TECHNICAL AND ECONOMIC STUDY OF PLANTAIN FOOD PRODUCTS

by

PAUL OKOROAFOR OGAZI
B.Sc.(Hons) CNAA, M.Sc. Reading

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SUMMARY

Plantain (Banana-Musa AAB) is a widely growing but commercially underexploited tropical fruit. This study demonstrates the processing of plantain to flour and extends its use and convenience as a constituent of bread, cake and biscuit.

Plantain was peeled, dried and milled to produce flour. Proximate analysis was carried out on the flour to determine the food composition Drying at temperatures below 70°C produced light coloured plantain flour.

Experiments were carried out to determine the mechanism of drying, the heat and mass transfer coefficients, effect of air velocity, temperature and cube size on the rate of drying of plantain cubes. The drying was diffusion controlled. Pilot scale drying of plantain cubes in a cabinet dryer showed no significant increase of drying rate above 70°C. In the temperature range found most suitable for plantain drying (ie 60 to 70°C) the total drying time was adequately predicted using a modified equation based on Fick's Law provided the cube temperature was taken to be about 5°C below the actual drying air temperature.

Studies of baking properties of plantain flour revealed that plantain flour can be substituted for strong wheat flour up to 15% for bread making and up to 50% for madeira cake. A shortcake biscuit was produced using 100% plantain flour and test-marketed

Detailed economic studies showed that the production of plantain fruit and its processing into flour would be economically viable in Nigeria when the flour is sold at the wholesale price of ₦0.65 per kilogram provided a minimum sale of 25% plantain suckers. There is need for government subsidy if plantain flour is to compete with imported wheat flour. The broader economic benefits accruing from the processing of plantain fruit into flour and its use in bakery products include employment opportunity, savings in foreign exchange and stimulus to home agriculture.

KEYWORDS: FOOD PROCESSING IN DEVELOPING ECONOMY, ECONOMIC FEASIBILITY STUDY, PLANTAIN DRYING, PLANTAIN BAKING

PREFACE

BACKGROUND TO PROJECT

The National Horticultural Research Institute (NIHORT) of Nigeria was established by the Federal Government of Nigeria in December 1975 to carry out research on all matters concerning non citrus fruits, vegetables and citrus fruits in Nigeria. A project jointly sponsored by the United Nation Development Programme and the Food and Agriculture Organisation of United Nations (UNDP/FAO Project NIR/72/007) was approved during June 1975 to assist the Government in establishing this new Institute. The UNDP/FAO co-operation in the project was originally scheduled to terminate by 1979 but was extended later to end of December 1981 after which the Government of Nigeria was to be solely responsible for the running of the Institute. The fruit and vegetable processing section of NIHORT was set up under the Utilisation Division to carry out research on the methods of processing and preservation with a view to improving commercial practice. A pilot processing factory was designed with all necessary facilities so as to establish an acceptable and sound research-based consulting service for the food processing industries but has not yet been built.

I was appointed in October 1977 as a counterpart to Mr Kenneth McLean, FAO Food Processing Adviser, attached to the Institute. We carried out a national survey to determine the potential for fruit and vegetable processing. The final report of this survey carried out over three years is titled "Conditions for Expansion of Fruit and Vegetable Processing" (McLean 1978). As a part of the assistance contract FAO awarded Fellowships to some Research Officers in particular fields to enable them to receive relevant training. Food Processing was one of the fields in which need for further training was recognised. I was nominated in May 1978 by Director of the

Institute for a 3-year Fellowship Award to carry out research on "Plantain Processing".

On 23rd October 1978, the Director of the Institute stressed in writing the need for research training which would enable me to acquire enough technical competence to be able to take charge of the proposed pilot food processing factory. I was given two months to study the traditional system of plantain flour production and to include all available local literautre and literature about the Puerto Rican Experience. A comprehensive report was submitted to the Director, (Ogazi, 1978).

The Institute has five research programmes - Citrus Fruits, Other Fruits, Vegetables, Extension Research, Liaison and Training and Special. Under the other Fruits Programme, the following fruits were selected for research during 1977 - 1981 period - Plantain, Banana, Mango, Pineapple, Pawpaw, Guava, Ogbono (Irvingia gabonensis), and African Breadfruit (Treculia africana). Plantain processing to produce flour was chosen as an appropriate research topic as there has been no direct research in Nigeria on processing the fruit in order to extend its shelf life.

A detailed discussion was held on 13th July, 1977 between myself and a team of IHD Scheme Tutors - Dr A J Cochran, Mr A Montgomerie and Dr D J van Rest on the possibility of a Total Technology (TT) Project based in Nigeria. On 18th July, 1977, I was offered a conditional place on the Interdisciplinary Higher Degree (IHD) Scheme, including TT coursework and the general topic was "Methods of reducing losses of crops, vegetables, and fruits during storage and processing in Nigeria". Dr van Rest became my Tutor for the research training and was responsible for the co-ordination and administration of the research project. After I took up my appointment with NIHORT Ibadan as a research officer, I was offered a confirmed place for the research training for the 1978/79 academic year. The topic was then changed to "The processing and preservation of plantain material with a view to commercialisation". The TT Programme of the University of Aston was considered most suitable because of its training in the Management of Technology. Most students taking part in the programme are normally sponsored by the Science Research Council of Britain and normally based in particular companies to research on a specific industrial problem. The companies originate the problems and usually co-operate to make the project a success by providing all the necessary facilities required for the research.

I was untypical in that the Institution which sponsored my work was abroad. My first task was to find a collaborating Institution who would provide facilities for the research in the UK. After four months of unsuccessful approaches to some research organisations, Dr P Wix, Head of Department of Applied Biology and Food Science, Polytechnic of the South Bank, London, agreed to make available equipment in his Food Pilot Processing Laboratory for the project. The arrangements also included the use of the facilities in the National School of Bakery attached to the department for assessment of the baking properties of the flour produced.

