FINAL TECHNICAL REPORT

Project:	**Improved cassava processing technologies**
Programme:	**Crop Post-Harvest Programme**
Purpose 4:	**(Non-Grain Starch Staple) Processing and Storage Losses Reduced**
Production System:	**Forest/Agriculture Interface**
Project code:	**R6332 (A0432)**
Start date:	**3 April 1995**
End date:	**31 March 1996**
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EXECUTIVE SUMMARY

1. The overall purpose of the project was to develop improved cassava processing methods that have enhanced post-harvest qualities including low cyanogen levels and/or product storability. The work undertaken had two definite parts:

(i) improved cassava processing technology for vulnerable households in Tanzania; and
(ii) optimisation of processing variables for *fufu*, a fermented cassava paste of Nigeria.

Improved processing for vulnerable groups

2. The on-station trials initiated in the previous financial year (not covered in this report) were completed and the analysis made. Crushing cassava root pieces prior to drying was found to significantly improve the efficiency of cyanogen removal by on average 22% during laboratory experiments and 12% during field trials. The crushing procedure was optimised and a low cost prototype crusher was developed. A reduction in the processing time resulted from crushing the root disks prior to the drying procedure. The processing method involving crushing was ranked second in terms of efficiency of cyanogen removal in a comparative study of sun-dry processing methods that are commonly used in East Africa. Pounding cassava to small pieces in a traditional pestle and mortar prior to drying was the most efficient method providing 90% removal of cyanogens. Pounding and crushing cassava prior to sun-drying were significantly better than all other root preparation pre-treatments tested.

3. On the basis of these results further field testing on-farm was not justified as the crushing method did not contribute a significant benefit over the current rapid processing method in terms of efficiency of cyanogen removal. Alternative strategies to meet the needs of these food insecure households were discussed with collaborating institutions and a proposal for an alternative strategy to identify appropriate technologies was developed that formed the basis for a project submitted to the Crop Post-Harvest Programme.

Optimisation of processing variables for fufu

4. Improvements to the traditional processing of wet fermented cassava in Nigeria have been investigated in collaboration with a visiting researcher from Nigeria. The traditional small scale processing of fermented products from cassava and more specifically *fufu* in Nigeria was reviewed with the aim of identifying means of improving the production and quality of *fufu*. Post-harvest constraints commented upon in the literature included aspects of handling, utilisation, efficiency of current processing practices, storability and external factors such as the problems of processing in the wet season (Annex 2).

5. A study of the traditional *fufu* processing method was made and the fermentation process was optimised with respect to piece size, fermentation time and inoculum by using physico-chemical and organoleptic analysis. The influence of different storage methods on the starch pasting characteristics and volatile components

that contribute to the texture and flavour of *fufu* was studied over a two month period. Appreciable differences were observed; freezing at -21°C was found to negatively influence the pasting characteristics of the *fufu*, while refrigeration at 5°C resulted in significant increase in the volatile components. The experimental procedure was optimised in order to take these changes into account.

6. The use of drying to produce a stable product form was evaluated and optimised using Response Surface Methodology (RSM). The influence of air drying conditions on the drying kinetics, chemical, volatile and pasting characteristics of *fufu* were investigated using an Experimental Drying Facility. Three critical variables, temperature, humidity and air velocity, were used to develop a design method that was analysed using Genstat. The best-fitting response surface for each of the variables was determined. The optimised drying conditions for *fufu* were temperature of 65°C, velocity of 4 m/s and moisture of 0.0139 kg/kg dry air. The optimum conditions for maintaining the desired properties of *fufu* were temperature of 65°C, velocity of 4 m/s and moisture of 0.0167 kg/kg dry air. At these optimal conditions, moisture content was reduced from between 60% (dry basis) to between 13% (dry basis) for dried samples within 5 h of drying. These conditions maximised the desirable properties in *fufu*.

7. The marketability of the product will be assessed by the visiting scientist on his return to Nigeria as a component of his research programme.

BACKGROUND

Improved processing for vulnerable groups

8. Bitter cassava varieties are an important staple crop in many drought prone areas of East Africa because they yield better than other staples under prevailing environmental conditions (Essers *et al.* 1992). The designation of bitter or sweet varieties depends on taste that is associated with the levels of cyanogenic glucosides mainly linamarin (Sunderesan *et al.* 1987). The bitter or sweet distinction is relative since roots can become bitter with increased glucoside levels because of environmental factors such as drought, pest attack or disease. The cyanogenic glucosides are removed by efficient processing methods before consumption to avoid exposure to cyanide that may cause acute intoxications (Mlingi *et al.* 1992), aggravate goitre (Bourdox *et al.* 1978) and in severe, chronic circumstances induce paralytic diseases (Tylleskär *et al.* 1992).

9. Effective cassava processing methods disintegrate the root tissue completely, thereby releasing an endogenous enzyme linamarase that hydrolyses the glucosides to corresponding cyanohydrins. These will spontaneously decompose at pH values above 5 to release volatile hydrogen cyanide (HCN) that is rapidly lost from the system (Cooke *et al.* 1978). The cyanogenic glucosides, cyanohydrins and HCN are collectively known as cyanogens. All cyanogens can be reduced through efficient processing to negligible levels below the recommended limit of 10 mg HCN equiv./kg dry weight set by FAO in 1988.

10. Masasi district in Southern Tanzania experienced drought in 1988 that resulted in an outbreak of acute intoxications. The established cassava processing method in which peeled roots are sun-dried for at least two weeks to a product known as *makopa* was replaced by a short-cut method that produces a product known as *chinyanya*. This change in practice was due to severe food shortage and the need for rapid methods of processing. The intoxications were attributed to consumption of insufficiently processed cassava. The short cut method provided flour within the same day by alternate pounding and sun drying of peeled cassava roots. High residual levels of cyanohydrins were held responsible for the cyanide exposure found in populations affected by the acute intoxications (Mlingi *et al.*, 1992). To identify the critical stages in removing cyanogens during normal and short-cut methods of cassava processing in the area, a field experiment was carried out in three villages of Masasi District in September 1991 (Mlingi *et al.*, 1995).

11. The normal method of processing cassava in Southern Tanzania by sun-drying peeled cassava roots for over two weeks to *makopa*, results in products with high levels of cyanogenic glucosides. The levels of residual cyanogens in *makopa* products are dependent on the variety processed, environmental factors and the duration of sun-drying and storage.

12. The short-cut method of processing cassava by pounding fresh roots followed by sun-drying, re-pounding and sieving out flour results in a sharp decline in glucoside levels, but moderately high cyanohydrin levels. High residual cyanohydrin levels in *chinyanya* results in cyanide exposure to consumers because the cyanohydrins are acid stable and are decomposed in the alkaline conditions of the gut to release HCN. Cyanohydrin levels in *chinyanya* can be reduced with sufficient sun-drying and/or the product stored at ambient temperatures to optimise the decomposition of the residual cyanohydrins.

13. The situation described above is not restricted to Southern Tanzania alone, Howlett *et al.* (1990) have studied an outbreak of konzo in the Lake Zone of Tanzania. The factors leading to this incidence resulted from consumption of cassava cyanogens through insufficient processing procedures adopted during food shortage. In this instance processors where practising a short cut method of solid state fermentation of cassava. Similar incidences have been reported in Zaire, Mozambique, Central African Republic and Uganda.

14. The short-cut method of processing cassava in Southern and Lake Zone Tanzania could be improved by grating cassava, followed by pressing, fermentation and sufficient sun-drying. There are methods that are currently used in West Africa that can consistently provide high quality processed products from bitter varieties. A programme of work was undertaken in Southern Tanzania to extend information concerning cassava cyanogens and alternative processing methods (Bainbridge *et al.*, 1994). Some feedback concerning the acceptability of various cassava products was obtained. It was noted that the organoleptic quality of the products as well as nutritional quality was of key importance. Further research is required to ascertain the reliability of "improved methods" in terms of food quality and to develop low cost methods that are within the resource capacity of farmers in marginal agricultural lands.

15. Data from the first phase of the Collaborative Study of Cassava in Africa has now been analysed by the Tanzanian National Root and Tuber Crops Programme (Kapinga and Nweke, unpublished). The main conclusion was that the range of cassava products was limited and this was connected to limited market opportunities. The diversification of cassava processing has therefore been given a high priority by the National Programme.

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Optimisation of processing variables for fufu

16. *Fufu* is a fermented wet paste produced from cassava roots and is widely consumed in West African countries including Eastern and South-western Nigeria. The processing of *fufu* in Nigeria, is typically carried out by peeling the root, washing, cutting into chunks and soaking in water at ambient temperatures for a period of 5-6 days. After soaking, liquid is poured off and the cassava is broken up by hand, sieved to remove fibre and dewatered by pressing the mash in cotton bags. The *fufu* is either white or creamy in colour and is sold in markets in this form (Akingbala *et al.*, 1991). *Fufu* is prepared for consumption by suspending it in water and heating with constant stirring over a fire until it forms a solid paste. The paste is then cooled and eaten along with vegetable soups and meats.

17. Soaking or retting has been reported to be the determining factor for the quality of *fufu* (Westby, 1994). This step is performed to soften the roots, yield specific flavour by the production of organic acids and degrade the endogenous cyanogenic compounds (Ayernor, 1985). Factors such as temperatures, root size during soaking and the use of starter inoculum have been proposed to influence the soaking period and the qualities of *fufu* (Oyewole, 1990; Okolie *et al.*, 1992; Oyewole and Odunfa, 1992; Blanshard *et al.*, 1994; Ampe *et al.*, 1994). Amongst these factors, temperature effect has been proven to influence the soaking period. The effect of initial root sizes and other practices such as addition of starter inoculum prior to soaking of cassava for *fufu* production requires further investigation to identify optimum conditions.

18. Unlike *lafun* and *gari*, which are dried products and can thus be preserved for some time, traditional *fufu* is produced in a wet form (~50% moisture content) which renders it highly perishable. It is consumed immediately after preparation or stored in baskets or plastic bags for some days until needed for cooking or until it is sold at the market. Poor shelf life of *fufu* is a serious limitation for large scale processors.

19. A practical approach for improving shelf life is to dry the wet *fufu*. Although, sun-drying methods look attractive because of their low-cost, the unpredictable nature of weather conditions can be problematic (Sanni *et al.*, 1995). Okpokiri *et al.* (1985) reported the production of good quality dried *fufu* when the wet form was dried in the oven at 55°C and the temperature gradually increased to 80°C over an 8 h time period. Drying of *fufu* in an oven at 60°C for 48 hours has also been reported to reduce the strong odour of *fufu*, but the product was sticky, bland and unacceptable compared to wet *fufu* by organoleptic techniques (Akingbala *et al.*, 1991). Optimisation of drying conditions to retain the desirable characteristic qualities of *fufu* is required.

20. The research undertaken has investigated the processing variables and their influence on the characteristic qualities of *fufu*. A Response Surface Methodology (RSM) was adopted to design a self replicating experiment through which the optimal conditions were identified. Transfer of the technology to Nigerian processors will improve the storability and marketability of the produce that is necessary to meet the increased demand for convenience foods by urban communities.

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PROJECT PURPOSE

21. The specific purposes of the project were:

- to test an improved cassava processing technique based on crushing roots;
- to disseminate results through the scientific literature; and
- to develop a strategy for assessing the needs of end users with respect to cassava processing.

22. The objectives were expanded to include work to improve the processing of fermented cassava to meet consumers' demands. This was undertaken in collaboration with a visiting Nigerian scientist. Although this work was focused towards Nigerian *fufu*, similar products are produced in Tanzania.

RESEARCH ACTIVITIES

Improved processing for vulnerable groups

23. Field trials were undertaken at Ukiriguru Agricultural Research Institute, analysis of samples was carried out by the Tanzania Food and Nutrition Centre and the Natural Resources Institute.

24. For each of the three varieties listed above, a quantity of roots was harvested and randomly divided into five batches. Each batch was randomly sub-divided into six and for each batch a particular treatment applied. After peeling sub-batch (1) was taken for analysis of cyanogen and dry matter - FR; (2) was chopped into finger size chips - FS, (3) remained whole - WR, (4) was cut into 4 cm length disks - SD; (5) was cut into 4 cm disks and crushed using the device (Annex 2) - CD; while (6) was pounded in a pestle and mortar - CY. Processing and sampling were completed within two hours from the time of harvesting. The initiation of processing the three varieties was on consecutive days.

25. The cassava treatments were evenly spaced on mesh drying trays. Due to the variability of the weather conditions, sun-drying was undertaken in a ventilated glass house. The cassava pieces were turned or mixed on a daily basis. The termination of drying was decided upon by processors that were experienced in processing cassava. Criteria such as colour and snapping sound when broken were used. Once dried the batches were pounded in a pestle and mortar and a sample taken for extraction of cyanogens, dry weight determination and storage. In general, the cassava treatments were dried for the following periods: CY for 2 days; FS for 3 days; CD for 5-6 days; SD for 6-7 days; and WR for 7-9 days.

26. Treatment and variety effects were verified by F-test and subsequently assessed with Students *t* test. Significances of difference are related to two-tailed probability (P) values.

Optimisation of processing variables for fufu

Effect of processing variables such as piece shapes, levels of inoculum and initial size of roots on the soaking period of cassava for fufu production.

27. Cassava roots from Nigeria were used to prepare *fufu* by the traditional method as follows. The roots were peeled, washed, cut manually into chunks and soaked in water at a ratio of root to water of 1:1.4. The roots were covered and fermented at 34°C. After 5 days the fermented liquid was stored in aliquots to be used as inoculum. The retted chunks were broken and sieved. The mash was allowed to sediment for 24 h. The water was decanted and the fine mash was dewatered. The *fufu* was stored in the freezer until required for use as an inoculum.

