conditions at 45°C for 24 hours. The steeping allowed the granules to absorb large amounts of water and swell. When these slurries were then heated, the absorbed water was converted into steam, which further

swelled the granules, and together with the acids produced during fermentation, enhanced their disintegration and leaching of the amylose. As a result of these granular changes shear resistance of the fermented slurries against the stirrers increased and this was recorded as an increase in viscosity on the amylograms.

The above explanation may be inadequate to explain the very large increase in viscosity that was recorded by maize and maize-finger millet slurries. The increases in viscosity when these two slurries were fermented could also have been influenced by the relatively high levels of lipids and proteins in maize compared to finger millet and cassava (Table 4). These internal (occurring in the granule interiors) and surface (occurring on the granule surfaces) lipids and proteins are associated with amylose (Penfield and Campbell, 1990) in the non-fermented maize and may have inhibited swelling of the granules and exudation of amylose polymers. But on fermentation, the LAB and yeasts utilised these lipids and proteins in their metabolism and in the process freed the amylose polymers and enabled the granules to readily swell when heated.

Table 10: Amylographic indices of fermented slurries

Slurry	Gelatinization Temperature (°C)		Viscosity (BU)	
	Onset	Peak	Peak	96°C
Maize	56.50 ± 0.87	62.25 ± 1.30	1343.33 ± 40.41	813.33 ± 20.82
Finger millet	55.75 ± 1.14	61.50 ± 1.30	1423.33 ± 61.10	1213.33 ± 313.90
Cassava	50.50 ± 0.87	52.75 ± 0.43	1813.33 ± 66.58	1226.67 ± 100.17
Maize-Finger millet	55.50 ± 1.30	59.00 ± 0.87	1453.33 ± 72.34	936.67 ± 130.51
Cassava-Finger millet	53.75 ± 1.73	56.25 ± 2.60	1780.00 ± 10.00	1553.33 ± 41.63

4.3.5 Effect of Fermentation and Drying on the Pasting Properties of the Flours

The amylographic indices of fermented and sun-, cabinet- and drum dried flours are presented in Table 11. All the flours recorded increases in peak and 96°C viscosity, except for fermented and drum dried cassava-finger millet, when compared to the non-fermented flours. The fermented and drum dried cassava-finger millet composite maintained a constant viscosity of about 1000 BU at 96°C (Figure 6). Fermented and sun- or cabinet dried samples recorded slight increases in gelatinization temperatures when compared to the non-fermented flours. The average increase was 3°C with individual values ranging from 0-10°C. In all these flours the root flours gelatinized at lower temperatures than the cereal flours; a behaviour that was similar to that exhibited by the non-fermented and fermented flours.

The effect of drying on the fermented slurries either resulted in slight increases or no change in onset and peak gelatinization temperatures. The greatest increase were recorded by the drum dried slurries. There was no consistent change in viscosity on drying the fermented slurries. The pure flours of maize and cassava recorded increased peak and 96°C viscosities while finger millet exhibited reduced viscosities. The composites either had increased or slight declines in both the peak and 96°C viscosities. Drying alone does not therefore seem to offer any significant beneficial effects pasting behaviour or viscosity of fermented slurries.

The gelatinization temperatures were significantly higher when finger millet, cassava and cassava-finger millet were fermented and drum-dried, but lower in maize and maize-finger millet, when these flours were compared to either their sun- or cabinet- dried counterparts ($p<0.05$) or to the non-fermented flours. Drum drying pregelatinizes the flours and hence gelatinization would be expected to occur at higher temperatures due to the extensive

hydration of the starch. However the slightly lower levels of amylopectin in maize (Penfield and Campbell, 1990) caused it to swell more rapidly and therefore gelatinize at lower temperatures.

All the fermented and drum dried flours recorded an instantaneous increase in viscosity (Figures 2-6) when Brabender Amylograph was turned on. This was attributed to the starch granules which had been damaged by the drum drying process and therefore had numerous exposed hydroxyl groups on the amylose and amylopectin polymers. These hydroxyl groups were able to form extensive hydrogen bonds and therefore readily swelled and thickened in cold water. It was these thick pastes which exerted a resistance to the rotating spindles of the amylograph and caused the sudden rise in viscosity. This initial rise in viscosity was greatest in cassava (1100 BU) followed by finger millet (920 BU) then maize (720 BU), the values suggesting a progressive decline in amylopectin levels in these flours.

The precooked nature of fermented and drum dried flours makes them appropriate as high energy giving foods especially where fuel requirement for food preparation is limited. The disadvantage of these pregelatinized flours is that they tend to lump when added to cold water. This problem could be overcome by adding a suitable wetting agent to the flours before drum-drying.