The next step was to appoint the supervisory team and formulate the research proposals. The selection of the supervisory team was very delicate because I had first of all to interest the prospective supervisory candidate on the objectives of the project. Secondly, an assurance was required by the candidates that adequate facilities would be available for the execution of the project. Eventually by April 1979 the supervisory team was selected as follows:

Dr M C Jones (Main academic supervisor)
Department of Chemical Engineering, Aston University

Mr K G Vaidya (Associate supervisor)
Management Centre, Aston University

Mr G Beswick (Associate supervisor)
Department of Biological Sciences and Food Science
Polytechnic of the South Bank, London

Dr D J van Rest (Tutor)
Interdisciplinary Higher Degrees Scheme, Aston University

At South Bank Polytechnic, Mr F C G Kidman, Head of the National Bakery School was elected to supervise the use of plantain as a composite in bread and cake manufacture. He nominated Mr I Wheal, lecturer in Biscuit Technology to supervise the production of plantain biscuits.

The supervisory team agreed that the research training would involve both the technical and economic aspects of the project. The title was again changed to "The Technical and Economic Study of Plantain Food Products" to reflect changes in research objectives.

The research proposals were drawn up in such a way as to satisfy both the Institute's objectives and the requirements of the University. The proposals shown in appendix APP-P were formally accepted by the FAO on 27th June 1979 and by the Director, NIHORT on 2nd August 1979. On 2nd October 1979, the Senate of the University approved my registration as a Sandwich Student in the IHD Scheme for a Higher Degree by Resarch and Thesis and recognised the supervisory team as above. The registration took effect from 22nd April 1979.

Obviously, the success of such a project will depend not only on the funding by the Federal Government of Nigeria and the FAO of UN but also on the co-operative efforts of the student and the supervisory team. Inspite of my great enthusiasm, the project could not have been successful without the unqualified support given by all the members of the supervisory team. There was some doubt at the beginning of NIHORT's commitment to the project, but when Mr S A O Adeyemi became the Director of the Institute by mid 1979 there was a positive response from NIHORT which continued until the end of the project period.

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I am grateful to Dr P Wix, Head, Department of Applied Biology and Food Science, Polytechnic of the South Bank, for allowing me free access and use of facilities in his department, to his technicians for their assistance and to Dr W R Johns, Dr P Nolan and technicians of the Department of Chemical Engineering, Polytechnic of the South Bank for allowing me the use of their laboratory facilities for my drying experiments.

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CHAPTER 1

General Introduction to Plantain Food Products Production in Nigeria and the Context for the Research

1. General Introduction to Plantain Food Products Production in Nigeria and the Context for the Research

"Development about and for people" can only be achieved if industrial growth benefits the right groups. Development must therefore begin by identifying human needs. The objective of development is to raise the standard of living of masses of the people and to provide all human beings with the opportunity to develop their potential (Streeten, 1976). A plantain industry whose activities will include production, preservation, storage and marketing in the country will surely provide this type of development.

1.1 Plantain as food crop:

Nigeria is a fast developing country with a tropical climate which varies from rather arid in the north to extremely humid in the south. In the decade between 1953 and 1963 when the last official census was taken, the population rose at a rate in excess of 2.5 per cent per annum. If this rate of growth continues in the next few decades, as it is likely with improved economic conditions and better health and medical facilities, the problem of feeding the increasing population at existing and gradually rising levels of nutrition is likely to become increasingly serious. The official estimate of the population now is between 80-100 million.

Socio- economic changes such as industrialisation and urbanisation call for sufficient and wholesome food supply for urban areas in conveniently transportable and usable forms. This is a challenge to farmers for the production of primary food crops and to the food technologists for the processing and preservation of crops especially the perishable and seasonal ones.

Plantain (Musa species AAB group) is a good example of such a crop. It is an important food crop in Nigeria as in all humid tropical zones of Africa, Asia and Central and South America. Plantain resembles a large banana and there are about 30 cultivars which have been separately distinguished in Nigeria. The cultivars have different local names (Ogazi, 1980), but all cultivars are similar in certain important characteristics - like fruit and pulp colour, hand and finger number under favourable growing conditions (Devos, 1978).

The publication by the Federal Department of Agriculture on Food Requirements, Supplies and Demand in Nigeria in the period 1968-85 predicts that by 1985 plantain will constitute the fourth main vegetable product in Nigeria (Olayide et al 1972). The inadequate public appreciation in the past years of the food values of plantain, however, may mean that the predicted demand has been underrated. It is estimated that for Nigeria a rise in the standard of living would lead to an increase in the demand for plantain (Paradisiaca, 1976), since it is a preferred food in a number of parts of Nigeria and consumers will be willing to buy more plantain as their incomes increase.

Previous investigations reported in the literature portray the plantain as a versatile crop to grow and to prepare different dishes in the kitchen. It is now not only grown on homesteads but recently has been grown in small plantations for the commercial market. In Nigeria it is mostly grown in Yoruba, Bini and Western