28. The fermentation step was optimised by varying the critical fermentation parameters. The root preparation prior to retting was varied: roots were grated; sliced to 0.5 cm and 3 cm thick slices. Two types of inoculum were tested, both the retting water and wet *fufu* were used as starter cultures at varying levels. Organoleptic, texture and organic acids analyses were undertaken.

Effect of drying conditions on the characteristic qualities of fufu.

29 The drying experiments were carried out on an Experimental Drying Facility at NRI. The drying temperature, humidity and air velocity were optimised using a three variables-three levels design, consisting of 15 design points (12 combinations with three replications of the centre point) was used (Box and Behnken, 1960). Drying conditions were selected based on previous reports on drying of *fufu* (Okpokiri *et al.*, 1985 ; Akingbala *et al.*, 1991).

30. Fresh and stored *fufu* were dried under combinations of the following conditions: air temperature: 45, 55, and 65°C; air moisture content: 0.0139, 0.0167, and 0.0194 kg water/kg dry air; and air velocity of 2, 3, and 4 m/s. The conditions were based upon Nigerian ambient conditions of 80% relative humidity at 28°C, 60 % relative humidity at 31°C and 40% relative humidity at 34°C. Bed layer thickness was 1 cm at an initial loading density of 12 kg/m^2. With accordance to the RSM experimental design, Table 1 gives the combination employed for drying procedures (Annex 3). As drying progressed, weight changes were recorded every five minutes. At the end of drying, the final product weight was recorded and its moisture content determined.

31. Physico-chemical analyses included: texture measurement using an Instron Universal Testing Instrument; total titratable acidity (TTA) and pH values; moisture content; pasting properties using a visco-amylograph; volatile analysis involving entrapment of the volatiles and analysis by gas chromatography using a flame ionisation detector; gas chromatography-mass spectrometry; and sensory evaluation using a panel of six Nigerian judges. Responses of the panellists were subjected to statistical analysis of variance and means were separated by Duncan's Multiple Range Test to establish if there were significant differences. Statistical analysis of the data was facilitated by Genstat 5 release 3.1 which was used to identify the best-fitting response surface for each of the variables that were measured.

OUTPUTS

Improved processing for vulnerable groups

32. The importance of the degree of cellular disruption and drying rate on the efficiency of cyanogen removal was illustrated by observations made during the comparative study of processing methods. Of the methods studied the ranking in order of efficiency was as follows: chinyanya; crushed disk; *makopa*; standard disk; and finger-sized *makopa*. Results detailed in Annex 1.

33. Chinyanya ranked first in the efficiency of cyanogen removal. It is a method whereby the tissue is highly disintegrated from the pounding action resulting a rapid breakdown of the cyanogens This is supported by work of Vasconcelos *et al.* (1992) and Jones *et al.* (1994) who observed complete removal of cyanogens after a high degree of tissue disruption brought about by grating and mincing. The small pieces also dry rapidly in up to 2 days due to the greatly increased surface area to volume ratio. Hence, the method is efficient in the removal of cyanogens and rapid compared to other sun-drying methods. The crushing method, ranking second was similar in efficiency of cyanogen removal. The treatment of the roots involved a lower degree of tissue disruption and a longer period of high moisture content. The crushing method was of similar efficiency but less rapid.

34. *Makopa* processing involves the sun-drying of whole root pieces for up to two weeks and was ranked third in the comparative study of methods. The degree of tissue disruption brought about by external forces was minimal. It has been postulated by Essers *et al.* (1995) that the endogenous cell wall degrading enzymes play a key role in disrupting the cellular integrity during the initial part of drying, thus allowing the contact between the linamarse and its substrate, cyanogenic glucosides (Okolie & Oguchukwu, 1988).

35. The standard, non-crushed disk method was less efficient in cyanogen removal than *makopa*. This was due to the increase in the surface area to volume ratio resulting in a higher drying rate and therefore less time for the action of the hydrolytic enzymes. Finally, the finger sized *makopa* ranked least efficient. The larger surface area to volume ratio combined with minimal tissue disruption resulted in high levels of residual cyanogens. Jones *et al.* (1994) observed that compared to manual slicing of cassava roots mechanical slicing of chips of similar dimensions resulted in an increase in the levels of cyanogens removed. It was postulated that this was due to the reduced level of tissue disruption resulting from the precise incisions of a sharp knife as compared to the rough blades of the mechanical chipper.

36. In conclusion, crushing the roots did significantly improve the removal of the cyanogens over those methods that involve drying of root pieces of similar dimensions. However, it provided no significant benefit in terms of cyanogen removal as compared with methods that involve a high level of root disintegration and are currently used in Eastern Africa. Although a key advantage of crushing over pounding to produce chinyanya is that crushing produces a product that can be stored and handled in the

same way as traditional *makopa* pieces. In addition, although effort is required to crush the pieces when fresh, considerably less effort is required to pound the dried pieces to a flour when compared to *makopa*.

37. The mechanism that mediates cyanogen removal is directly related to the balance between the degree of tissue disruption and rate of drying. This was illustrated by the comparative study of processing methods used currently (Table 1 and Annex 1). Sun-drying of cassava is considered the least efficient of the various categories of processing commonly practised. Processing steps such as crushing and pounding may be incorporated to decrease the cyanogen level. However sun-drying alone as a processing method for highly cyanogenic cassava varieties remains inadequate if levels are to be reduced to the safe limit of 10 mg HCN equiv./kg dry weight recommended by the FAO/WHO (1991).

Table 1: Efficiency of cyanogen removal during a variety of sun-drying methods of processing (given as a percentage reduction).

Processing method	Processing method	Drying time (days)	Average total cyanogens (mg HCN equiv./kg DW)	Percentage reduction of cyanogens (%)
Fresh root (FR)	-	0	242 ± 112	0
Chinyanya (CY)	Roots pounded to very small pieces and dried.	2	23 ± 26	90
Makopa (WR)	Whole roots dried.	7 - 9	44 ± 34	82
Finger sized *makopa* (FS)	Roots sliced into small chips and dried.	2 - 3	69 ± 34	71
Standard disk (SD)	Transverse root disks of 4 cm length dried	6 - 7	58 ± 37	76
Crushed disk (CD)	Transverse root disks of 4 cm length dried.	5 - 6	38 ± 32	88

Optimisation of processing variables for fufu

Processing of fufu from cassava in Nigeria: problems and prospects for development

38. Traditional small scale processing of fermented products and more specifically, *fufu* from cassava was reviewed with the aim of identifying means of improving production and quality of *fufu* in Nigeria. Post-harvest constraints commented upon in the literature included aspects of handling, utilisation, efficiency of current processing practices, storability and external factors such as the problems of processing in the wet season. Researchable issues have been identified and are reported in the review given in Annex 2.

Influence of the roots piece shape and inoculum on acidity, moisture and texture of cassava during soaking

39. Cassava is often cut into various piece shapes prior to soaking for processing *fufu*. To establish if this practice had an influence on the soaking time required before softening, changes in chemical and textural properties were monitored during the soaking of differently shaped root pieces. Generally, there was a decrease in moisture content after 24 h of soaking (Table 3, Annex 3). The force required to penetrate cassava pieces decreased substantially during the soaking period due to the softening of the root pieces during the fermentation process (Table 3, Annex 3).

40. The pH values consistently decreased while total acidity (g/kg lactic acid) increased over the soaking period. The rate of decrease was proportional to the decreasing size of root pieces (Tables 2 and 5, Annex 3). Similar observations were recorded by Okafor *et al.* (1984); Oyewole & Odunfa (1992). Contrary to the reports of Ampe *et al.* (1994) and George (1994), root piece size had significant effect on soaking time.

41. The influence of starter inoculum using fermentation water and wet *fufu* at increasing concentrations was observed. The addition of starter culture portions had no appreciable influence on the soaking period, acidity and moisture absorption of soaked roots (Table 4, Annex 3). Addition of an inoculum did promote softening of the root pieces.

42. Sensory evaluation of cooked *fufu* produced using variable piece size was undertaken by Nigerian nationals. A significant difference especially for texture, of *fufu* samples ($P = 0.05$) was detected. Panellists preferred *fufu* samples produced from slices of 3 cm thickness in terms of colour, taste, odour, texture and acceptability (Table 7, Annex 3). *Fufu* from grated cassava obtained the lowest rating in terms of texture because it was coarse and sticky. Africans will generally reject any food that is eaten with the fingers if it is sticky (Akingbala *et al.*, 1991).

43. From these studies it was concluded that: the addition of inoculum had no effect on the fermentation in terms of pH change, but did promote softening of the root pieces; the speed of fermentation could be increased by reducing the piece size of the material to be soaked, but this was less acceptable to consumers than the product of a larger piece size. These preliminary results enabled the standardisation of the fermentation procedure in the following experiments. Roots disks of 3 cm thickness and a 2% fermentation water inoculum were used in the fermentation procedure.

Influence of storage conditions (low temperature) on the properties of fufu

44. In order to determine the correct storage conditions for *fufu* during the experimental period, low temperature storage conditions and their influence on the pasting characteristics, chemical and volatile compounds were investigated.

45. Pasting characteristics are an important factor in routine tests for process control or product-quality examination for *fufu*. Using a Brabender Visco-amylograph, the viscosity of wet and refrigerated *fufu* were observed to show a similar

trend. The temperatures required for the initiation of paste formation were 71°C and 68°C for wet and stored *fufu* respectively (Table 7, Annex 3). The Brabender traces for frozen *fufu* showed considerable differences in peak viscosity and paste stability. Wet *fufu* has a high moisture content which increases the risk of damaging the starch granules as a result of ice crystal formation. Damage to the starch granule structure would make paste formation easier but also reduce the hot paste stability.

46. Moisture content remained stable over the storage period at refrigeration temperatures (Table 8, Annex 3). However, the pH and TTA values for fresh and refrigerated *fufu* (Table 8, Annex 3) indicated that there was an increase in acidity over the 7 week storage period from 0.6 to 0.9 g/kg lactic acid, the pH reduced from 3.6 to 3.3.

47. A quantitative method for analysing the volatiles for *fufu* was developed. Volatile compounds were trapped on Porapak Q and separated by gas chromatography. Volatile compounds of fresh and refrigerated *fufu* were identified using gas chromatography-mass spectrometry (Tables 9 and 10, Annex 3). The compounds were further characterised by their retention times and their peak areas. The volatile compounds present in fresh and refrigerated *fufu* the same, however, the concentrations of volatiles after storage was significantly different, for example: butanoic acid was observed to reduce from 905 to 11 µg/20 g wet weight .

48. These studies enabled the experimental details to be further defined. It was observed that the major influence of freezing on the pasting characteristics of *fufu* would not allow storage at freezing temperatures. Storage at refrigerator temperatures was adopted and an allowance made for the resultant reduction in volatiles in the statistical analysis using RSM. Wet *fufu* was prepared in one batch and stored in the refrigerator for seven weeks, portions were removed for the drying trials during this time period.

Effect of Drying Conditions on the drying kinetics and qualities of fufu using Response Surface Methodology

49. In this study, RSM was adopted to explore the effect of drying conditions (temperature, air velocity and air moisture) on the quality of *fufu*. The drying conditions were the operating variables while the values of drying rate, moisture loss, drying time, pasting properties, volatile components and sensory qualities after drying were the responses. The aim was to model these relationships to enable the optimisation of the characteristic properties of *fufu* by varying drying conditions.

50. The kinetic curves for drying rates versus moisture content and drying time (Figure 1, Annex 3) of dried *fufu* at different combinations of drying conditions were obtained using the Experimental Drying Facility. It was observed that *fufu* exhibited the characteristic drying curves known for biological materials Generally, the curves exhibited a warming-up period (0.5 h) followed by a constant rate period, the length of which depended on the drying conditions (1-2 h). A prolonged falling rate period was then observed. Chirife (1983), Fornell *et al.* (1980) and Bimbenet *et al.* (1985), have reported that the existence of a constant rate period in food drying is rather exceptional. The presence of a constant rate period here is likely to be due to the small

particle size of the granules in the *fufu*. This is in line with the earlier reports of drying kinetics of starch gel by Raouzeos and Saravacos (1982).

51. Air temperature was the most important factor influencing the drying rates. The moisture content was reduced from between 145-156% (dry basis) to between 6-19% (dry basis). The highest drying rates (49-52 kg/h) were recorded for samples dried at higher temperatures with elapsed drying time in the range of 5-13 h depending on temperature.

52. Moisture versus time relationship for each observation was modelled using exponential curves. The parameters of the curves were analysed to see if there were differences in the values of A, B and K due to temperature, velocity, and air moisture. The analysis confirmed that to maximise K, (the drying rate), the optimal conditions were: temperature, T = 65°C; velocity, V = 4 m/s; and air moisture, RH = 0.0139 kg/kg dry air. The exponential model fitted the data very well, explaining 94% of the variation in K. There was no evidence of interaction between the three variables. Statistically there was no evidence that days of storage of *fufu* before drying affected the parameters of the curve fitted to the data.

53. The optimum conditions for drying irrespective of the product quality were determined. In the next section RSM is used to determine how the drying variables influenced the characteristics of the fufu in order to determine the optimum conditions for maintaining the quality of the product.