Table 11: Amylographic indices of fermented and dried flours

Drying condition	Flour	Gelatinization temperature (°C)		Viscosity (BU)	
		Onset	Peak	Peak	96°C
Sun	Maize	57.50 ± 1.73	64.75 ± 2.16	1380.00 ± 6.06	833.00 ± 41.63
	Finger millet	63.50 ± 0.87	68.00 ± 0.87	1430.00 ± 55.68	940.00 ± 40.00
	Cassava	51.50 ± 0.87	53.50 ± 1.73	1907.00 ± 11.55	1493.00 ± 11.55
	Maize-Finger millet	61.00 ± 1.73	62.00 ± 0.87	1403.00 ± 68.07	887.00 ± 23.09
	Cassava-Finger millet	55.50 ± 1.98	56.00 ± 0.87	1860.00 ± 0.00	1470.00 ± 43.59
Cabinet	Maize	63.00 ± 2.41	71.75 ± 3.85	1237.00 ± 68.07	907.00 ± 61.10
	Finger millet	56.75 ± 2.84	61.25 ± 1.56	1337.00 ± 15.28	1087.00 ± 15.28
	Cassava	54.00 ± 1.50	58.00 ± 2.29	2000.00 ± 0.00	1880.00 ± 0.00
	Maize-Finger millet	56.50 ± 1.73	61.00 ± 1.14	1450.00 ± 43.59	1057.00 ± 11.55
	Cassava-Finger millet	52.50 ± 1.30	56.00 ± 0.87	2000.00 ± 0.00	1960.00 ± 20.00
Drum	Maize	55.50 ± 1.50	65.50 ± 2.84	1427.00 ± 127.02	1123.00 ± 177.86
	Finger millet	80.00 ± 3.12	81.50 ± 3.85	1373.00 ± 219.39	1033.00 ± 300.22
	Cassava	72.00 ± 1.50	79.00 ± 1.73	1820.00 ± 0.00	1793.00 ± 11.55
	Maize-Finger millet	53.00 ± 0.87	59.00 ± 1.89	1283.00 ± 83.86	797.00 ± 72.34
	Cassava-Finger millet	90.00 ± 0.00	93.00 ± 2.64	1053.00 ± 141.89	1080.00 ± 87.18

4.4 TOTAL TITRATABLE ACIDITY, FIXED ACIDITY, PH AND CARBOXYLIC ACID LEVELS IN THE FLOURS

The total titratable acidity (TTA), fixed acidity (FA) and pH of the fermented slurries are presented in Table 12. The TTA of the non-fermented flours ranged from a low of 0.22% in cassava to a high of 0.36% in the maize-finger millet composite. Lactic acid was the predominant fixed acid comprising 85-95% of TTA in all the fermented slurries. The pH of the non-fermented flours was about 5.5 and declined to about 4.0 after fermentation at 45°C for 24 hours.

The R_f values (Table 14) and retention data of the standard acids (Figure 8) were compared with those of the fermented slurry extracts and hence the caboxylic acids of the fermented slurries were identified (Table 15). Formic acid had almost the same R_f value as acetic acid hence it was not possible to distinguish these two acids from the spot developed. Banigo and Muller (1972) reported similar difficulties in separating the two acids from *ogi* by paper partition chromatography, though they were able to achieve good separations on TLC. The failure to separate the two acids by TLC in this procedure could be attributed to the different developing solvent other than that of Banigo and Muller (1972). Hence the spots were calculated as acetic acid.