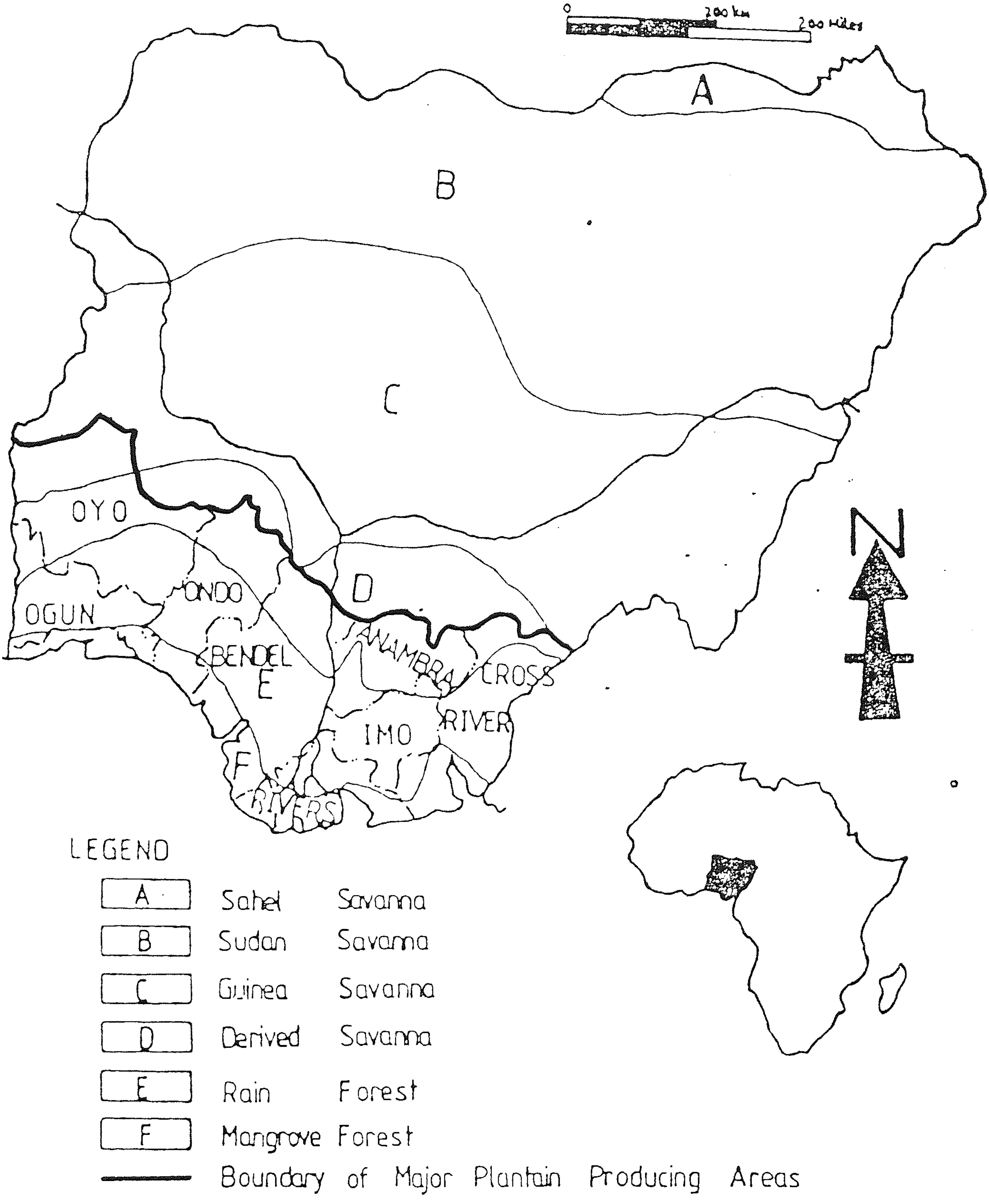
Ijaw and inter-cropped with cocoa and rubber. It is grown in compounds in Urhobo, Itsekini, Eastern Ijaw, Ibo and Ibibio and inter-cropped with cassava, maize and cowpea (Devos, 1978). Figure 1.1. shows the southern states where plantain is grown as one of the main cash crops and these states provide for about 80% of all the plantains eaten in the country. The uses of plantain in Nigeria has been documented as shown in the appendix (APP-1). The uses of plantain flour have been discussed in the report very briefly. However, the use of plantain flour as composite with wheat flour in the production of bread, biscuit and cake will be discussed in detail in chapter 5 of this report. Plantain, whether eaten as flour or in any other form is regarded as a favourite and nutritious dish. This is connected with its iron and mineral contents which makes it special among other staple, starchy foods.

1.2 The Establishment of plantain industry in Nigeria

In 1980, the Federal Ministry of Industries commissioned a study on the establishment of integrated food complexes in the southern zone. The major food crops of this zone are cassava, cocoa, cocoyam, cowpeas (beans), maize, plantain and yam. A detailed study has been carried out on the feasibility of establishing integrated food complexes in various parts of the country based on the six crops cassava, cocoa, cocoyam, cowpeas (beans), maize and yam. The study concluded that cassava, cocoa and maize were potentially the most suitable crops for the proposed complexes.

Plantain has been left out of the above study because of the lack of national awareness of its importance in the national food basket.

FIGURE 1.1: MAP OF NIGERIA SHOWING VEGETATION ZONES AND MAJOR PLANTAIN PRODUCING AREAS



Source: Agboola, S. A. (1979) An Agricultural Atlas of Nigeria (Adapted)

Plantain like other fruits and vegetables has until recently been neglected in the national plan for food production. The recent awareness of the Federal Government has led to the establishment of the National Institute for Horticultural Research. This has been a positive step towards the development of indigenuous fruits and vegetables. The Institute has plantain as the most important crop in the fruit programme. A number of studies of which this project is one of them have been commissioned by the Director in order to provide a Data Bank on plantain as a crop.

It is envisaged that plantain production and processing in Nigeria could develop on lines similar to the already established cocoa production and processing. The Cocoa Board was established by the Federal Government to run the cocoa industry. The goverment also established the Cocoa Research Institute of Nigeria to research on all aspects of cocoa production. In 1970, the Cocoa Development Unit was established between the farmers of the Western States and the World Bank to combat the decline of cocoa production. The Unit acts as a link between the Research Institute and the farmers. While the Institute researches on high yielding varieties and the government provides subsidies through agricultural input, the unit raises young cocoa plants for distribution to the farmers (Adigun - Personal Communication, 1980).