Effect of drying conditions on the chemical, volatile and pasting characteristics of fufu using Response Surface Methodology

54. Using RSM the influence of the drying variables on the characteristics of fufu were examined. A model describing the key variables for each characteristic was determined.

55. The titratable acidity was influenced by temperature, velocity, and air moisture and there was strong evidence that the effect of temperature was dependent on both the air moisture and the velocity. The model fitted the data well, explaining 90% of the variation in the data.

56. It was observed that, drying of wet *fufu* resulted in losses of the major volatile compounds (Table 12, Annex 3). For instance butanoic acid a major flavour compound, was reduced from 11.1 µg/20 g of *fufu* to between 0-3.8 µg/20 g of *fufu* at the end of drying process. The model worked well for butanoic acid at 91% but explained less than half of the variability for the other volatile compounds.

57. The pasting characteristics of dried *fufu* varied depending on the drying regime used. There was evidence that the velocity and air moisture influenced the pasting temperature. The response to velocity was not linear and was dependent on the air moisture ($p = 0.05$). For peak viscosity, there was evidence that velocity and air moisture had effect on the response ($p = 0.10$). There was strong evidence that temperature, air moisture and number of storage days affected the retrogradation of the paste.

58. Generally, the pasting temperatures of 69-81°C for dried *fufu* was higher than that of wet *fufu* at 68-71°C. In practical terms, more energy will be required to cook the dried *fufu* as compared to the wet form. The dry *fufu* does not form as strong a paste as the wet *fufu*, although optimisation of the drying conditions could potentially minimise these differences. Indications were that the dried *fufu* was not as stable as the wet form during cooling, this may also influence consumer preference as cooked *fufu* is allowed to cool prior to consumption and is required to be firm in texture.

59. The optimum drying conditions are: temperature at 65°C, velocity 4 m/s and air moisture 0.0167 kg/kg dry air. These conditions maximised desirable characteristics of dried *fufu* including chemical and volatile compounds and pasting properties, while minimising what can be considered an undesirable odour.

60. The study design allowed the influence of the processing variables on the chemical, volatile compounds and pasting properties to be assessed and optimum drying conditions to be determined. Combining this information with consumers' perception and socio-economic cost benefit analysis will provide an indication of the market potential of "instant" fufu will have in the urban market place.

CONTRIBUTION OF OUTPUTS

Improved processing for vulnerable groups

61. Crushing cassava roots improves significantly the removal of cyanogens over those methods that involve drying of root pieces of similar dimensions. However, it provides no significant benefit in terms of cyanogen removal as compared with methods currently in use in East Africa that involve a high level of root disintegration. A key advantage of the crushing over the pounding method termed *chinyanya* is that the former produces a product that can be stored in the same way as traditional *makopa*

62. The mechanism that mediates cyanogen removal is directly related to the balance between the degree of tissue disruption and rate of drying. This is illustrated by the comparative study of processing methods used currently. It may be considered that inhibition of the enzyme systems at low moisture content can result in the cyanogenic glucosides being trapped in the dried matrix. Sun-drying of cassava is considered the least efficient of the various categories of processing commonly practised. Processing steps such as crushing and pounding may be incorporated to decrease the cyanogen level. However, sun-drying alone as a processing method for highly cyanogenic cassava varieties remains inadequate if levels are to be reduced to the safe limits of 10 mg HCN equiv./kg dry weight recommended by the FAO/WHO (1991)

63. The outputs of the project will benefit researchers, national programmes and extension officers that are concerned with the development, technology transfer and dissemination of high quality processing methods for cassava. This is of particular relevance to East Africa where there is currently concern for communities that rely on

cassava as a primary staple and are subject to food shortage. Further research is required to identify and develop rapid processing methods that are appropriate for such communities where women play a key role in the production, processing and handling of cassava and its products. Identification of products will have significance in improving the status of household food security as well as provide income generating opportunities for women. A project proposal to continue this research has been presented to the Crop Post-Harvest Programme for funding and is due to commence in mid-1996.

List of publications

BAINBRIDGE, Z., HARDING, S., FRENCH, L., KAPINGA, R., WESTBY, A. A study of the role of tissue disruption in the removal of cyanogens during cassava root processing. *Food Chemistry* (submitted, Annex 1).

BAINBRIDGE, Z. Report on a visit to Tanzania to undertake cassava processing trials in collaboration with the National Root and Tubers Programme. 29 January - 12 April 1995. R2244(R).

Optimisation of processing variables for fufu

64. The objective of the research programme was to investigate the production of a dried *fufu* and optimise the production parameter in order to maintain the key characteristics that are important to the consumer.

65. A review of the scientific literature was made and through this the critical stages in the *fufu* processing method were identified. The physico-chemical properties of the traditional wet *fufu* product were characterised. Using Response Surface Methodology the drying of the *fufu* to a flour was analysed and the optimum parameters identified.

66. Although this research project has terminated at NRI, the visiting Nigerian researcher will be continuing the investigation in Nigeria. It is his aim to complete the organoleptic analysis of the products and continue the socio-economic evaluation and cost-benefit analysis of the proposed method. Additional research funding has been sought from the Internal Foundation for Science.

67. There is one review paper (Annex 2) and 3 technical research papers in progress at present that will contribute as outputs of this project. The outputs of the project will benefit researchers involved in the development of novel products using Response Surface Methodology and National Programmes involved in the Adaptive Transfer of the optimised production of *fufu*. Ultimately on completion and in light of positive socio-economic evaluation the production of "instant" *fufu* may benefit micro-entrepreneurs willing to invest in the production of novel products for the urban market.

List of publications

SANNI, L. O., Effect of process variables on the characteristic properties of *fufu* (a fermented paste). PhD thesis, University of Ibadan (Draft).

SANNI L. O., OGUNTUNDE A. O., BAINBRIDGE Z., GRAFFHAM A. AND WESTBY, A. Processing of *fufu* from cassava in Nigeria: problems and prospects for development. A Review. (Annex 2)

ANNEX 1

A study of the role of tissue disruption in the removal of cyanogens during cassava root processing.

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ABSTRACT

Sun-drying as a means to reduce the cyanogen content of the cassava roots is commonly known to be inefficient. This paper reports on modifications to the processing procedure used for sun-drying and their effectiveness at removing potentially toxic cyanogenic glucosides. Commonly used processing methods were compared. Crushing cassava root pieces prior to drying was found to significantly improve the efficiency of cyanogen removal by on average 22 % during laboratory experiments and 12 % during field trials. The crushing procedure was optimised and a low cost prototype crusher developed. A reduction in the processing time resulted from crushing the root disks prior to the drying procedure. The processing method involving crushing was ranked second in terms of efficiency of cyanogen removal in a comparative study of sun-dry processing methods that are commonly used in East Africa. Pounding cassava to small pieces in a traditional pestle and mortar prior to drying was the most efficient method, providing 90% removal of cyanogens. Pounding and crushing cassava prior to sun-drying were significantly better than all other root preparation pre-treatments evaluated.

INTRODUCTION

In cassava (*Manihot esculenta* Crantz), cyanogenic glucosides are synthesised in the leaves and stored in the roots (Mkpong *et al.*, 1990). This class of compounds is present in a number of plant groups. The compounds are thought to provide a nitrogen store and their potential toxicity provides a deterrent against predators and disease (Kakes, 1990). This provides the plants with resistance then enables them to thrive under hostile conditions. The presence of potentially toxic compounds in food for human consumption is not uncommon. Societies that regularly consume such crops have developed processing methods that reduce the levels of such toxic compounds to provide an edible product.

In Sub-Saharan Africa, cassava is an important staple for resource poor farmers. In Africa, there are currently a variety of methods used to process cassava roots into storable products (Natural Resources Institute, 1992). Methods of processing may be simple, such as sun-drying of peeled cassava whole roots, a product termed *makopa* in Tanzania; to more involved methods that require grating, fermentation and roasting steps giving a product called gari in West Africa. Research into the efficiency of processing methods in the removal of cyanogens varies, the critical steps in processing that are important in removing the cyanogenic compounds have been investigated for a number of methods (Mlingi *et al.*, 1994; Essers *et al.*, 1995a & b; Vasconcelos *et al.*, 1990; Westby & Choo, 1994).

The critical stages fundamental to the removal of cyanogens during processing include tissue disruption and drying. Tissue disruption can be brought about by: physiological deterioration mediated by endogenous enzymes; exogenous microbial enzymes during lactic or fungal fermentation; or by physical shearing by means of pounding, grating and chopping. A breakdown of the root cell integrity allows the enzymes linamarase to catalyse the hydrolysis of the cyanogenic glucosides to glucose and the appropriate cyanohydrins. The cyanohydrins then decompose spontaneously or through the action of the enzyme α-hydroxy nitrile lyase (Conn, 1969; Mkpong *et al.*, 1990; Fomunyam *et al.*, 1985). Removal of the cyanohydrins at pH >5 and their subsequent breakdown product hydrogen cyanide can be brought about by thorough drying (Mlingi *et al.*, 1995; Essers *et al.* 1995b).

Investigation of sun-dry processing of cassava has been investigated by Mlingi *et al.* (1995) in response to an outbreak of acute intoxication in communities of Southern Tanzania. This incidence was attributed to the consumption of insufficiently processed cassava during a period of severe food shortage (Mlingi *et al.*, 1992). In this region, cassava is a main staple and has an important role in food security.

The incidence of health disorders such as the acute intoxication, chronic aggravation of goitre or konzo (Rosling, 1987; Tylleskär *et al.*, 1992) occur in regions where food insecurity influences processors to deviate from their normal cassava processing practices. In Southern Tanzania, bitter cassava varieties with correspondingly high levels of cyanogenic glucosides are processed into storable products by simple sun-drying of whole roots or chips. The product, termed *makopa*, can be stored for up to one year. In a survey of 31 households cyanogenic glucoside levels were highly variable with an average 145 ± 26 mg HCN equiv./kg dry weight and a range of 67 to 757 mg HCN equiv./kg dry weight (Mlingi *et al.*, 1995). During the period of severe food shortage, processors deviated from normal practices and processed *chinyanya*, involving a rapid processing method taking only one day. Although this method was shown to reduce cyanogen levels to low levels in trials undertaken by Mlingi *et al.* (1995), the level of the cyanohydrins remained high, 23 ± 14 mg HCN equiv./kg dry weight, due to inadequate drying of the flour. Consumers were exposed to high levels of cyanogens in their diet which resulted in acute intoxication.

The role of cassava in food security is increasing with the increase in population, depletion of soil fertility and failure of traditional crops. Maintaining the quality of cassava products may be achieved in the long term by the identification and introduction of low cyanogenic varieties, however this will take many years for national breeding programmes to achieve. The short term solution requires the development or identification of improved processing methods that are culturally and technically acceptable to the cassava consumers in marginal areas. The reduction in the processing time is a key criterion during periods of food shortage.

This paper reports upon a comparative study of current and improved modifications of processing by sun-drying that are used by cassava consumers in Africa and more specifically in Southern Tanzania. Specific attention was given to crushing the roots prior to sun-drying since tissue disruption is known to be critical to cyanogen reduction. This involved the use of low cost methods to produce products with characteristics which meet with consumer requirements.

METHOD

Cassava varieties used

Laboratory trials were undertaken using cassava variety MCol1684, a high cyanogenic variety, supplied by the Centro Internacional de Agricultura Tropical, Cali, Colombia. In field trials, local varieties provided by Ukiriguru Agricultural Research Institute, Tanzania, were used. These included: the bitter varieties, Liongo and Eala; and the bitter/sweet variety, Mamasheri. All varieties were planted 12 months in advance of harvesting.

Cyanogen reduction in crushed roots

Crushing cassava roots

In the laboratory, the crushing of cassava root pieces was first investigated using an electrical operated Macklow-Smith Compressor. This allowed the crushing surfaces to be varied and the degree of compression to be adjusted. A 1 mm mesh was used as the optimal crushing surface in the experiments using the Macklow-Smith Compressor. Using the information gained from the mechanical crusher, a manual crusher using wooden lever and crushing block was developed (Figure 1) as a prototype for a low cost appropriate technology.

Extent of crushing

Four kilos of peeled cassava roots (MCol1684) were randomised and divided into three replicate batches. Each batch was treated using a standard procedure. Each root was transversely sectioned into length of 4 and 1 cm consecutively. The 4 cm disks were put aside for processing, while the 1 cm disks for each batch were chopped into 1 cm cubes. The cubes were randomised and sampled for dry weight and cyanogen determination. This is referred to as the fresh root (FR) sample. The remaining 4 cm disks of each batch were again sub-divided into four sub-batches. For each batch the first sub-batch was placed on a rack. The second, third and fourth were crushed to a 3, 2 and 1 cm aperture distance respectively using the Macklow-Smith Compressor. These are referred to as 3/4, 1/2 and 1/4 crush respectively. Only one replicate for the 3/4 crush was possible due to the limitations of the compressor. The crushed disks were evenly spaced on the drying racks in a fan assisted oven. The preparation of the roots for drying and sampling for analysis step was completed within two hours.

After 60 hours at 50°C each sub-batch was removed from the oven and pounded in a pestle and mortar to a flour. After mixing, a sample was taken from each flour for cyanogen and dry weight determination.

Cyanogen reduction with time.

Roots (3.5 kg, peeled) of variety MCol1684 were divided into three batches. Each batch was prepared and sampled for the FR sample as described above. Each batch of the 4 cm root disks was sub-divided into two. The first sub-batch was placed on a drying rack using even spacing. The second sub-batch was crushed as described above in a 2 cm aperture, that is a 1/2 cm crush. Each sub-batch was sampled regularly over a 165 h time period.