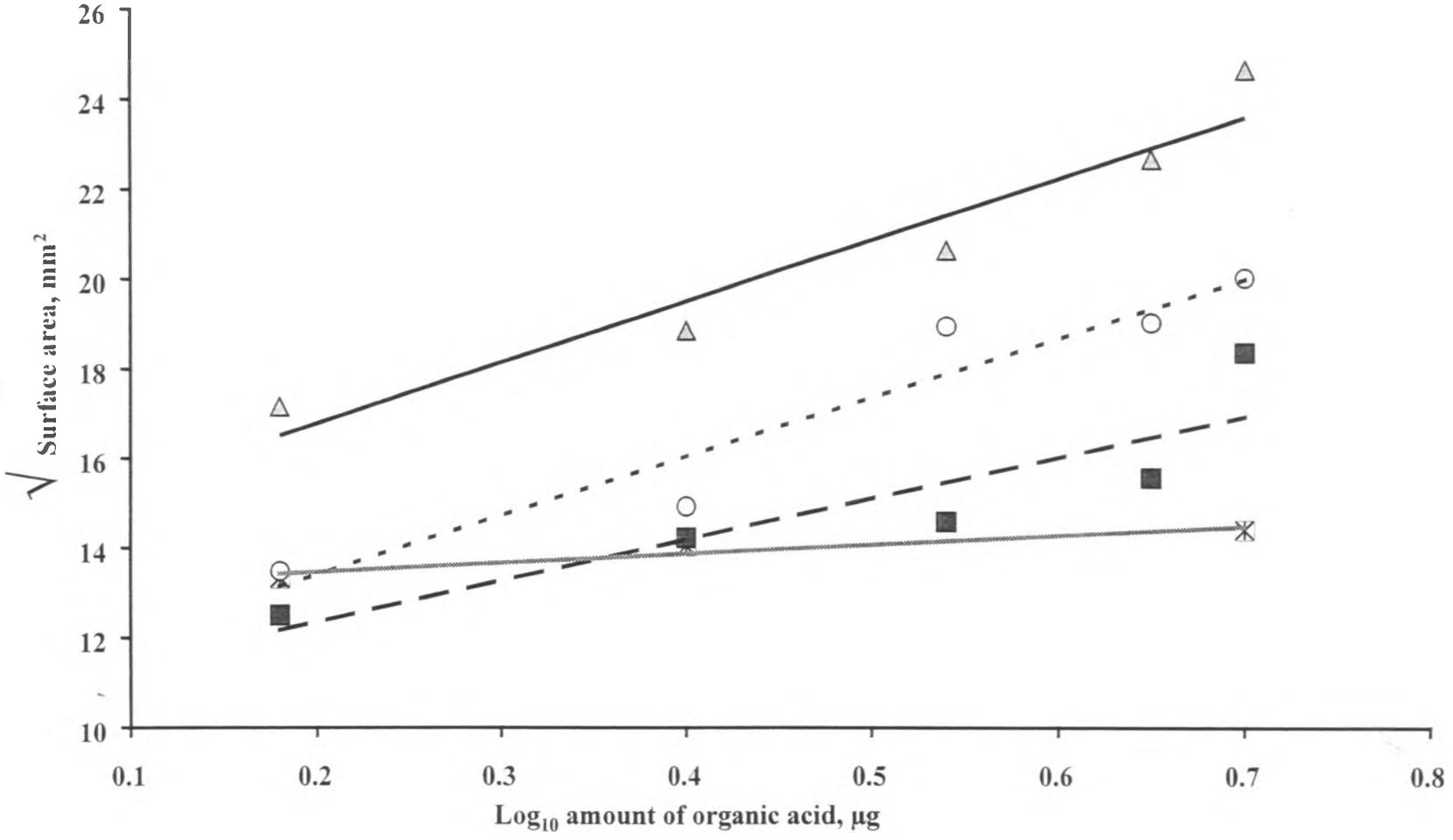

Figure 8. Relation of spot area and applied standard substance. Adsorbent: silica gel with fluorescent indicator. Solvent butanol saturated with ethanol; time of run 6 hours; amounts of each 5 µg.

—△— hexanoic acid, ·····○····· propionic acid, – –■– · acetic acid and —✳— Formic acid

Lactic acid is the predominant non-volatile acid in cereal and root crop fermentations (Banigo and Muller, 1972). The high moisture content (65%) of the slurries together with backslopping allowed for the establishment of a stable mixture of LAB and hence accelerated production of lactic acid. This acid is produced by the homofermentative action of *Lactobacillus plantarum* on residual sugars and dextrins (Akinrele, 1970). In this study, the heterofermentative betabacterium groups of LABs were the most predominant probably due to the high fermentation temperatures employed. Apart from lactic acid, these heterofermenters also produced copious amounts of acetic acid (Table 15) and carbon dioxide from the hexoses via the hexose monophosphate shunt. Gas production was identified by bubbles seen on the surface of the slurries.

The level of acetic acid was almost the same in all the non-composited flours. Compositing the flours enhanced the levels of the acetic acid in the fermented slurries. Formic acid has been shown to occur only in trace amounts in fermented cereal substrates while acetic and the non volatile lactic acid occur in abundant amounts (Banigo and Muller, 1972; Nout *et al.*, 1989). These acids contribute to the sour taste of fermented cereals and also inhibit intestinal pathogenic bacteria (Svanberg *et al.*, 1992).

Propionic acid was not detected in any of the fermented substrate slurries. However Plahar and Leung (1982) reported that propionic acid could be detected in dough if the fermentation period is extended beyond 24 hours. Propionic acid is the principal by-product in the metabolism of *Propionibacterium* spp and *Clostridium propionicum*, which are microaerophilic and obligate anaerobes respectively. These microbes are thus only able to start their metabolic activities when the redox potential of the medium has been sufficiently lowered by the LABs.