A plantain industry can be encouraged analogously by establishing a company to exploit commercially the research findings of NIHORT. The establishment of this industry would help to fulfil the main objectives of the Green Revolution which is to overcome our inability to feed ourselves. The processing of agricultural primary produce is desirable when the products are cheaper to transport in a processed form rather than in their raw state. This is particularly relevant in the case of plantain because there is a weight reduction of about 70 per cent when it is preserved in a dried form. Although plantain can be used in the preparation of many different dishes, it is, however, very perishable and has a shelf life of about ten days from the harvest under a tropical climate. There is need for longer shelf life which can only be achieved by processing the fruit into flour. This issue is discussed in detail in the next section.

1.3 Justification for plantain flour production

Innovations which make food products made from domestically produced crops more appealing and hence reduce the import of food products make a contribution towards bridging the gap between domestic food supply and demand. Plantain flour, and bread, biscuit and cake made from it are such innovations.

The many other reasons for processing plantain fruit into flour include (a) Preservation, (b) improved quality of flour, (c) price stability, (d) wider availability and (e) stimulate agricultural production.

(a) Over 70 per cent of the harvest of plantains is obtained during the period July to December and there is much wastage of this crop during the period of peak supply. Most plantain products cannot be stored for a long period resulting in seasonal availability and limitations on their use by urban populations. Plantain flour production would lessen the wastage during peak production.

(b) The existing methods of production use sun-drying and grinding with crude equipment into flour. There is an existing market for the flour, although unorganised with little or no packaging provided. Plantain flour could be provided in small packs for gruel or fufu (see appendix APP-1) and bakery products preparation, thereby providing a convenience food for housewives. The use of modern technology for the processing of plantain into flour will lessen the drudgery of the traditional methods and improve both hygiene and quality in the process.

(c) The processing of plantain into flour increases its shelf life. It could be available for different uses and help to reduce seasonal fluctuation in the price of plantain. Plantain flour does not lose its value as plantain fruit does when it is overripe.

(d) The demand for plantain in the northern states of Nigeria (see figure 1.1.) where it is not easily and economically grown is great and undersupplied. It is transported over long distances by train and road. This results in wastage due to damage to the fruit because of bad packaging and fruits being overripe before reaching their destination. The easy transportation and distribution of well-packaged plantain flour would make plantain products available in all parts of the country.

(e) The processing of plantain into flour will stimulate agricultural production and the establishment of plantain plantations, thus creating employment which would contribute added value to the economy and save foreign exchange by reducing imports of wheat flour. It will also help eliminate the plantain peels which constitute about 35 per cent of the whole fruit weight and thereby reduce the volume of garbage in the urban centres.

1.4 Technology Transfer

Practical plant manufacture of plantain food products in the developing Nigerian economy is an example of Technology Transfer. Methods of food processing are well established in advanced economies, where they meet needs of large urban populations backed up by many decades of engineering and business experience. In Nigeria this experience cannot be guaranteed, and the technical and financial plans to produce plantain foods must take this into account.

Plantain is processed into flour as a food product and the flour used to manufacture bread, biscuit and cake. Plantain flour has been produced traditionally by drying under the sun and grinding to produce flour. For the industrialisation of this process, there is a need for judicious selection of equipment that will fit into the economic and technological environment in Nigeria. The transfer of the new process of flour making or the production of the other plantain baked products could be hampered not only by the inappropriate technology but by the people's attitude to work and other externalities like power failure, transportation problems.

Some of these problems are highlighted in the following examples.

(a) Rouwen (1979) emphasised the need to start with intermediate technology in developing countries with respect to food industry to minimise the problem of technology transfer. He cited the case of the citrus processing plant in Brazil, where he worked briefly, which he referred to as advanced technology. The plant was designed in America and run by Americans using cheap labour from Brazil for the routine type of the work. He noted the regular incidence of power failures and the high rate of labour turnover because workers being less motivated left their employment to enjoy their leisure (an opportunity cost of having to work for small wages).

Obviously, a technology transfer could only take place when the new knowledge is actually passed on from one culture to the other involving peoples. Therefore, there is a need for a technology transfer that will guarantee economic development through good wages and offer learning opportunity for the indigenuous people.

(b) Meuser (1979) carried out the design of a process plant for the processing of cassava to garri and flour for Chief A C Okenwa of Onitsha, Nigeria. The plant was delivered to Chief Okenwa and was lying in the port of Lagos for more than one year. An excuse was given by the chief that cement was not available for the building of the platform for the installation. The actual reason might be that the plant was probably too complex with drum drying incorporated for the production of the flour. Meuser was disappointed that the plant has not been installed and he could not claim a complete success until it has been commissioned. On the other hand, Chief Okenwa might be reluctant to instal the plant if he believed that it would be an unprofitable venture. He might consider it better to abandon the plant instead of incurring more debt by commissioning it.

Two issues are at stake here - financial loss by the local entrepreneur and loss of market by the designer. Normally such projects are partly financed by low interest loans backed by the Federal government. If such projects fail the government is unable to recover its capital contributions (section 6.5.2). This is an example of inappropriate technology and bad planning resulting from the entrepreneur being technologically inexperienced . There is need for experts to guide entrepreneurs in their choice of technology.

From worldwide experience of technology transfer the following conclusions apply to the present project and these include (a) simple technology, (b) extension of uses of traditional crop in food industry, (c) objectives to be understood by all and need for self-discipline and interests, (d) allow for transport and utility unreliability, (e) need for good leadership and flexibility, (f) due consideration given to technology transfer in the planning stage, (g) good understanding of food raw material and (h) needs the right institutional framework.