Cyanogen reduction in crushed and non-crushed root disks.

Two kilos of peeled cassava roots (MCol1684) were randomised and divided into 10 replicate batches. The roots were prepared and the FR sample taken as described above.

In each batch, the 4 cm root disks were randomised and divided into two sub-batches, CR and STD. The CR root disks were taken to be crushed by the prototype crusher. The root disks for crushing were placed one at a time into the manual crushing device depicted in Figure 1. The crushing device used a lever action to crush cassava from a depth of 4 cm to 2 cm, that is a 1/2 crush, between two striated wooden plates in juxtapositions. The crushed disks were then placed along side the standard disks on the drying rack and dried in an air assisted oven at 50°C for 60 h. Dried disks for each batch and treatment were crushed using a pestle and mortar and sampled for dry weight and cyanogen analyses.

Crushing in comparison with other traditional methods of root tissue disruption

Field trials were undertaken at Ukiriguru Agricultural Research Institute, analysis of samples was carried out by the Tanzania Food and Nutrition Centre and the Natural Resources Institute.

For each of the three varieties listed above, a quantity of roots was harvested and immediately randomly divided into five batches. Each batch was randomly sub-divided into six and for each sub-batch a particular treatment applied. After peeling sub-batch (1) was taken for analysis of cyanogens and dry matter; (2) was chopped into finger size chips (FS), (3) remained whole (WR), (4) was cut into 4 cm length disks (SD); (5) was cut into 4 cm disks and crushed (CD) using the device illustrated in Figure 1 while (6) was pounded in a pestle and mortar (CY). Processing and sampling were completed within two hours from the time of harvesting. The initiation of processing of the three varieties was on consecutive days.

The cassava treatments were evenly spaced on mesh drying trays. Due to the variability of the weather conditions, sun-drying was undertaken in a ventilated glass house. The cassava pieces were turned or mixed on a daily basis. The termination of drying was decided upon by processors that were experienced in processing cassava.

Criteria such as colour and snapping sound when broken were used. Once dried the batches were pounded in a pestle and mortar and a sample taken for extraction of cyanogens, dry weight determination and storage. In general, the cassava treatments were dried for the following periods: CY for 2 days; FS for 3 days; CD for 5-6 days; SD for 6-7 days; and WR for 7-9 days.

Cyanogen determination

All dried cassava products were pounded into a flour using a pestle and mortar prior to sampling for subsequent analysis. Extraction and analysis of cyanogens from fresh root and dried flour samples were undertaken as describes by O'Brien *et al.* (1992). Moisture was determined by a gravimetric procedure using drying to a constant weight Sample extracts were maintained at 6 °C and analysed within 6 weeks. Flour samples were maintained at refrigeration temperature.

Statistical analysis

Treatment and variety effects were verified by F-test and subsequently assessed with Students *t* test. Significances of difference are related to two-tailed probability (P) values.

RESULTS

A vertical action was used to bring about the crushing of cassava root disks in controlled laboratory experiments and field trials. Using a compressor, it was determined that a textured surface provided optimal tissue disruption whereby root disks became soft under pressure. In the absence of such a surface or during crushing of longitudinal root sections, shearing was observed and the tissue remained firm under pressure. The root pieces remained intact during the crushing process although a significant number of fissures within the tissue were observed.

The compressor allowed variations in the degree of crushing to be investigated. It was noted that the degree of visible tissue disruption was directly proportional to the level of crushing. Crushing the root disks by a 1/4 and 1/2 the original height resulted in a 5% and 38% improvement in the removal of cyanogens respectively. A further increase in the level of crushing resulted in a greater degree of tissue disruption. Only one sample set was analysed, this indicated that there was no further decrease in the cyanogen levels observed.

Further investigation of cyanogen removal during drying revealed that the cyanogen levels in both standard and crushed root disks decreased rapidly for the first part of the drying period and then levelled off as the moisture content was reduced. This influenced the rate of drying. The cyanogen levels were observed to level out approximately 50 h prior to the standard, non-crushed disks.

Using the prototype lever crusher as depicted in Figure 1, a highly significant difference ($P = 1.43 \times 10^{-5}$) in the efficiency of cyanogen removal in crushed cassava root disks as compared to standard non-crushed disks was observed. A 22%

improvement in levels was brought about by crushing the root disks (refer to Table 1). Using the information gained a sampling regime was determined for the field trials. For the 10 replicates taken the least significant difference (LSD) was 12%, at n=5 the LSD was therefore 17%, a level that was within the mean difference of 50% that was observed. For future trials n=5 would be used.

The degree of cyanogen reduction achieved by various means of traditional and improved processing methods was investigated by means of field trials in Tanzania. A highly significant ($P<0.0001$) reduction of cyanogen levels by all methods and for all varieties was obtained after pre-treatment and sun-drying. In addition, a significant difference in the efficiency of cyanogen removal ($P<0.0001$) between treatments and varieties was detected. Refer to Table 1 for P values.

Ranking in order of efficiency, *chinyanya* processing was found to be most efficient with a 90% reduction in cyanogen levels. This was closely followed by crushed disks using the prototype crusher with a 88% reduction. There was no significant difference detected between these two methods. *Chinyanya* and crushed disk processing methods were significantly better at removing cyanogens than all other processing methods to the at least the 5% significance level. There was a strong significant difference detected at the 1% level between the crushed and standard root disks, corresponding to a 12% improvement. Of the remaining three methods, *makopa* processing ranked third with a 82% reduction in levels, followed by standard disks and finger sized *makopa* at 76 and 71% reduction, respectively.

DISCUSSION

The sampling strategy adopted during this experimental work was designed to take into account the high degree of heterogeneity of cyanogen levels in cassava roots. Using the least significant difference determined from the laboratory experiments, the number of replicates required to detect a difference in the comparative field study was determined. Although full cyanogen analyses were undertaken giving values for linamarin, cyanohydrin and free cyanide, the results for total cyanogens alone are reported for fresh and processed flour samples. In all samples, the major cyanogens present were cyanogenic glucosides. The non-glucosidic levels were negligible in the fresh root samples analysed due to the cyanogenic glucosides remaining intact in freshly harvested roots (White *et al.*, 1994). In flour samples, the lack of lactic fermentation which known to stabilise the cyanohydrins and the low moisture content after drying both contributed to negligible non-glucosidic levels being present in the products (Banea *et al.*, 1992).

The efficiency of sun-drying processing methods in the removal of cyanogens was assessed. A comparison of efficiency brought about by the treatment of roots prior to drying was made involving a novel crushing step and three methods commonly used in East Africa: pounding to produce a product termed *chinyanya*; chipping, termed finger-sized *makopa*; and no diminutive action taken, termed *makopa*. The action of crushing as a means to optimise tissue disruption prior to drying was identified due to the simplicity of operation and its potential for use by processors in marginal regions.

The incorporation of crushing in the processing procedure will still produce a product similar to those that are currently acceptable.

A vertical action was used to bring about the crushing of cassava. The root when cut in transverse sections remained intact during the crushing process although a network of longitudinal fissures within the tissue was observed. The intactness of the pieces was considered an important asset by processors in Southern Tanzania, in that it reduces perceived problems including: contamination; and product losses (Bainbridge *et al.*, 1995). In addition, the effort required to pound the crushed root disks to flour was less than that required for standard, non-crushed root disks. A reduction in the labour demand would be a positive consideration in identifying an appropriate technology.

Research has proven that tissue disruption is a critical step in optimising the removal of potentially toxic cyanogens from cassava (Jones *et al.*, 1994; Vasconcelos *et al.*, 1992). Breakdown of the cell compartments allows the endogenous enzyme linamarase, situated on the cell wall, to come in contact with its substrate cyanogenic glucosides, that are situated in the cytoplasm of the cell (Mkpong *et al.*, 1992; White *et al.*, 1994). Previous work by Jones *et al.* (1994) compared different process variables including pressing prior to drying as one of the least effective treatments as compared to mechanical mincing or rasping, however, the degree of tissue disruption during this pressing was minimal. Using the compressor to crush transverse sections of cassava roots, it was observed during the laboratory trials, that the degree of tissue disruption was directly proportional to the level of crushing. Incorporating a crushing step into the standard drying procedure resulted in a highly significant improvement in the removal of cyanogen.

The crushing action lead to a distortion of the cassava root disks and a softening of the tissue that was due to longitudinal fissures in the tissue. This effectively increased the surface area to volume ratio allowing a greater area from which moisture could evaporate. In addition, fluid was expelled during the procedure. The combined influence of the increased surface area to volume ratio and lowered moisture content due to crushing resulted in an increase in the drying rate. Monitoring the cyanogen levels of standard and crushed disks during drying, revealed the levels in both rapidly decreased during the initial 95 h and 50 h respectively. The rate then decreased with reducing moisture content, corresponding to 9 % and 12 % moisture content. Crushing the root tissue resulted in an increased efficiency in cyanogen removal compared to standard root batches. Due to greater rate of drying, the cyanogen reduction of the crushed root disks levelled approximately 45 h prior to non-crushed disks.

Levelling of the rate of cyanogen removal during drying was also observed by Mlingi *et al.* (1995) and Essers *et al.* (1995b) at 12 and 18-13 % moisture content respectively. It is hypothesised that at these low levels of moisture, the linamarase enzyme activity and that of other cell wall degrading enzymes is substantially decreased (Essers *et al.*, 1995a; Iwatsuki *et al.*, 1984; Okolie & Oguchukwu, 1988). Hence, the removal of cyanogens does not depend on the degree of tissue disruption alone but is also influenced by the rate of drying. This was supported by the findings of Jones *et* *al.* (1994) and Mlingi *et al.* (1992) in their comparison of pre-drying treatments of cassava roots.

In practical terms, the influence of the degree of cellular disruption and drying rate on the efficiency of cyanogen removal can be illustrated by observations made during the comparative study of processing methods. Of the methods studied the ranking in order of efficiency was as follows: *chinyanya*; crushed disk; *makopa*; standard disk; and finger-sized *makopa*.

Chinyanya ranked first in the efficiency of cyanogen removal. It is a method whereby the tissue is highly disintegrated from the pounding action resulting a rapid breakdown of the cyanogenic glucosides. This is supported by work of Vasconcelos *et al.* (1992) and Jones *et al.* (1994) who observed complete removal of cyanogenic glucosides after a high degree of tissue disruption brought about by grating and mincing. The small pieces also dry rapidly in up to 2 days This was due to the greatly increased surface area to volume, hence the method is efficient in the removal of cyanogens and rapid. The crushing method, ranking second was similar in efficiency of cyanogen removal. The treatment of the roots involved a lower degree of tissue disruption but has a longer period of high moisture content. The crushing method was of similar efficiency but less rapid.

Makopa processing involves the sun-drying of whole root whole root pieces for up to two weeks and was ranked third in the comparative study of methods. The degree of tissue disruption brought about by external forces was minimal. It has been postulated by Essers *et al.* (1995b) that the endogenous cell wall degrading enzymes play a key role in disrupting the cellular integrity during the initial part of drying thus allowing the contact between the linamarse and it's substrate, cyanogenic glucosides (Okolie & Oguchukwu, 1988).

The standard, non-crushed disk was less efficient in cyanogen removal than *makopa* due to the increase in the surface area to volume ratio resulting in an increase in the drying rate and less time for the action of the hydrolytic enzymes. Finally the finger sized *makopa* ranked last in efficiency. The larger surface area to volume ratio combined with minimal tissue disruption resulted in high levels of residual cyanogens. Jones *et al.* (1994) observed that compared to manual slicing of cassava roots mechanical slicing of chips of similar dimensions resulted in an increase in the levels of cyanogens removed. It was postulated that this was due to the reduced level of tissue disruption resulting from the precise incisions of a sharp knife as compared to the rough blades of a mechanical chipper.

CONCLUSION

Crushing the cassava roots does improve significantly the removal of cyanogen over those methods that involve drying of root pieces of similar dimensions. However, it provides no significant benefit in terms of cyanogen removal as compared with methods currently in use in East Africa that involve a high level of root disintegration. A key advantage of the crushing over the pounding method termed *chinyanya* is that the former produces a product that can be stored in the same way as traditional *makopa*.

The mechanism that mediates cyanogen removal is directly related to the balance between the degree of tissue disruption and rate of drying. This is illustrated by the comparative study of processing methods used currently. It may be considered that inhibition of the enzyme systems at low moisture content can result in the cyanogenic glucosides being trapped in the dried matrix. Sun-drying of cassava is considered the least efficient of the various categories of processing commonly practised. Processing steps such as crushing and pounding may be incorporated to decrease the cyanogen level. However, sun-drying alone as a processing method for highly cyanogenic cassava varieties remains inadequate if levels are to be reduced to the safe limits of 10 mg HCN equiv./kg dry weight recommended by the FAO/WHO (1991).

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of the Tanzania Food and Nutrition Centre the analysis of the samples, the Centro Internacional de Agricultura Tropical for provision of cassava, the field workers of Ukiriguru Agricultural Research Institute for their assistance during the field trials and Statistics Group of the Natural Resources Institute.