Table 12: PH value, total titratable acidity (TTA) and fixed acidity (FA) of slurries after 24 hours of fermentation at 45°C

Flour	pH	TTA[a](% lactic acid)	FA[a]
Maize	3.67 ± 0.03	3.91 ± 0.05	3.34 ± 0.06
Finger millet	4.12 ± 0.03	3.77 ± 0.05	3.43 ± 0.12
Cassava	3.85 ± 0.09	3.71 ± 0.04	3.48 ± 0.05
Maize-Finger millet	3.80 ± 0.05	4.54 ± 0.22	4.26 ± 0.15
Cassava-Finger millet	4.07 ± 0.08	3.26 ± 0.05	2.86 ± 0.02

a: All data are expressed on a dry-matter basis

Among the non-composited fermented slurries, (Table 14) the TTA of the finger millet did not differ from that of either maize or cassava ($p<0.05$) but maize had a significantly higher TTA than cassava ($p<0.05$). Cassava had higher levels of non-volatile acids than either maize or finger millet, but the latter two did not show any significant difference ($p<0.05$). Among the composites, maize-finger millet had a higher TTA and FA than the cassava-finger millet slurry. The maize-finger millet composite developed a higher TTA and FA than either of the flours fermented individually, while in contrast the cassava-finger millet slurry had a lower TTA and FA than either the fermented cassava or finger millet flour individually ($p<0.05$). Though red finger millet was used its high tannin content did not seem to inhibit the process of acidification either when the flour was fermented alone or as a composite with maize flour. It would thus be unnecessary to remove the tannins of red finger millet grains before fermentation. The rather high acidity values for maize-finger millet composite could be due to its lower level of the heterofermentative betabacterium group (Table 5) in favour of the homofermentative LAB which produce predominantly lactic acid.

The effect of fermentation and drying on the acidities and pH of the flours are shown in Table 14. The TTA and the FA of all the flours declined on drying. The decline in the TTA could be attributed to the loss of the more volatile acetic acid (Nabors and Salunkhe, 1969). Cassava had the greatest percentage decrease in both TTA and FA, with values averaging 50-60%. This was then followed by cassava-finger millet with losses of 20-37% for both TTA and FA. The other substrates experienced losses of around 20% on drying. Cassava slurries exhibited poor development of acidity and readily lost these on drying; however compositing with finger millet greatly reduced the amount of acids lost on drying, probably reflecting the ability of the fermentation acids to get more strongly adsorbed to the finger millet granules. Slight increases in pH were recorded after drying the fermented slurries. This could have been due to oxidation

of the acids on exposure to air, thus reducing their active oxygen concentration, or probably due to the oxidation of lactic acid to form weak acetic acid (Nabors and Salunkhe, 1968).

Table 16 shows the levels of hexanoic acid in the flours after they were fermented and dried under different conditions. Acetic and formic acids were not identified on the TLC plates. These acids are volatile and were lost with the moisture during the drying process. Similar losses of volatile fatty acids have been reported by Dirar *et al.* (1985) when sun drying fermented leaves of *Cassia obtusifolia*. Comparison in the levels of hexanoic acid after fermentation (Table 15) and after fermentation and drying (Table 16) show that cassava experienced the greatest decline (84 – 94%). Fermented maize, cassava and maize-finger millet slurries (Table 16) experienced higher losses of hexanoic acid when drum dried than when either sun-, or cabinet dried (Table 16). The high losses of hexanoic acid on drum drying may have been due to volatilization of the acid on the hot contact surface of the drum; especially when the slurry might have overstayed on the surface before being scraped off. The losses of non-volatile hexanoic acid on sun-drying may have been due to microbial transformation resulting in the partial destruction of hexanoic acid. This oxidation is caused by some yeasts e.g *Candida mycoderma* (Akinrele, 1970) which are favoured by the sun drying temperatures but get killed at the cabinet or drum drying conditions.

Table 13: PH value, total titratable acidity (TTA) and fixed acidity (FA) of fermented and dried flours

Drying Condition	Flour	pH	TTA[a] (% lactic acid)	FA[a]
Sun Drying	Maize	3.98 ± 0.20	2.70 ± 0.18	2.40 ± 0.06
	Finger millet	4.10 ± 0.10	3.22 ± 0.19	2.92 ± 0.10
	Cassava	4.53 ± 0.06	1.63 ± 0.04	1.35 ± 0.17
	Maize-Finger millet	3.98 ± 0.03	3.63 ± 0.03	3.45 ± 0.03
	Cassava-Finger millet	4.40 ± 0.10	2.05 ± 0.08	1.94 ± 0.07
Cabinet Drying	Maize	3.60 ± 0.10	3.46 ± 0.04	2.46 ± 0.02
	Finger millet	4.23 ± 0.06	2.99 ± 0.04	2.52 ± 0.14
	Cassava	4.43 ± 0.12	1.64 ± 0.02	1.39 ± 0.07
	Maize-Finger millet	3.90 ± 0.00	3.40 ± 0.04	2.96 ± 0.02
	Cassava-Finger millet	4.32 ± 0.03	2.28 ± 0.07	1.98 ± 0.07
Drum Drying	Maize	3.72 ± 0.10	4.00 ± 0.07	3.06 ± 0.07
	Finger millet	4.27 ± 0.12	3.00 ± 0.12	2.70 ± 0.27
	Cassava	4.48 ± 0.03	2.00 ± 0.10	1.33 ± 0.04
	Maize-Finger millet	4.03 ± 0.03	3.90 ± 0.11	3.36 ± 0.11
	Cassava-Finger millet	4.23 ± 0.03	2.62 ± 0.08	2.12 ± 0.03