(a) The simpler the technology, the easier it can be adapted in the developing economy (e.g. use of cabinet dryer, liquidiser and ADD as opposed to CBP method in breadmaking - see chapters 4 and 5 of this report).

(b) (i) A technological innovation that improves or extends the use of traditional staple crop will be well received by the masses (e.g. plantain bread, cake and biscuit).

(ii) For research to be effective and to make the most of any investment in it, it is a good plan to start off with the possibilities for better methods of exploitation and processing local natural resources taking into consideration any peculiar characteristics.

(c) (i) The objectives of a technology should be understood by the policy makers as well as the masses who are the recipients. When a technology is developed, its selection and eventual implementation often depend on economic and political decisions. When it is selected and implemented its dissemination and acceptance by the public depend on the acceptability of the product to consumers.

(ii) Without self-discipline among the workers at all levels the full benefits of labour-intensive projects cannot be achieved. The new technology must be able to stimulate the interest and imagination of the scientists and technologists (e.g. manufacture of plantain shortcake biscuit at Bisco Factory in Lagos where every worker was anxious to see what it would look like).

(d) Allowance should be made for the unreliability of the transport system and utility supply (e.g. electricity and water).

(e) There is need for a motivated and aggressive leader who should act with reasonable freedom and seek good opportunities and be flexible enough as to respond to some inevitable changes whether economic, social or political.

(f) (i) The problem of transfer of technology should be considered right from the planning stage by asking the question "technology for whom and where ?"

(ii) There should be a close liaison among the people who develop the ideas, their agents and the people who originate the concepts. A good example is the use of plantain pulp in bread and cake making.

(g) The development of new technology in food processing should be carried out with full understanding of the agricultural raw material as different variables/ cultivars could give different throughput and product e.g. plantain, mangoes, tomatoes and oranges.

Schumacher was quoted as saying, "If you want to be a good shoemaker, you must not only be able to make good shoes, you must also know a lot about feet - because the aim of the shoe is to fit the foot." (Davis 1981).

(h) A transfer of technology usually involves a process of innovation and diffusion of the new technique by imitation and acceptance. It needs adaptation and sometimes some form of resistance could be met. The economical, cultural, social and political aspects of the transfer of technology cannot be separated from one another. Therefore given the inherent difficulties, technology transfer and diffusion cannot be expected to be a spontaneous process as many people tend to regard it but require institutional channels of concerted actions.

1.5 The Technical, Economic and Marketing Aspects of a Project

For the success of any project, an integrated approach should be adapted in solving the technical, economical and marketing problems. There are differences between the approach to these problems in the developed and developing economy. Certain things taken for granted in advanced economy are sometimes non existent in developing economy. In a developing economy, a project leader often finds himself having to direct and supervise all different sections of the project in order to achieve complete success. Therefore, there is need for a research training that will deal with the above problems encountered in a project, especially when it is intended for a developing economy.

A project could be technically feasible but if the return on investment is negative or very low an entrepreneur would not invest in it. The results of research should generate proposals that produce realistic financial and economic rates of return for project sizes. Translation of such results by sponsors should depend on the attractiveness of such returns. The government may, for other social reasons, undertake the implementation of those projects which are unattractive to private sponsors.

Kilby (1969) writing on the utilization of domestic resources with particular emphasis on the applied industrial research made the following observation:

"One of the criticisms of applied research in Nigeria is that insufficient attention has been paid to the economic, as opposed to the technical aspects of the projects being investigated. Such important factors as the logistics of raw material supply, the size of markets as compared to efficient scale of plant, the effect on prices of the implementation of the project and the net advantage of displacing cottage industry are given only cursory, if any, attention."

The marketing problem can be tackled by carrying out pre-marketing research to find out what the consumers would like to buy before producing a range of products based on the finding. When the products are produced a test marketing is carried out in order to select the final product for commercialisation. Ricker (1969), who maintains that marketing is a part of production and not of distribution, made the following observations:

1. "A technical break-through is one starting point for innovation, but for a new product development a clearer understanding of consumers' needs is of paramount importance. The critical problem of new product development is to bring as clearly as possible, the realities of consumer needs into line with the activities of material and processess available. Some costly errors in the development of new products have resulted from carrying one aspect of research and development too far before investigating others."

2. "To be a success, business must serve a need. The needs to be served are the needs of consumers. A successful product can be launched if the marketing man has done his job well and the product is technical and economically feasible."

3. "The food technologist must ever realise the great contribution he can make to the marketing man, his company and himself, not alone through his technical proficiency but through a strict sense of the need for quality, wholesomeness, consumer value in the product in which he works."

From the above observations, the obvious conclusion is that there is need for an interdisciplinary approach towards the development of a new product. The technical, economical and marketing aspects of a project for new products should be complementary for a complete success.

In the present project, an assumption was made that there is market for plantain flour for the preparation of gruel and bakery products where possible, and that the market is undersupplied. The preoccupation was to develop technically internationally acceptable food products from plantain and to carry out an economic appraisal on the flour production from a plantain plantation. The costs of the bakery products will depend mainly on the cost of the plantain flour and have yet to be determined.

The consumer acceptability test for the plantain biscuit produced was carried out in London, UK and Ibadan, Nigeria. However, in order to obtain an estimate that could be translated into sales, a preliminary test marketing of the biscuit was carried out at the South Bank Polytechnic baker shop. The actual test marketing, however, will be carried out in the countries where the products would be sold.

1.6 Objectives of the present study:

The aims of this project fall into four sections.

1. Because of the underlying reason that plantain is a perishable crop, it is necessary to carry out quality assessment of the plantain fruits and flour. The physical and chemical changes that take place during storage will be examined. The effect of temperature during drying and maturation on plantain as measured by the colour of the resultant flour will be determined. The preliminary processing and proximate analysis will help to determine the temperature range and establish quality standard for plantain raw material for processing.