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List of figures

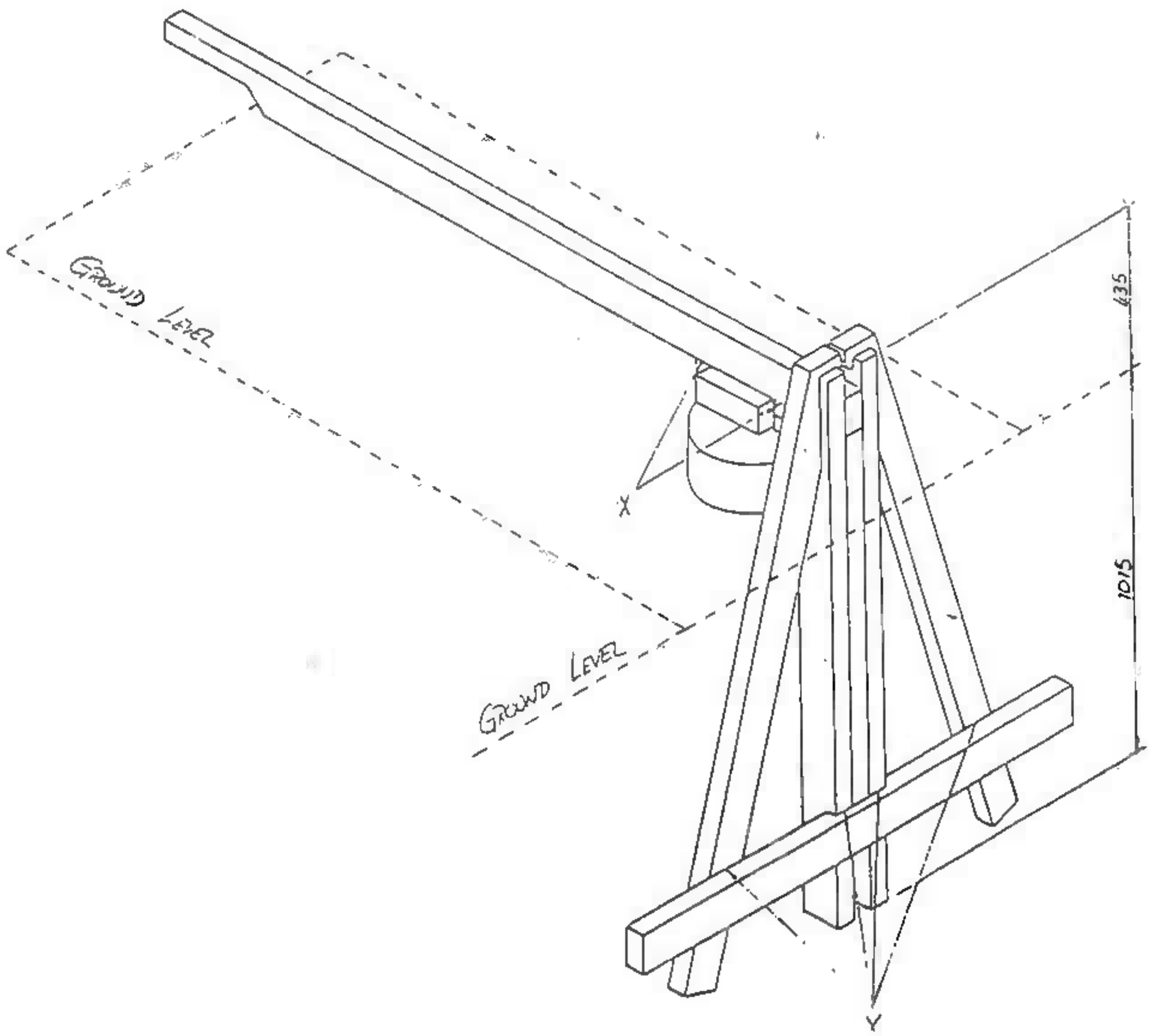
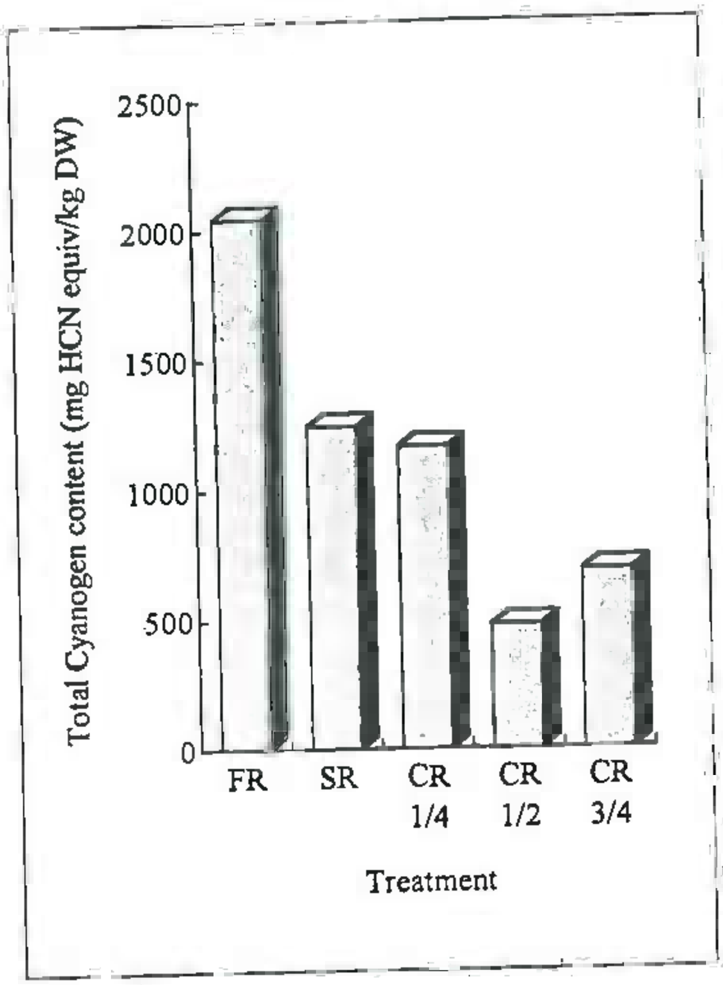


Figure 1?   Lever-arm crusher



Key : FR - fresh root; SR - standard root; CR 1/4, CR 1/2, CR 3/4 - crushed root disk compressed to a quarter, half and three quarters of the original disk depth.

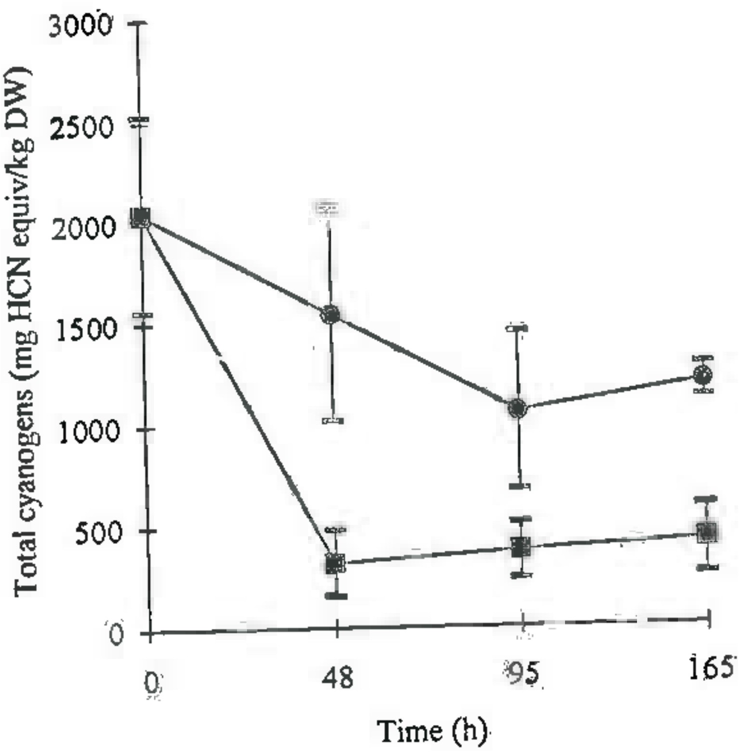
Figure 2: Optimisation of cyanogen removal by variation in the degree of crushing.

Table 1: Levels of cyanogens in standard and crushed root disks of cassava obtained when using the prototype crusher.

Treatment	Total cyanogen content (mg HCN equiv./kg dry weight)*	Total percent reduction (%)
Fresh root	1942 ± 281	
Standard root disk	1040 ± 270	50 ± 12
Crushed root disk	470 ± 175	77 ± 9

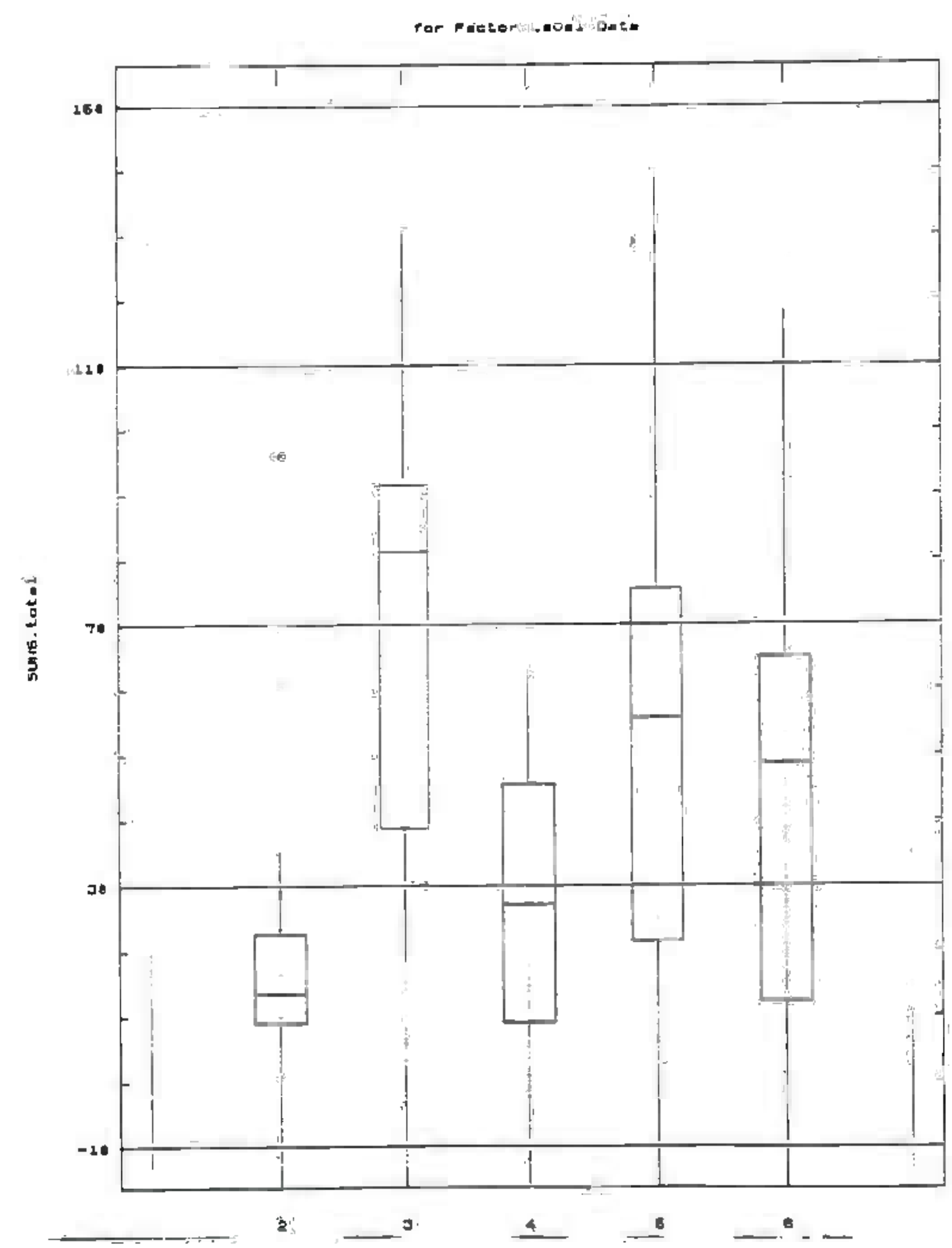
*Mean and standard deviation σ_{n-1}, where n=10.

Mean of difference between standard and crushed = 570 mg/kg
Standard error of difference = SD/√n = 67.5
t value = 57.0/67.5 = 8.4
95% Confidence interval is that 417 to 723 mg/kg difference with 9 degrees of freedom



Key: ● Standard disk; ■ crushed disk

Figure 3: Cyanogen removal from standard and crushed root disks against time indicating standard deviation (σ_{n-1}).



Key: 2 - Pounded; 3 - fingersixed pieced; 4 - crushed disk; 5 - standard disk; and 6 - whole root

Figure 4: Box plot of cassava root treatment versus cyanogen removal.

Table 2: Probability level of differences for processing cassava by varied means.

Processing method	FR	CY	WR	FS	SD	CD
FR	-	6.3x10-6	2.2x10-7	4.2x10-6	2.3x10-7	1.8x10-6
CY		-	0.0343	0.0005	0.0185	0.3482
WR			-	0.0021	0.1734	0.0647
FS				-	0.2256	7.5x10-5
SD					-	0.0074
CD						-

Key: Fresh root (FR); *Chinyanya* (CY); *Makopa* (WR); Finger sized *makopa* (FS); Standard disk (SD); Crushed disk (CD)

ANNEX 2

A REVIEW

PROCESSING OF *FUFU* FROM CASSAVA IN NIGERIA: PROBLEMS AND PROSPECTS FOR DEVELOPMENT

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ABSTRACT

Traditional small scale processing of fermented products and more specifically, *fufu* from cassava has been reviewed with the aim of identifying means of improving production and quality of *fufu* in Nigeria. Post-harvest constraints commented upon in the literature included aspects of handling, utilisation, efficiency of current processing practices, storability and external factors such as the problems of processing in the wet season. Researchable issues have been identified and are reported in this review.