a: All data are expressed on a dry-matter basis

Table 14: R_f values of standard ammomium salts of carboxylic acids

Acid	R_f values
Formic	0.15
Acetic	0.16
Propionic	0.23
Hexanoic	0.29

Table 15: Levels[a,b] of acetic and hexanoic acids in the fermented substrates

Substrate	Acetic Acid	Hexanoic Acid
Maize	0.803	0.874
Finger-millet	0.863	1.097
Cassava	0.860	1.808
Maize-Finger Millet	0.954	1.154
Cassava-Finger millet	0.877	1.327

a: µg/5 µl
b: All data are expressed on a dry-matter basis

Table16: Levels [a,b] of hexanoic acid in fermented substrates dried under different conditions

	Drying Condition	Maize	Finger millet	Cassava	Maize-Finger Millet	Cassava - Finger Millet
	Sun	0.483	0.348	0.258	0.665	0.290
	Cabinet	0.862	0.801	0.106	0.829	0.717
	Drum	0.406	0.598	0.106	0.552	0.618

a: µg / 5 µl

b: All data are expressed on a dry matter basis

4.5 EFFECT OF FERMENTATION AND DRYING ON THE FLAVOUR OF *UJI*

The flavour of fermented and dried flours was evaluated organoleptically by the multiple comparison test in which the fermented non-dehydrated slurries were used as the reference. Rank sums of the scores of the taste panel were analysed for statistical significance at the 5% level of significance. The mean values for each substrate are presented in Table 17. Fermented and dried *uji* were not significantly different in flavour from the reference (i.e. fermented only) samples at the 5% level. Drum dried *uji* had lower acceptability values for flavour than either the sun or cabinet dried slurries. Drum dried cassava *uji* had the least acceptability and on average was rated as being inferior to the fermented cassava slurry. Cabinet dried cassava-finger millet composite was the only *uji* with a higher average rating than the fermented slurries. Panelist response differences were insignificant for the maize, finger millet and cassava *uji* but significant for the composites of maize-finger millet and cassava-finger millet *uji* ($p<0.05$). The panelists who differed from the rest preferred *uji* prepared from the fermented and dried flours and referred to the fermented samples as being too acidic.

These results on *uji* flavour compare well with the earlier findings (section 4.4) where TTA, FA and hexanoic acid levels were not significantly reduced irrespective of the drying system employed. The volatile acids (i.e. acetic and formic) that were lost during drying (section 4.4) might have been the cause for the slightly lower flavour acceptability values of *uji* prepared from dried flours. But the flavour changes were not large enough to be detected by the panelists at the 5% level of significance. It can therefore be concluded that the acceptable flavour of the dehydrated flours is dictated by the fixed acids rather than by the volatile acids.

Table 17: Average score for the flavour of *uji* prepared from the dried flours

Flour	Drying System			Flour Means	SEM
	Sun	Cabinet	Drum		
Maize	3.75	3.25	3.88	3.63	±0.271
Finger millet	3.12	3.12	3.38	3.21	±0.366
Cassava	3.62	3.25	4.00	3.62	±0.251
Maize- Finger millet	3.22	3.44	3.22	3.29	±0.344
Cassava- Finger millet	3.11	2.78	3.56	3.15	±0.272
Drying System Means	3.36	3.17	3.17		

a : Paired comparison scale of 1-5 used; where 1: extremely better than ; 2: better than ;3: equal to ; 4: inferior to and 5: extremely inferior to the reference sample.

5 CONCLUSIONS

The purpose of the study was to produce fermented and dehydrated *uji* flour with minimal loss of flavour and that could be easily reconstituted in water. This purpose was to be achieved by comparing the carboxylic acid levels and pasting properties of the fermented slurries with the fermented and either sun-, cabinet-, or drum dried flours.