2. The technical problem will deal with the dehydration of plantain and design of the plant. The drying mechanism of

plantain cubes and the effects of temperature, air flowrate, and cube size on the rate of drying will be studied. The heat and mass transfer coefficients for plantain cubes will be determined and the effective diffusion coefficient and energy of activation established. A process for the production of plantain flour will be designed after due consideration of all possible routes. The quantity of flour to be processed per 8-hour shift will be estimated for the selection of appropriate equipment size and the design of the plant layout.

3. The baking properties of plantain flour with respect to bread, biscuit and cake will be determined. The consumer acceptability test and a preliminary test marketing will be carried out on the biscuit to determine the actual degree of acceptance and help to estimate demand. The results of the tests will be used to determine whether plantain flour could help to lessen dependence on wheat importation.

4. The financial and economic evaluation will be carried out to establish the cost of plantain fruit from a given plantation size and price of the flour from the fruit. The economic benefits and financing will be assessed in terms of the net present value and internal rate of return. The economic aspects of bakery products production using plantain will be treated with respect to food balance sheet and national economic policy. The principle of shadow pricing will be applied in order to show the value of plantain flour as a substitute for wheat flour. Plantain will be considered in the overall context of government policy on food production

and the social benefits that could be derived from a plantain food industry. The role of government for effective implementation will be examined and discussed in the light of financial and material incentives.

Each section above uses the methods of a different discipline, hence the need for the interdisciplinary approach adapted in the execution of the project. A separate introduction and literature review have been provided for each chapter - so that the different results can be judged in their proper context. The overall contributions made in the project will be summarised in the conclusion section.

CHAPTER 2

Quality Assessment of Plantain Fruits

2. QUALITY ASSESSMENT OF PLANTAIN FRUITS

2.1 Introduction

The quality and maturity of plantain is of paramount importance for industrial production of plantain flour and allied food products. When the term "Plantain" is used alone in this report, it implies plantain fruit. It is necessary to characterise the varieties planted by farmers and to obtain information on the production patterns and fruit characteristics.Sanchez Nieva et al (1968b) reported that processed products of acceptable quality can be prepared from fruit harvested throughout the year provided the fruits are harvested at a proper stage of development. This corresponds to the stage at which the fruit reaches a pulp content of about 60 per cent which corresponds to a pulp: peel ratio over 1.5:1. This does not, however, provide a means of judging when plantain is over mature for commercial drying.

Freshly harvested green plantains are usually stored in some manner before processing or selling in the fresh market. For commercial processing, stocks of plantain fruits are usually held for sometime, thus making allowance for any unexpected interruption in the supply of fresh fruits. There is therefore a need to determine the changes which take place in a mature plantain during the storage period which might affect processing characteristics.

Experiments were carried out to determine the composition and physical properties of the green plantains used for flour production. Also the effect of temperature of drying and sugar content on the colour of the flours produced was studied.

2.2 REVIEW OF LITERATURE

2.2.1. Composition and Properties of Plantain

2.2.1.1. Chemical Analysis of Plantain

Nieva Sanchez et al (1968a) found that two cultivars, Maricongo and Guayamero planted in the same field had different chemical compositions as shown in table 2.1.

	Acidity as Anhydrous Citric Acid % W/W	pH	Moisture % W/W	Starch %	Reducing Sugar %	Total Sugars as Invert %
Maricongo (Green)	0.09	6.27	58.82	27.29	0.39	0.57
Guayamero	0.15	6.06	60.42	25.19	0.57	0.90

Table 2.1. Chemical composition of green plantains of the Maricongo and Guayamero cultivars.

Ketiku (1973) carried out a detailed chemical analysis of green and ripe plantains. The raw material for these studies was grown in Ibadan, Nigeria. The details of his analysis are given in table 2.2., 2.3 and 2.4.

	Unripe Skin	Ripe Skin	Unripe Pulp	Ripe Pulp
Protein	8.0	8.0	3.0	3.5
Ash	10.1	10.1	2.0	2.2
Ether Extract	5.1	5.6	1.1	2.2
Crude Fibre	5.6	5.6	0.5	1.1
Nitrogen-free Extract	71.2	70.0	93.4	92.0
Dry Matter	15.0	17.0	44.0	43.0

Table 2.2 Proximate chemical composition of unripe and ripe plantains (g/100g dry samples), %.

Constituent	Unripe Skin	Ripe Skin	Unripe Pulp	Ripe Pulp
Glucose	1.6	9.0	0.4	5.6
Fructose	0.6	19.0	0.7	9.0
Sucrose	0.7	2.2	0.7	2.4
Maltose	-	Trace	-	-
Total Sugars	3.0	31.6	1.3	17.3
Starch	50.0	35.0	83.2	66.4
Cellulose	9.0	10.5	1.6	1.3
Hemicellulose	12.4	14.0	1.9	0.8

Table 2.3 Carbohydrate Constituents of Unripe and Ripe Plantains (g/100g dry matter).

Amino Acid	Unripe Pulp	Ripe Pulp	Amino-Acid	Unripe Pulp	Ripe Pulp
Lysine	89	168	Glycine	94	95
Histidine	75	85	Alanine	122	118
Arginine	141	320	Valine	103	106
Aspartic Acid	179	214	Methionine	24	45
Threonine	66	65	Isoleucine	75	95
Serine	75	84	Leucine	132	151
Glutamic Acid	165	302	Tyrosine	56	84
Proline	103	123	Phenylalanine	94	101

Table 2.4 Amino-Acid Content of Plantain Pulp (mg/100g dry matter).