Keywords: Cassava, process development, *fufu*, Nigeria.

INTRODUCTION

Cassava is a root crop cultivated and consumed as a main staple in many regions of the developing world. The success of cassava is attributed to its ability to produce reasonable yields on poor agricultural land (de Bruijn and Fresco, 1989). The whole plant is used, the roots and leaves for consumption and the stem for propagation (Lancaster *et al.*, 1982). The roots are a good source of carbohydrate and commonly processed to remove naturally occurring toxins and provide storable products that can be consumed or used in the production of secondary products (Lancaster *et al.*, 1982).

In Sub-Saharan Africa, cassava roots are processed by a variety of methods to provide products that are used in diverse ways according to local preferences. Processing involves combinations of unit activities such as peeling, slicing, grating, soaking, boiling, steaming, roasting, drying, pounding and milling. The final product characteristics are dependent on the combination of activities undertaken (Longe, 1980; Hahn, 1989; Oguntunde and Orishagbemi, 1991). Cassava products have thus been classified into four major groups by work as part of the Collaborative Study of Cassava in Africa (COSCA) these were: roasted granules; steamed granules; flour/dry pieces; and fermented wet pastes (Natural Resources Institute, 1992).

According to COSCA, the roasted granule product, *gari* is known throughout West Africa (Natural Resources Institute, 1992). *Gari* is of primary importance in rural and urban areas of Nigeria and is used as a convenience food because of the ease by which it may be prepared for consumption (simple addition of hot water or milk). As an alternative, *fufu*, a fermented wet paste from cassava, is widely consumed in eastern and south western Nigeria and other parts of West Africa such as Sierra Leone (Blanshard *et al.*, 1994). In Nigeria, it has commercial potential that has been reported to be increasing (Nweke and Bokanga, 1994). In general, the rural and urban demand for *gari* is higher than that of *fufu* and it is the preferred product for higher income consumers due the ease by which it may be prepared for consumption.

Since rapid urbanisation is a driving force behind the desire for more convenience foods such as *gari*, there is a need to review the traditional processing of alternative products such as *fufu* to identify possible means for improving and increasing their production to meet changing demand for such products.

Importance of cassava and *fufu* in Nigeria

Cassava is increasingly one of the most important food staples in the tropics. The roots provide a valuable source of calories and staple food for about 800 million people (Oyewole, 1992; Poulter *et al.*, 1992). World production of fresh cassava root increased from 70 millions tonnes in 1960 to 154 million tonnes in 1991. Nigeria is the second major producing country contributing 20 million tonnes of fresh roots per annum (CIAT, 1993). Cassava is well known for its ability to tolerate drought and yet maintain yields, it can be harvested at any time from 7 months to 3 years after planting and most importantly, the crop is very flexible in that it can be processed into many products (CIAT, 1993).

There are a number of products that are commonly processed in Nigeria. In recent years consumer preference for various products has been shown to be dynamic. Between the 1960s and early 1970s the breakdown of consumption by product type was: 15% of all cassava was eaten as fresh roots, 5% as *gari*, 60% as *fufu*, 10% as starch and 10% as cassava flour (Abiagom, 1971). By the early 1980s, the consumption of *fufu* had declined to 14% of all cassava consumed, while that of *gari* rose to 65% according to a national consumption survey by the Federal Office of Statistics, FOS (1981). The reduction in consumer preference for fufu is said to be due to its inherent undesirable characteristics mainly odour, short shelf life and tedium in preparation (Okpokiri *et al.*, 1985).

The distribution of fermented wet paste processing in West Africa shown in Figure 1 (Natural Resources Insitute, 1992) revealed that production is concentrated near the coast and declines in importance further north. These areas provide an abundant water supply needed for *fufu* production (Nweke, 1994). Nweke (1994) reported that granules and fresh roots are more frequently produced where the market access infrastructure is relatively well developed in high population density areas. These observations suggest that roasted granules (*gari*) are more associated with commercialisation than the other processed cassava products.

Processing of fermented products in Nigeria

In order to assess the relative importance and intensity and scale of processing operations in Nigeria, a description of common processing methods is given below.

Fufu

A generalised scheme for traditional *fufu* production in south west Nigeria is shown in Figure 2. Small variations such as partial steaming and pounding of rolled balls of *fufu* mash in the processing technique are practised by the Ibos and Efiks tribes of eastern Nigeria (Grace, 1971; Etejere and Bhat, 1985).

Apart from the Federal Institute for Industrial Research Oshodi (FIIRO), that adapted a *gari* processing plant to produce *fufu* (FAO, 1984; Subrahmanyam, 1990), no mechanised processing fo *fufu* exists. *Fufu* is currently produced mainly by rural processors at both household and on a small scale specifically in eastern and south western Nigeria.

Peeling of roots is normally done manually by women and girls using hand knives. The rate per person can be as high as 400 kg per 8 hours. After the roots have been peeled, they are washed and made ready for soaking. Some processors do not peel cassava before soaking and instead remove the peel from the softened roots, but it is generally considered that this produces a poor quality product.

The peeled and washed cassava roots are cut into chunks of different sizes manually using a hand knife and soaked in streams, drums or preferably earthen pots of water for 3-5 days to undergo a lactic acid fermentation. During soaking, the natural fermentation decreases the pH value, softens the roots and facilitates the reduction in potentially toxic cyanogenic compounds (Ayernor, 1985; Westby, 1994; Oyewole and Odunfa, 1992; Westby and Choo, 1994).

When sufficiently soft, the roots are taken out, broken by hand and the fibre is removed by sieving. At present, processors sieve manually by adding water to the retted mass on a nylon or cloth screen. The fibre produced as a by-product is used for animal feed either in its wet form or after drying.

The sieved mass is allowed to sediment in a large container for about 24 hours. After sedimentation, the water is decanted while the fine, clean filtrate (mainly starch) is dewatered by putting it into raffia or cotton bags, pressing with heavy stones and leaving it overnight to remove excess water.

The *fufu* is collected and sold to the consumers in its wet form in small units packaged in plastic or polypropylene bags (Hahn, 1989).

To prepare *fufu* for consumption a known quantity of the slurry containing about 25% *fufu* solids in water is boiled directly in an open pan. After constant stirring using a wooden rod, a strong paste or dough is formed (Etejere and Bhat, 1985; Kwatia, 1986; Ayankunbi *et al*., 1991; Anon, 1994). Cooked *fufu* is usually eaten warm with fish, meat, vegetable stew or soup.

Lafun

Lafun is similar to *fufu* in Nigeria. The principal differences are that *lafun* is a dried product that has a good shelf life, whereas *fufu* is a wet product with low fibre content.

Fresh cassava roots are cut into different chunks and soaked for 3-4 days or until the roots become soft. The fermented roots are peeled, broken up into small crumbs and sun-dried on mats, flat rocks, cement floors or similar flat area. Once dried the crumbs are milled into a flour. Alternatively, chips are made directly from fresh roots whereby the fresh cassava roots are cut into chunks and dried by sun drying. Lafun is consumed in a similar way to *fufu*.

Gari

Gari is widely known in Nigeria and other west African countries (Nweke, 1994). Fresh roots are peeled and grated. The grated pulp is put in sacks that are pressed using a jack or heavy objects to express excess liquid from the pulp while it is fermenting. After 3-4 days the dewatered, fermented lumps of pulp are sieved and the resulting fine pulp is roasted in a pan. Palm oil is often added during roasting to prevent the pulp form burning. This has the additional desirable effect of changing the colour of the product from white to yellow.

Gari is preferred by urban consumers because it is a pre-cooked convenience food. It is commonly consumed either by soaking in cold water with sugar or salt and taken with coconut, peanut, fish, bean porridge or as a paste made with hot water and eaten with vegetable sauce. Certain processing steps in *gari* making such as grating, milling and water expressing are mechanised (Lancaster *et al.*, 1982; FAO, 1984; Igbeka *et al.*, 1992; Nweke *et al.*, 1992; Nweke and Bokanga, 1994).

Other minor products

Starch is produced in either as a wet paste or more commonly dried. Cassava roots are peeled, washed and grated. The grated pulp is steeped for 2-3 days in a large quantity of water, stirred, and filtered through a piece of cloth. The filtrate is allowed to stand overnight and is then decanted. The sedimented starch is air dried in the shade.

Abacha is another product that is commonly produced in parts of south east Nigeria but is rare elsewhere. Its production involves boiling roots in water and cutting them into small flat pieces. The sliced pieces are soaked overnight to make wet *abacha*, to produce a dried product.

CONSTRAINTS TO CURRENT *FUFU* PROCESSING

Fufu is considered by consumers to be of good quality when it is: creamy-white, grey or yellow in colour; with smooth texture and with a characteristic aroma (Akingbala *et al.*, 1991; Oyewole and Odunfa, 1992; Blanshard, 1994). The quality of *fufu* has been reported to vary between processors and according to season (Oyewole and Sanni, 1995). This variability has been attributed to various local practices during the soaking or submerged fermentation stage of processing. For instance, processors confirmed that for sufficient retting to occur, shorter fermentation periods (2-3 days) are required during the dry (hot) seasons, while longer periods (3-5 days) are required during the rainy (cold) season. Data collected during the COSCA survey confirmed that in Nigeria considerable variations in the soaking time for *fufu* production were practised (Figure 3). Some processors expose their fermenting roots to direct sunlight as a means of enhancing the fermentation process, while others adopt 'short-cuts' such as fermenting the roots for less than two days or processing immature cassava roots to enhance financial gain (Oyewole and Sanni, 1995). Hahn (1989) reported that during the rain season there is less sunshine and lower temperatures for processing cassava, particularly in lowland humid areas, where much cassava is grown and utilised. Researchers (Oyewole and Odunfa, 1992; Blanshard *et al.*, 1994; Ampe *et al.*, 1994) have reported effective retting of not less then 60 hours for temperatures of between 30-35°C in the laboratory. This data corresponds with typical processing conditions in Nigeria.

At present cassava roots brought from farm to the market are often stored at ambient temperature for two to three days prior to processing either due to transportation problems between the farm sites and the processing centres, or delay in processing caused by the slow manual processing methods employed (Idowu and Akindele, 1994). This could also contribute to variable quality of *fufu*.

The production of *fufu* is largely home based and fermentation is usually left to chance inoculation from the environment (Oyewole, 1990; Oyewole and Sanni, 1995). Little or no control is involved in the processing and this may influence the quality of the product. The fermentation vessels used for previous batches usually serve as a source of inoculum for the initiation of fermentation (Oyewole, 1995).

In terms of nutritional quality, potential toxicity in cassava is due to the presence of the cyanogenic glucosides, linamarin and lotuastralin, which are synthesised in the leaves and stored in the roots. Although health problems have been attributed to cyanide exposure from insufficiently processed cassava, there are only few reports of acute poisoning in Nigeria (Oshuntokun, 1981; Akintonwa and Tunwashe, 1992). It is generally considered that effective processing of cassava practised in Nigeria, is sufficient to reduce the cyanogen content to low levels (Obigbesan, 1994).

Other factors that could be responsible for the variable quality of *fufu* include the size to which the roots are cut prior to soaking (Okafor *et al.*, 1984), varietal differences in dry matter content (Hahn, 1989) and the quality of the roots and of the water used for processing.

In a survey carried out among 50 processors, generally women, in ten localities around Abeokuta, south west Nigeria, the processors identified manual peeling of cassava roots using a hand knife to be tedious and time consuming (Oyewole and Sanni, 1995).

Root size and shape vary among cultivars of cassava. Roots with irregular shapes are difficult to harvest and peel by hand and this leads to great losses of useable root material. Smaller roots require more labour for peeling (Hahn, 1989). In addition to peeling, sieving is another unit operation that is time consuming though it is not considered too labour-intensive.

As was stated earlier, unlike *lafun* and *gari*, which are dried products and can thus be preserved for some time, *fufu* is a wet product (moisture content of about 50%) which renders it highly perishable. It is consumed immediately after preparation or stored in baskets or plastic bags for up to a week. The poor shelf-life of *fufu* is a serious limitation for large scale processors.

PROSPECTS AND FUTURE RESEARCH FOR IMPROVED *FUFU*

Although there had been a decline in the demand for *fufu* between 1960 and 1980 (FOS, 1981), its potential in the domestic market is now increasing. Consumers prefer ready to serve cooked pastes that involve minimal preparation (Nweke and Bokanga, 1994). However, cooked pastes have a short shelf life. There is therefore potential for a dried product that combines extended shelf life with minimal preparation. Low-income groups are the main consumers of *fufu* whereas *gari* has a significant market among high-income consumers (Nweke, 1994).

The extent to which the market for *fufu* can be expanded, will therefore depend largely on the degree to which its quality can be improved to make it attractive to the higher-income consumers without significant increases in processing costs. Such an approach would provide income generating opportunities for the processors who are mostly women and the retailers. With this in mind the following researchable issues have been identified with a view to controlling and standardising the *fufu* processing method for larger scale commercial production.

Post harvest storage of cassava roots

Idowu and Akindele (1994) reported that the storage of freshly harvested cassava roots at ambient temperature for 0-4 days helps to detoxify the roots and their products, *gari* and *fufu*, but lead to drastic reduction in their percentage yield of 50% and 60% respectively. They found out that the storage of cassava roots had no significant effect on their organoleptic qualities. However, Ampe *et al*. (1994) observed that a slight increase in the production of lactate and ethanol during retting of cassava roots, stored under ambient condition, could partially decrease the acceptability of *foo-foo*. In essence, storage at ambient conditions will contribute to the post harvest losses of cassava roots and variability in the quality of the products.