All the fermented slurries had strong distinctive flavours which was further enhanced on cooking, possibly indicating the occurrence of post-fermentation physico-chemical reactions. There is a need therefore to compare the flavour profiles of fermented *uji* with fermented and cooked *uji*

Fementation increased the viscosity of the slurries. This was due to the ease of disintegration of the granules, caused by the acidic conditions, hence encouraging exudation of amylose and amylopectin polymers. This has important negative implications, especially if the *uji* is to be used as a weaning food, because low flour concentrations will be required to make a thin gruel that the child can readily consume. However the flour concentrations and hence the energy values of the porridge could be increased if appropriate germinated cereal flours are incorporated either before cooking is commenced or aseptically after cooking. Though commercial enzymes are expensive, the little amounts required and their high activity could make them economical for use in medium to large scale enterprises.

It was found that there were no major changes in flavour when the fermented slurries were either sun-, cabinet-, or drum dried. Sun and cabinet drying did not change the granular characteristics of the starch components of the flours but drum drying pregelatinized the starch.

The advantage of the latter process is that the material is also pre-cooked and only requires to be reconstituted in warm water before consumption. This saves on cooking fuel requirements, which happen to be very scarce and expensive, especially among low-income workers and the rural population. Though sun and cabinet drying technologies are cheaper than drum drying, the slurries required at least 24 hours before their moisture contents could be lowered to acceptable levels (about 11%); and also they occupied large drying areas.

6 RECOMMENDATIONS

The use of dried foods is increasing rapidly in developing countries mainly because of shortages of refrigeration and freezing facilities. As has been shown in this study, though drum drying offers several advantages such as reduced process time and physical effort; hygienic production; high quality long term storability and a good natural taste it also poses new challenges related to reconstitution of the product. It is thus recommended that further work be done on selecting suitable wetting agents and/or adjusting the drum drier parameters to ensure that the dehydrated flour does not lump when added back into warm water.

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8 APPENDICES

Appendix 1:

Onset Gelatinization Temperatures of Non-Fermented Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Treatment	4	89.85	22.46	8.32*	3.48
L1		27.09	27.09	10.03*	4.96
L2		33.84	33.84	12.53*	4.96
L3		0.12	0.12	0.04	4.96
L4		0.84	0.84	0.31	4.96
L5		0.00	0.00	0.00	4.96
L6		16.80	16.80	6.22*	4.96
L7		13.90	13.90	5.15*	4.96
L8		0.14	0.14	0.05	4.96
Error	10	27.00	2.70		
Total	14	116.85			
	CV=3.02%		Sem=±0.95		

Appendix 2:

Onset Gelatinization Temperatures of Non-Fermented Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Treatment	4	473.10	118.28	27.19*	3.48
L1		15.84	15.84	3.64	4.96
L2		128.34	128.34	29.50*	4.96
L3		54.00	54.00	12.41*	4.96
L4		49.60	49.60	11.40*	4.96
L5		0.38	0.38	0.09	4.96
L6		315.38	315.38	72.50*	4.96
L7		121.50	121.50	27.93*	4.96
L8		45.38	45.38	10.43*	4.96
Error	10	43.50	4.35		
Total	14	516.60			
	CV=3.02%		Sem=±0.95		

Appendix 3:

Peak Viscosity of Non-Fermented Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Treatment	4	3286893.33	821723.33	1053.49*	3.48
L1		5208066.67	5208066.67	677.00*	4.96
L2		1392016.67	1392016.67	1784.64*	4.96
L3		205320.00	205320.00	263.32*	4.96
L4		25350.00	25350.00	32.50*	4.96
L5		266.67	266.67	0.34	4.96
L6		1837066.67	1837066.67	2355.21*	4.96
L7		784816.67	784816.67	1006.17*	4.96
L8		220416.67	220416.67	282.58*	4.96
Error	10	7800.00	780.00		
Total	14	3294693.33			
	CV=2.18%		Sem=±16.12		

Appendix 4:

Viscosity at 96°C of Non-fermented Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Treatment	4	149759.99	374339.99	40.99*	3.48
L1		260416.67	260416.67	28.51*	4.96
L2		714150.00	714150.00	78.19*	4.96
L3		112066.67	112066.67	12.27*	4.96
L4		30816.67	30816.67	3.37	4.96
L5		45066.67	45066.67	4.93	4.96
L6		653400.00	653400.00	71.54*	4.96
L7		470400.00	470400.00	51.50*	4.96
L8		15000.00	15000.00	1.64	4.96
Error	10	91333.33	9133.33		
Total	14	1588693.33			
	CV=8.90%		Sem=±55.18		

Appendix 5:

Onset Gelatinization Temperatures of Non-Fermented Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Treatment	4	69.22	17.30	11.53*	3.48
L1		0.84	0.84	0.56	4.96
L2		54.00	54.00	36.00*	4.96
L3		41.34	41.34	27.56*	4.96
L4		1.50	1.50	1.00	4.96
L5		15.84	15.84	10.00*	4.96
L6		4.59	4.59	3.06	4.96
L7		0.09	0.09	0.06	4.96
L8		6.00	6.00	4.00	4.96
Error	10	15.00	1.50		
Total	14	84.22			

CV=7.08% Sem=±0.707

Appendix 6:

Peak Gelatinization Temperatures of Fermented Slurries

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Treatment	4	183.97	45.99	20.79*	3.48
L1		0.84	0.84	0.04	4.96
L2		135.38	135.34	63.70*	4.96
L3		114.84	114.84	54.04*	4.96
L4		15.84	15.84	7.46*	4.96
L5		18.37	18.37	8.65*	4.96
L6		11.34	11.34	5.34*	4.96
L7		9.37	9.37	4.41	4.96
L8		9.37	9.37	18.68*	4.96
Error	10	22.12	2.21		
Total	14	206.1			

CV=2.55% Sem=±0.86

Appendix 7:

Peak Viscocity of Fermented Slurries

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Treatment	4	568626.66	142156.66	56.26*	3.48
L1		9600.00	9600.00	3.80	4.96
L2		331350.00	331350.00	131.14*	4.96
L3		228150.00	228150.00	90.30*	4.96
L4		18150.00	18150.00	7.18*	4.96
L5		1666.67	1666.67	0.66	4.96
L6		160066.67	160066.67	63.35*	4.96
L7		1350.00	1350.00	0.53	4.96
L8		190816.67	190816.67	75.00*	4.96
Error	10	25266.67	2526.67		
Total	14	593893.33			
	CV=3.22%		Sem=±29.02		

Appendix 8:

Viscocity at 96°C of Fermented Slurries

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Treatment	4	994239.99	248559.99	9.73*	3.48
L1		240000.00	240000.00	9.39*	4.96
L2		256266.67	256266.67	10.03*	4.96
L3		266.67 266.67 0.01		4.96	
L4		22816.67	22816.67	0.89	4.96
L5		160066.67	160066.67	6.26*	4.96
L6		570416.67	570416.67	22.32*	4.96
L7		114816.67	114816.67	4.49	4.96
L8		173400.00	173400.00	6.78*	4.96
Error	10	255533.33	25553.33		
Total	14	1249773.33			
	CV=13.90%		Sem=±92.29		

Appendix 9:

Onset Gelatinization Temperatures of Non-Fermented Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Replication	2	12.98	6.49	2.19	3.34
Treatment	14				
Substrate	4	2053.64	531.41	173.15*	2.71
Drying	2	21.38	10.69	3.60*	3.34
Subtrate X Drying	8	2944.62	368.08	124.16*	2.29
Error	10	83.02	2.96		
Total	44	5115.64			
	CV=3.00%		Sem=±0.99		

Appendix 10:

Peak Gelatinization Temperature of Fermented and Dried Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Replication	2	23.28	11.64	2.04	3.34
Treatment	14				
Substrate	4	479.80	119.95	20.98*	2.71
Drying	2	1636.22	818.11	143.08*	3.34
Subtrate X Drying	8	1897.78	237.22	41.49*	2.29
Error	28	160.10 5.72			
Total	44	4197.18			
	CV=3.70%		Sem=±1.38		

Appendix 11:

Peak viscosity of Fermented and Dried Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Replication	2	3453.00	1727.00	0.23	3.34
Treatment	14				
Substrate	4	2103391.00	525848.00	69.69*	2.71
Drying	2	437373.00	218687.00	28.98*	3.34
Subtrate X Drying	8	1294182.00	161773.00	21.44*	2.29
Error	28	211280.00	7546.00		
Total	44	404968.00			
	CV=5.70%	Sem=±50.20			

Appendix 12:

Viscosity at 96°C of Fermented and Dried Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Replication	2	12413.00	6207.00	0.63	3.34
Treatment	14				
Substrate	4	483302.00	1208326.00	121.77*	2.71
Drying	2	555293.00	277647.00	27.98*	3.34
Subtrate X Drying	8	1132418.00	141552.00	14.26*	2.29
Error	28	277853.00	9923.00		
Total	44	6811280.00			
	CV=8.10%	Sem=±57.50			

Appendix 13:

TTA of Slurries after 24 Hours of Fermentation at 45°C

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Treatment	4	0.32	0.08	56.89*	3.48
L1		0.004	0.004	2.77	4.96
L2		0.007	0.007	5.06*	4.96
L3		0.0005	0.0005	0.34	4.96
L4		0.08	0.08	54.50	4.96
L5		0.04	0.04	26.34	4.96
L6		0.31	0.31	218.00	4.96
L7		0.12	0.12	81.80	4.96
L8		0.05	0.05	32.00	4.96
Error	10	0.01	0.001		
Total	14	0.33			