Gomez and Mattill (1949) reported that plantain contains 15-18mg of total ascorbic acid per 100 grammes of pulp of which dehydroascorbic acid is only 20-30 per cent of the total. They also determined the carotene content to be about 3ppm irrespective of the stage of ripeness. Where as Asenjo and Porrata (1956) found that the carotene content of green and yellow (ripe) plantains were 10.43 ± 3.66 and 6.68 ± 2.27 mg per gram of raw edible portion respectively.

The proximate analysis of flour produced from some plantain cultivars has been carried out by different workers. Rahman (1964) analysed plantain flour and obtained the following values in percentage: moisture 11.87, protein 2.8, starch 70.4, alcohol-insoluble solids 86.8, total sugar 0.18 and crude fibre 1.08. The mineral content was 1.61 and 0.07

per cent respectively, for potassium and phosphorus, with 6mg/100gm of sodium and (in parts per million), calcium 643, magnesium 1414, manganese 10, and iron 15.

2.2.1.2. Preharvest Changes in the Physical Properties of Plantains

Sanchez Nieva et al (1968b) studied the characteristics which could be used as criteria for harvesting of the fruit at a proper stage for processing. They suggested that plantains should be harvested for processing when the pulp content is over 60 percent which corresponds to a pulp: peel ratio over 1.5:1. Also, from shear-press measurements, it was established that plantains become softer as they mature, which suggests that the change in texture taking place during the maturation process is an important quality-determining factor. They, however, acknowledged the practical limitation of the above measurements for field work, since both are destructive.

Sanchez Nieva et al (1971) studied the effect of time of planting on yields and processing characteristics of plantain and found that fruit reached the proper stage for harvesting in about 90 days after shooting, irrespective of the time of planting. The processing quality of the fruit was not affected by the time of planting and harvesting, and the summer production peak could be avoided by spreading plantain production by scheduling the planting. Sanchez Nieva, et al (1975) also studied the effect of stage of maturity at harvest on quality of frozen products (e.g. tostones of pre-fried slices) and maintained that the effect of the stage of development on quality was more pronounced on the attribute of appearance than on flavour. They also claimed that for commercial processing, products of acceptable quality can be prepared from plantains with pulp content ranging from 55 to 65 percent.

I found during my survey of the Southern States of Nigeria that local farmers considered plantain fruits as mature when the bud was fully opened and dried. Usually the bud comes out first and continues to open as fruiting continues. An experienced farmer will through visual observation and experience know when a fruit is fully mature.

2.2.1.3. Post-harvest Changes in the Physical and Chemical Properties of Plantain

Sanchez Nieva, et al (1970) studied the ripening of plantains in a walk-in ripening room with temperature and airflow set to the desired limits and relative humidity at 95-100 percent and found that the age of fruit had little effect on ripening and that starch conversion to sugar started significantly the day after harvesting. The reducing - and total-sugars increased during the first six days and then levelled off. Non-reducing sugars increased to a maximum up to the start of ripening and decreased, reaching a minimum value at the overripe stage. The moisture and pulp content increased steadily from the green stage to the over-ripe stage, probably through the process of respiration which utilises sugars by converting them into carbon dioxide and water. Pulp from a green mature plantain may have moisture content ranging from 52-62%, (Nieva Sanchez, et al 1970; Hernandez, 1973; Ketiku, 1973; Karikari,et al 1979). The acidity increased to reach a maximum value by the sixth day, decreasing from then on. The pH decreased during the first six days, increasing again steadily to the over-ripe stage.

Hernandez (1973) studied the storage of green plantains under different conditions and noted that freshly harvested green plantains start to ripen in about seven days, reaching full ripeness two days later when kept under room conditions of relative humidity 90 percent and temperature of about 30^{o}C. If stored in refrigerator chambers, they remained green for twelve days, but the products made from them were of poor quality. By using 200ppm of the chemical thiobendazole (TBZ) the fruits can be kept perfectly green for twenty-five days at room temperature (30^{o}C) and for fifty-five days under refrigeration (15^{o}C).

Awan and Ndubizu (1978) studied some changes in the nutrients contents of stored plantain fruits in a room at ambient temperature of 28^{o}C and relative humidity 85 percent and reported that mature plantains contained on average 2.63 percent reducing sugar which increased to about 17.95 percent in two weeks; the protein content increasing from 2.9 to 3.5 percent; the fibre content from 0.96 to 1.4 percent but the ascorbic acid content decreasing from 17 to 9.29 percent.

2.2.1.4. Food Texture Measurement

Texture is an important food attribute which must be taken into account together with colour and flavour when judging the quality of a sample of food. Szczesniak and Kleyn (1963) demonstrated that not only is texture a very important food quality attribute, but in certain cases is more important than flavour. Therefore, the importance of texture in the food industry, particularly in developing new products, controlling manufacturing conditions and evaluating the quality of the finished products cannot be over-emphasised.

Brennan, (1976) classified the various methods used to study food texture as follows:

(a) sensory methods, (b) instrumental methods involving deformation of the sample, (c) sonic methods, (d) methods for structural examination, (e) chemical analytical methods, (f) miscellaneous methods.

Only the instrumental methods involving sample deformation reported by Brennan will be described as they are very relevant to the methods used in this work.

2.2.1.4.1. Instrumental methods involving sample deformation

Instrumental methods of texture measurement are widely used in industry and research and offer advantages which include:

(a) Tests which are comparatively quick and easy to carry out;

(b) Test conditions which are relatively easy to control;

(c) Reproducible results which are usually better than with sensory methods;

(d) Equipment which although is of high capital cost is generally cheaper to operate than a sensory panel.

On the other hand, such methods yield only indirect measurements of texture and the results need careful and expert interpretation.

Most of the instrumental methods of texture description are based on mechanical tests which involve measurement of the resistance of food to applied forces greater than gravity. All instruments have certain essential components:

(i) A head or probe which comes into contact with the sample and exerts the forces in it. This may take the form of a simple cylindrical plunger, a flat plate, a cone, a knife edge, or be of some other basic design.