Improvements in post harvest management in cassava would significantly increase overall food availability and reduce costs for producers, distributors and consumers, thereby enhancing food security. Thus, there is a need to investigate alternative low cost storage techniques that would improve the present approach of storing cassava before processing and evaluate its effect on the yield and quality of the resultant products.

Optimisation of retting

Another factor of importance to *fufu* quality is the size of the fermenting roots. The processors cut the roots into variable piece sizes and this may influence the quality of the product. Okafor *et al.* (1984) and Oyewole and Odunfa (1992) have each reported that small pieces of cassava allow retting to be completed more quickly while Ampe *et al.* (1994) and George (1994) reported contrary opinions. In terms of quality, larger pieces of cassava produced *fufu* with good texture and consistency and characteristic aroma (Oyewole and Odunfa, 1992). Further clarification of the situation is required to settle this controversy bearing in mind the importance of this unit operation. Thus, there is the need to investigate the effect of initial root size prior to soaking on the retting period during *fufu* production and quality of the finished product. This is very important for maintaining product quality standards in larger scale processing of cassava for *fufu* production.

Starter culture

The provision of pure starter cultures is an issue commonly raised in relation to fermented foods in developing countries (Westby *et al.*, 1995). There are three main simple, low-cost, technologies: natural inoculation, transfer of an old batch of fermented product to a new batch (back-slopping), and indigenously derived cultures (Westby *et al.*, 1995). Oyewole (1990) and Okolie *et al.* (1992) have each reported successfully producing acceptable *fufu* by the use of isolated pure culture starter cultures. It is unlikely that the use of pure culture starter inocula will be viable at the household level. The financial costs to the processor and problems of propagating and disseminating such cultures will be a major limiting factor. Such inocula may be more appropriate in very large scale processing where the extra costs involved can be offset against the demand for consistent quality. Ampe *et al.* (1994) reported that inoculation of water with liquid from previous fermentation's prior retting helps in detoxification and reduced the variability in the quality associated with spontaneous fermentation of cassava for *fufu* production. It would be cost effective to promote the use of undefined starter cultures (back-slopping) in ensuring consistency of quality on the *fufu* fermentation.

Mechanisation

Mechanisation is not used by small scale processors although some aspects of the *fufu* processing are considered time-consuming, labour intensive by processors and cause bottlenecks in the production (Oyewole and Sanni, 1995). It has also been noted that small scale processing results in non-uniform product quality (Oyewole and Odunfa, 1992).

Manual peeling was considered by women processors as the most labour intensive step and as such a major constraint. Investigation of appropriate means to mechanise this operation should be considered. A possible solution is currently used in Brazil and involves the debarking of the cassava root prior to processing (Westby and Cereda, 1994). Usually this is done mechanically, first by abrasion and then by abrasion with water to remove the soil and pieces of bark. The debarking technology would offer two distinct advantages over hand peeling. First, the amount of labour required and the losses of root material would be greatly reduced. A cost-benefit analysis of this technology for larger scale processors should be undertaken. The technology would also be relevant to *gari* processing.

As an alternative to peeling, unpeeled roots can be soaked in water and the peel removed from the softened roots. The is a very easy process, but it is generally considered that it produces *fufu* with poor colour. There is a need to investigate processing of roots without peeling and determine if any simple step can be taken to avoid discoloration of the product.

A practical approach for improving shelf life of *fufu* by drying to form a dried product. The resultant product could then compete with *gari* as a convenience food provided it could be produced at a price acceptable to the consumers and it's quality characteristics were acceptable. Although, sun and solar drying methods are attractive because of their low cost they are subject to weather conditions (Westby and Cereda, 1994; Sanni, 1992; Sanni *et al.*, 1995). Okpokiri *et al.* (1985) reported good quality dried *fufu* when wet *fufu* was dried in the oven at 55°C for the first 8 hours and gradually increased to 80°C. Drying of *fufu* in an oven at 60°C for 48 hours has also been reported to reduce the strong odour of *fufu* but the products are sticky, bland and the quality unacceptable compared to wet *fufu* when assessed by a taste panel (Akingbala *et al.*, 1991). Systems for artificial drying that would retain the characteristic quality of *fufu* should be investigated.

Fufu powder is assumed to be hygroscopic in nature and will gain or lose moisture depending on the relative humidity of the surrounding air after processing and at the market place. This will make it susceptible to deteriorative biological and chemical changes. Knowing that the ability to store dried *fufu* will be a key issue the following need to be established: the temperature dependence of moisture adsorption and desorption characteristics of the dried product; and the influence of storage conditions on the quality of the dried product.

With the current high levels of urbanisation in Nigeria, consumers are demanding foods that are more convenient. This market niche can be filled by imported goods, but it would be better to rely on locally produced traditional products. The continued success of cassava as a staple food in urban centres and as a source of steady income for rural households will, to a large extent, depend upon its ability to compete with grains (Berry, 1993) and, in case of West Africa, with yam. Dried *fufu* could be one of such products that could be introduced to the consumers. Prior to its introduction to the market, there is the need to ascertain the cost-benefits of the scale-up processing of dried *fufu*. Thus, factors such as raw materials supply, production and product cost should be evaluated to assess the feasibility of industrial production of *fufu*.

Apart from the cost-benefit, there is the need for assessment of the social-economic acceptability of dried *fufu*. Information such as marketing survey into why *fufu* appeals to low-income group and not high-income group is required. It is essential also to assess whether the introduction of dried *fufu* would be acceptable relative to the traditional fresh and cooked *fufu* on one hand and *gari* on the other hand. This information must be considered essential prior to embarking on the task of developing the technology further.

The characteristic odour of liquid waste from fermenting cassava that is often found offensive is another constraint to production of *fufu*. At present *fufu* is only produced on a small scale, hence, odour is not a great problem. However, if *fufu* is industrialised large amounts of waste water with a high Biological Oxygen Demand will be produced and this could cause serious pollution problems if not controlled. A case study of *gari* processing in Ibadan, Nigeria by Sanni (1994) where the effluent from the de-watering press was directly discharged into drains and streams highlighted the problems of effluent pollution resulting from large processing centres. Another reported case is the pollution problems associated with starch extraction during cassava starch production in Brazil (Westby and Cereda, 1994). It would be anticipated that the pollution problems associated with large scale *fufu* processing would be more like those of starch because of the need to wash the fermented material through a sieve before allowing the *fufu* to sediment. A low cost treatment technique which would have wide applicability for cassava processing industries needs to be developed. It is important that the methodologies devised can cope with seasonal and intermittent flows of waste water.

CONCLUSION

Fufu is a processed product for which there is potential to increase production through the development of the product as a convenience food in urban areas. To achieve this, a number of important constraints to *fufu* production have been discussed in this review. These have lead to the identification of a number of researchable issues that must be addressed in order to assist processors of *fufu* and to assess the potential for industrialisation of the process. Improved product quality as a result of large scale production may improve the acceptability of *fufu* in the urban cities of Nigeria as well as providing employment opportunities for cassava processors and a market outlet for fresh cassava.

ACKNOWLEDGEMENT

The first author acknowledges with thanks the financial support by the World Bank Assisted Programme for Academic Staff under the auspices of Nigerian Universities Commission and the senate of University of Agriculture, Abeokuta, Nigeria. Financial support of the ODA Crops Post-Harvest Programme is also acknowledged.

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ANNEX 3

Table 1: Air drying combinations used in the drying procedures

Samples	Temperature °C	Velocity ms^{-1}	Relative humidity kg water/kg dry air
1	65	3	0.0194
2	65	4	0.0167
3	65	2	0.0167
4	65	3	0.0139
5	55	4	0.0194
6	55	4	0.0139
7	55	2	0.0194
8	55	2	0.0139
9	45	3	0.0194
10	45	2	0.0167
11	45	4	0.0167
12	45	3	0.0139
13	55	3	0.0167
14	55	3	0.0167
15	55	3	0.0167

Table 2: Effect of cassava piece shape on the acidity content of *fufu* during soaking for 4 days at 34°C.

Root shape	pH				TTA (g/kg, lactic acid)			
	1	2 (days)	3	4	1	2 (days)	3	4
Chip	5.94	5.57	4.98	3.77	0.11	0.26	0.36	0.33
Slice	5.97	5.34	4.92	3.67	0.07	0.21	0.27	0.24
Disc	5.54	5.11	5.00	4.89	0.14	0.32	0.36	0.27

Fresh root pH 6.19 and TTA 0.18 g/kg, lactic acid.
Standard deviation from the mean of duplicate determinations was ≤ 0.01 for each determinations.

Table 3: Effect of cassava piece shape on the moisture absorption and texture during soaking for 4 days at 34°C

Root shape	Moisture (kg/kg) *				Peak force (kg)			
	1	2 (days)	3	4	1	2 (days)	3	4
Cubes	404	750	634	551	3.55	3.00	2.65	1.80
Slices	556	590	691	632	2.45	2.10	2.05	1.10
Disc	466	648	620	581	4.85	4.20	3.65	3.30

Fresh cassava 688 kg/kg ; 7.50 kg force.
* Standard deviation from the mean of duplicate determinations was ≤ 0.30 for each determination.

Table 4: Effect of concentration of inoculum on the acidity, moisture and texture of cassava root at 96 h of soaking

Inoculum concentration	pH *	TTA * g/kg	Moisture ** g/kg	Texture/firmness kg
Fresh root	6.7	0.16	689	7.4
Water inoculum	3.5	0.71	n.d	n.d
Fufu inoculum	3.8	0.39	494	n.d
Fermentation water inoculum (% v/w)				
10	3.9	0.37	690	1.1
15	3.9	0.39	633	1.7
20	3.9	0.44	522	1.6
Fufu inoculum (% w/w)				
10	3.7	0.47	569	1.1
15	3.8	0.48	573	1.8
20	3.7	0.53	653	2.5

n.d = Not determined.
* Standard deviation from the mean of duplicate determinations was ≤ 0.01 for each determination.
** it was ≤ 0.2 for each determination.

Table 5: Changes in acidity and moisture content of cassava root of various sizes during soaking

Sizes	Time (h)	pH *	TTA* (g/kg)	Moisture content ** (g / kg)
Grated				
	0	6.2	0.13	679
	24	3.9	0.15	853
	48	3.7	0.58	887
	72	3.6	0.61	864
	96	3.5	0.63	810
Slice (0.5 cm thick)				
	0	6.2	0.13	658
	24	5.0	0.21	711
	48	4.4	0.40	780
	72	3.5	0.42	655
	96	3.5	0.44	635
Slice (3.0 cm thick)				
	0	6.2	0.13	656
	24	5.8	0.16	659
	48	4.9	0.26	749
	72	4.4	0.32	680
	96	3.8	0.41	655

* Standard deviation from the mean of duplicate determinations was ≤ 0.01

** Standard deviation from the mean for duplicate determinations was ≤ 0.2.

Table 6: Mean scores for sensory evaluation of *fufu* processed from different root sizes for 96 h of soaking.

Fufu samples	Mean Score*				
	Colour	Taste	Odour	Texture	Acceptability
Grated	5.80b	3.83c	5.67b	3.33d	3.83c
Slice (0.5 cm thick)	6.00b	5.83b	5.67b	5.50b	5.17b
Slice (3 cm thick)	8.00a	6.67a	7.50a	7.33a	6.83a

*Means scores with the same letters in a column are not significantly different ($P < 0.05$).

Table 7: Changes in pasting characteristics of *fufu* during storage

Analysis	Samples		
	Fresh	Refrigerated	Frozen
Pasting Temperatures (°C)	71	68	66.5
Peak Viscosity (BU)*	280	265	1676
Viscosity at 95°C (BU)*	260	235	1696
Viscosity at 95°C/20 min hold (BU)	350	260	1476
Viscosity at 50°C (BU)**	900	795	2476
Viscosity at 50°C/30 min hold (BU)***	880	860	2076

Standard deviation for the mean of two determinations: (*) ≤ 21.21 ; (**) ≤ 63.64 ; (***) ≤ 28.28

Table 8: Chemical composition of fresh and refrigerated *fufu**

Analysis	Samples	
	Fresh *fufu*	Refrigerated *fufu*
Moisture content (% dry basis)	146	158
pH	3.6	3.3
Titratable acidity (g/kg, lactic acid)	0.65	0.91

* Standard deviation was ≤ 0.02 for all means of two determinations.

Table 9: Volatile compounds of *fufu* identified by GC-MS

Peak No.	Compound	Retention time (min)
1	Butanol	8.56
2	Dimethyl, N, N, Formamide	12.63
3	Acetic Acid	17.60
4	2-ethyl-1-hexanol	18.98
5	Propionic Acid	20.75
6	Butanoic Acid	23.71

Table 10: Level of volatile compounds determined in fresh and refrigerated *fufu*

Compound	Concentration (μg/20g *fufu* weight)	
	Fresh *fufu* *	Refrigerated *fufu*
1- Butanol	21.83	2.91(0.91)
Dimethyl, N, N, Formamide	156.32	61.62(27.94)
Acetic acid	43.58	2.73 (1.29)
2 ethyl- 1-hexanol	0.50	0.05 (0.02)
Propionic acid	1.64	0.07 (0.00)
Butanoic acid	905.10	11.08 (0.54)

* One determination.
( ) Standard deviations for two determinations.