CV=2.79% Sem=±0.02

Appendix 14:

PH of Slurries after 24 Hours of Fermentation at 45°C

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Treatment	4	0.42	0.11	30.36*	3.48
L1		0.30	0.30	86.00*	4.96
L2		0.05	0.05	14.40*	4.96
L3		0.11	0.11	30.48*	4.96
L4		0.03	0.03	7.60*	4.96
L5		0.07	0.07	20.12*	4.96
L6		0.11	0.11	30.48*	4.96
L7		0.15	0.15	42.98*	4.96
L8		0.004	0.004	1.07	4.96
Error	10	0.04	0.004		
Total	14	0.46			

CV=1.52% Sem=±0.034

Appendix 15:

FA of Slurries after 24 Hours of Fermentation at 45°C

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Treatment	4	0.37	0.09	92.00*	3.48
L1		0.002	0.002	1.64	4.96
L2		0.19	0.19	188.00*	4.96
L3		0.22	0.22	225.20*	4.96
L4		0.15	0.15	154.00*	4.96
L5		0.05	0.05	53.00*	4.96
L6		0.35	0.35	355.00*	4.96
L7		0.12	0.12	124.70*	4.96
L8		0.06	0.06	58.90*	4.96
Error	10	0.01	0.001		
Total	14	0.37			
	CV=2.60%		Sem=±0.02		

Appendix 16:

TTA of Fermented and Dried Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Replication	2	0.01	0.006	0.66	3.34
Treatment	14				
Substrate	4	17.44	4.36	463.31*	2.71
Drying	2	1.38	0.69	73.54*	3.34
Subtrate X Drying	8	1.65	0.21	21.89*	2.29
Error	10	0.26	0.009		
Total	14	20.74			
	CV=3.80%		Sem=±0.06		

Appendix 17:

PH of Fermented and Dried Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Replication	2	0.04	0.02	2.95	3.34
Treatment	14				
Substrate	4	2.99	0.75	106.50*	2.71
Drying	2	0.06	0.03	4.65*	3.34
Subtrate X Drying	8	0.24	0.03	4.21*	2.29
Error	28	0.20	0.007		
Total	44	3.54	18.67		
	CV=2.00%		Sem=±0.05		

Appendix 18:

FA of Fermented and Dried Flours

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Replication	2	0.04	0.02	2.85	3.34
Treatment	14				
Substrate	4	15.74	3.93	487.92*	2.71
Drying	2	0.75	0.38	46.75*	3.34
Subtrate X Drying	8	1.90	0.24	29.49*	2.29
Error	28				
Total	44				
	CV=4.10%		Sem=±0.05		

Appendix 19:

Multiple Comparison Test for Maize

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Sample	2	1.75	0.88	1.48	3.74
Panelist	7	9.63	1.38	2.33*	2.85
Error	14	8.25	0.59		
Total	23	19.62			
	CV=21.18%		Sem=±0.27		

Appendix 20:

Multiple Comparison Test for Finger Millet

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Sample	2	0.33	0.17	0.16	3.74
Panelist	7	8.62	1.23	1.15	2.85
Error	14	14.99	1.07		
Total	23	23.96			
	CV=32.24%		Sem=±0.37		

Appendix 21:

Multiple Comparison Test for Cassava

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Replication	2	2.25	1.12	2.22	3.74
Treatment	7	6.29	0.89	1.77	2.85
Error	14	7.08	0.51		
Total	23	15.62			
	CV=19.62%		Sem=±0.25		

Appendix 22:

Multiple Comparison Test for Maize – Finger Millet

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Sample	2	0.30	0.15	0.14	3.63
Panelist	8	32.30	4.04	3.79*	2.59
Error	16	17.04	1.06		
Total	26	49.63			
	CV=31.31%		Sem=±0.34		

Appendix 23:

Multiple Comparison Test for Cassava-Finger Millet

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Sample	2	2.74	1.37	2.05	3.63
Panelist	8	30.74	3.84	5.76*	2.59
Error	16	10.67	0.67		
Total	26				
	CV=25.94%		Sem=±0.27		

Appendix 24:

Rehydration of Fermented and Dried Flours at 30°C

Source of Variation	df	SS	MSS	Computed F	Tabular F (5%)
Replication	2	0.06	0.03	1.55	3.34
Treatment	14				
Substrate	4	0.02	0.005	0.26	2.71
Drying	2	64.31	32.15	1610.42*	3.34
Subtrate X Drying	8	0.13	0.02	0.79	2.29
Error	28	0.56	0.02		
Total	44	65.08			
	CV=5.20%		Sem=±0.08		