Table 11: **Effect of drying conditions on the chemical properties of *fufu*.**

Samples	Conditions *	pH*	Titratable acidity* (g/kg lactic acid)
1	65°C, 3 m/s, 0.0194 kg/kg	3.88	0.44
2	65°C, 4 m/s, 0.0167 kg/kg	3.79	0.49
3	65°C, 2 m/s, 0.0167 kg/kg	3.80	0.43
4	65°C, 3 m/s, 0.0139 kg/kg	3.86	0.43
5	55°C, 4 m/s, 0.0194 kg/kg	4.32	0.36
6	55°C, 4 m/s, 0.0139 kg/kg	4.31	0.33
7	55°C, 2 m/s, 0.0194 kg/kg	4.17	0.41
8	55°C, 2 m/s, 0.0139 kg/kg	4.26	0.33
9	45°C, 3 m/s, 0.0194 kg/kg	4.50	0.27
10	45°C, 2 m/s, 0.0167 kg/kg	4.19	0.38
11	45°C, 4 m/s, 0.0167 kg/kg	5.44	0.28
12	45°C, 3 m/s, 0.0139 kg/kg	4.02	0.41
13	55°C, 3 m/s, 0.0167 kg/kg	3.90	0.42
14	55°C, 3 m/s, 0.0167 kg/kg	3.95	0.41
15	55°C, 3 m/s, 0.0167 kg/kg	3.85	0.42

* Standard deviation was within the range of 0.0-0.03.

** Temperature (°C), velocity (m/s), air moisture content (kg/kg dry air)

Table 12: Effect of drying conditions on the volatile compounds of *fufu*

Samples	Conditions	Butanol	DMF	Acetic acid	2-ethyl 1-hexanol	Propionic acid	Butanoic acid
1	65°C 3m/s 0.0194kg/kg	1.36± 0.06	19.58± 0.19	0.75± 0.17	1.43± 0.79	0.16± 0.23	0.26± 0.18
2	65°C 4m/s 0.0167kg/kg	2.30± 0.25	21.78± 1.06	0.54± 0.09	0.03± 0.04	0.00± 0.00	0.16± 0.07
3	65°C 2m/s 0.0167kg/kg	1.06± 0.05	19.45± 0.92	1.01± 0.09	1.77± 2.08	0.04± 0.05	1.81± 1.11
4	65°C 3m/s 0.0139kg/kg	1.19± 0.13	19.84± 0.10	0.97± 0.03	0.05± 0.02	0.00± 0.00	0.00± 0.00
5	55°C 4m/s 0.0194kg/kg	1.25± 0.02	20.75± 0.14	1.01± 0.19	0.23± 0.25	0.00± 0.00	0.05± 0.07
6	55°C 4m/s 0.0139kg/kg	1.08± 0.08	19.00± 0.53	1.07± 0.11	0.04± 0.00	0.00± 0.00	0.22± 0.24
7	55°C 2m/s 0.0194kg/kg	0.96± 0.09	20.17± 0.47	0.92± 0.20	0.05± 0.03	0.00± 0.00	0.37± 0.04
8	55°C 2m/s 0.0139kg/kg	1.06± 0.03	20.75± 0.64	0.94± 0.15	0.05± 0.00	0.00± 0.00	0.02± 0.03
9	45°C 3m/s 0.0194kg/kg	1.02± 0.03	19.41± 1.36	1.56± 0.41	0.14± 0.16	0.00± 0.00	0.81± 0.58
10	45°C 2m/s 0.0167kg/kg	1.20± 0.03	21.43± 0.50	0.86± 0.26	0.04± 0.00	0.00± 0.00	0.23± 0.02
11	45°C 4m/s 0.0167kg/kg	1.58± 0.72	20.11± 1.29	0.93± 0.06	0.05± 0.01	0.00± 0.00	2.23± 3.02
12	45°C 3m/s 0.0139kg/kg	2.20± 0.17	20.57± 0.01	1.22± 0.46	0.07± 0.04	0.09± 0.13	0.11± 0.03
13	55°C 3m/s 0.0167kg/kg	1.18	21.29	1.52	0.04	0.00	0.32
14	55°C 3m/s 0.0167kg/kg	1.16± 0.08	21.65± 0.69	1.29± 0.12	0.07± 0.04	0.00± 0.00	0.00± 0.00
15	55°C 3m/s 0.0167kg/kg	1.48	17.93	0.88	0.56	0 40	3.79

Standard deviation where σ_{n-1}

Table 13: Influence of drying condition on the pasting characteristics of *fufu*

Table 13

Effect of Drying Conditions on the Pasting Characteristics of fufu

Samples	pasting temperature (°C)	Stdev	Peak Viscosity (BU)	Stdev	Viscosity at 95°C (BU)	Stdev	Viscosity at 95°C for 20 min holding (BU)	Stdev	Viscosity at 50°C (BU)
1	69.50	0.00	750	14.14	750	14.14	565	35.36	630
2	76.00	1.41	740	28.28	740	28.28	585	7.07	655
3	70.10	0.00	770	42.43	770	42.43	615	35.36	700
4	69.80	0.42	950	70.71	950	70.71	690	14.14	770
5	70.85	0.21	810	14.14	810	14.14	680	0.00	800
6	80.60	0.00	780	0.00	780	0.00	640	0.00	780
7	68.75	1.91	890	14.14	890	14.14	730	14.14	860
8	69.80	0.42	860	0.00	860	0.00	745	7.07	820
9	70.70	0.85	755	7.07	755	7.07	700	0.00	830
10	70.95	1.34	800	0.00	800	0.00	720	0.00	790
11	80.23	0.32	500	0.00	500	0.00	480	0.00	700
12	70.10	0.00	810	14.14	810	14.14	710	14.14	770
13	69.50	0.00	820	0.00	820	0.00	700	28.28	770
14	69.50	0.00	825	7.07	825	7.07	710	0.00	840
15	69.50	0.00	810	14.14	810	14.14	680	0.00	765

Table 14: Statistical results for chemical and volatile compounds of dried *fufu*

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pH
Eqn: 6.109 - 0.0353(T)
R2: 37 %
Op: T = 65°C.

Titratable acididty
Eqn: 2.185- 0.04647(T) + 0.0472(S) - 00058(S 2) - 143.3 (RH) +2.447 (T)(RH) - 0.2082 (V) + 0.003696(T) (V).
R2: 90.4 %
Op: T = 65°C, V = 4 m/s, RH = 0.0194 kg/kg dry air.

Butanol
Eqn: 23.83 + 0.241(V) - 0.619(T) + 0.0037 (T 2) - 723 (RH)+ 12.37 (T)(RH)
R2 44.90 %
Op: T = 45°C, V = 4 m/s , RH = 0.0139 kg/kg dry air (Maximised).

DMF
Eqn. 2.3 - 0.285(T) + 4144 (RH) - 124800(RH 2) - 5.04 (V) + 0.0912 (T)(V)
R2 37.30 %
Op: T = 45°C, V = 2 m/s, RH = 0.0164 kg/kg dry air.

Acetic acid
Eqn: - 6.87 + 2.030 (V) - 0.342 (V 2) + 0.206 (T) - 0.00202 (T 2).
R2 52.80 %
Op: T = 51°C, V = 2.97 m/s (Maximised).

2-ethyl 1-hexanol
Eqn: 2.036 - 0.0401 (S).

Propionic acid
No evidence that any of T, V, and RH affect it.

Butanoic acid
Eqn: - 9.79 + 1819 (RH) - 53063 (RH 2) - 0.333 (T) + 0.00539 (T 2) + 2.595 (V) + 0.409 (V 2) - 0.0913 (V)(T).
R2 90.50 %
Op: T = 65°C, V = 4 m/s, RH = 0.0139 kg/kg dry air (Minimised).
T = 45°C, V = 4 m/s, RH = 0.0171 kg/kg dry air (Maximised).

Eqn: Equation ; R2 : Coefficient of determination ; Op : Optimum drying conditions ; T : Temperature ; V : Velocity ; RH : air moisture ; S: Storage days before drying.

Table 15: Statistical results for pasting characteristics of dried *fufu*

Pasting temperature °C
Eqn: 59.8 - 4.72 (V) + 3.56 (V 2) + 1892 (RH) - 789 (RH)(V).
R2: 76.8 %
Op: V = 4 m/s, RH = 0.0139 kg/kg dry air.

Peak Viscosity (BU)

Eqn: 4243 - 61.2 (V) - 391088 (RH) + 11500000 (RH 2).
R2: 28.70 %
Op: T = 2 m/s, RH = 0.0139 kg/kg dry air.

Viscosity at 95°C
Eqn: 947 - 61.2 (V).
R2: 16.00 %
Op: V = 2 m/s.

Viscosity at 95°C for 20 minutes holding (BU)
Eqn. - 264 - 342 (V) + 58.6 (T) - 0.694 (T 2) + 5.25 (T)(V).
R2: 56.90 %
Op: T = 45°C, V = 2 m/s.

Viscosity at 50°C
Eqn: 904 + 5.80 (T) - 298681 (RH) + 9372292 (RH 2) + 80.4 (S) - 0.828 (S 2).
R2: 80.30 %
Op: T = 65°C, RH = 0.0194 kg/kg dry air.

Viscosity at 50°C holding for 30 min (BU)
Eqn: - 1354 + 51.8 (T) - 0.470 (T 2) + 29.5 (S) - 0.330 (S 2).
R2: 57.40 %
Op: T = 55.1°C

BU - Brabender Unit ; T- temperature ; V-velocity ; RH- air moisture ; S-Days of storage before drying ; R2 - Coefficient of determination ; Optimum condition was achieved by maximising the response.

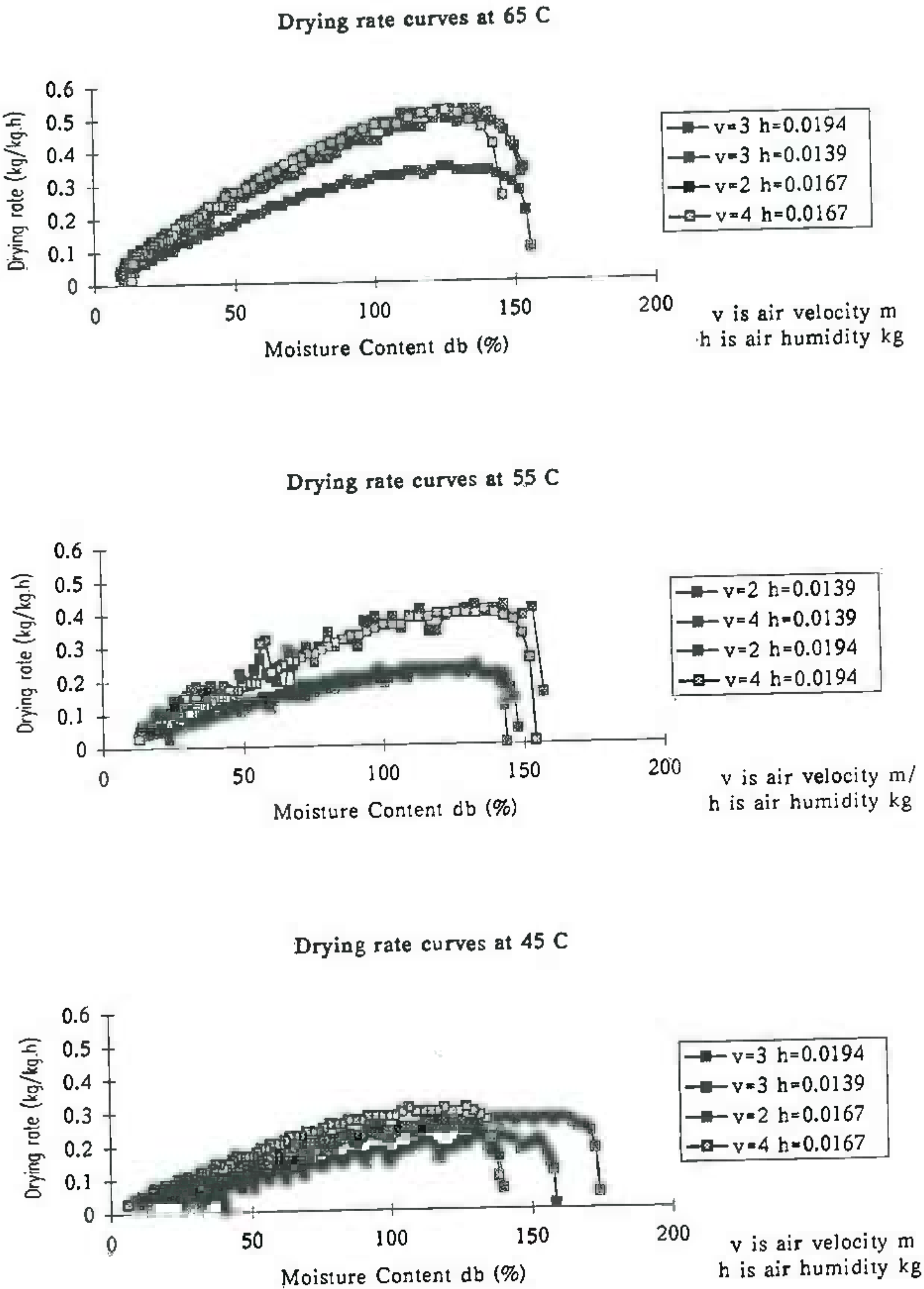

Figure 1: Drying rate curves for 45, 55 and 65 °C for *fufu*