(ii) A sample retaining plate or cell to hold the sample in position during the test. This may be a simple flat platen, a cup, or some specially designed cell.

(iii) A driving mechanism to impart motion to the probe. The motion may be vertical, horizontal, oscillatory or rotational. The mechanism may vary from a simple weight or pulley arrangement.

(iv) A load (or deformation) sensing device to detect and measure the resistance offered by the food sample. This may consist of a spring or lever, a simple strain gauge or a sophisticated load cell.

(v) A display or read-out system to enable the results to be seen and recorded.

The measurement of the properties of samples which are not well defined and cannot be easily expressed in fundamental terms is usually carried out by empirical means. However, with certain types of foods, the results have been found to relate to one or more textural attributes and so they can be used as indirect measurements of the attribute(s). The many different instruments used may be classified according to the type of action involved (e.g. compression).

Compression - The sample is compressed by a plunger or plate and the force required to attain a specific change in sample height or the height change brought about by a fixed load, is measured and used as a textural index. Bulk compression, in which the sample is restrained in a cell while a plunger descends onto it, is also used. Bread, cake, cheese, fruit and vegetable tissue are examples of foods often tested by this method.

2.3. EXPERIMENTAL

2.3.1. Materials

Green plantains of Uniban, Turbo, Colombia, South American were purchased from a dealer, Mr P Bodel, 90/91 Granmire Arcade, Brixton, SW9 London and used throughout the experiment.

Unless otherwise stated, all reagents used were of analytical grade and all the quantitative measurements were with grade A glassware.

2.3.2. Proximate Analysis of Green Plantain

2.3.2.1. Moisture Content

The moisture content of green plantain and plantain flour was determined using vacuum over at 75°C and 740mm Hg for several hours until constant weight was recorded. For the green plantain, 5g of cubes (1cm) were put in nickel moisture dish with lid and dried in the oven, while for plantain flour a 5g lot was dried using an aluminium dish with lid.

2.3.2.2. Protein Content

The protein content of plantain flour was determined using the semi-micro Kjeldahl method as described on pg 11 of "The Chemical Analysis of Foods", (Pearson, 7th Ed. 1976).

2.3.2.3. Fat Content

The fat content of plantain flour was determined using the soxhlet extraction method as described on page 14 of "The Chemical Analysis of Foods". (Pearson, 7th Ed. 1976).

2.3.2.4 Alcohol Insoluble Solids

The alcohol insoluble solids was determined according to the method described in A.O.A.C. 1975 32.006 for vegetable products.

2.3.2.5 Flour Acidity

The acidity of the flour was determined using the water extract method described on page 209 of "The Chemical Analysis of Foods" (Pearson, 7th. Ed. 1976).

2.3.2.6. pH of Flour

The pH of the flour was determined as described on page 210 of "The Chemical Analysis of Foods". (Pearson, 7th Ed. 1976).

2.3.2.7. Fibre of Flour

The fibre content of the flour was determined as described on page 16-18 of "The Chemical Analysis of Foods". (Pearson, 7th Ed. 1976).

2.3.2.8. Ash Content

The ash content of green plantain cubes was determined as described on page 8 of "The Chemical Analysis of Food". (Pearson, 7th Ed. 1976).

2.3.2.9.1. Reagents

Pure Sucrose
1% agueous methylene blue solution
Sodium Hydroxide
Concentrated Hydrochloric Acid (AR)

Fehling's Solution A: This was prepared by dissolving 69.278g copper sulphate pentahydrate in distilled water and making up to one litre.

Fehling's Solution B: This was prepared by dissolving 100g sodium hydroxide and 346 Sodium Potassium tartrate in distilled water and making up to one litre.

Standard Invert Solution: (2mg/ml)	This was prepared by weighing accurately 9.5g pure sucrose and dissolving it in 50ml distilled water in 100ml volumetric flask. 5ml concentrated HCl was added and the solution kept in an incubation room at 25°C for 3 days. It was then diluted to 1 litre and this was equivalent to 1% acidified solution of invert sugar. 100ml of the acidified solution was neutralised with sodium hydroxide and diluted to 500ml.
Zinc Acetate Solution: (Clearing Agent)	21.0g of crystallized zinc acetate $Zn(C_2H_3O_2)_2$, $2H_2O$ and 3ml of glacial acetic acid in water were mixed and diluted to 100ml.
Potassium Ferrocyanide Solution: (Clearing Agent)	This was prepared by dissolving 10.6g of Potassium Ferrocyanide in 100ml of distilled water.

2.3.2.9.2. Standardisation of Fehling Solution

A soxhlet solution was prepared by mixing equal amount of Fehling's Solutions A and B. The standardisation was carried out as described in A.O.A.C. 1975, 31.036.

2.3.2.9.3. Determination of Reducing Sugars in Plantain Flour (Lane Eynon Volumetric Method).

2.3.2.9.3.1. Clarification of Plantain Flour

20g of the plantain flour was weighed into 200ml volumetric flask and 100ml of distilled water added. 10ml each of zinc acetate solution and potassium ferrocyanide solution was added and then made up to 200ml with distilled water. The solution was filtered. The filtrate was used for the determination of the sugars.

2.3.2.9.3.2. Determination of Reducing Sugar in the cleared Plantain Flour Extract

This was carried out as described in A.O.A.C. 1975, 31.038 - on cleared extract (2.3.2.9.3.1.)

2.3.2.9.3.3. Determination of Sucrose in Plantain Flour as Invert Sugar

5ml concentrated hydrochloric acid was added to 50ml of the filtrate (2.3.2.9.3.1.) in 100ml volumetric flask and allowed to stand over-night at 25°C. It was then neutralised and diluted to 100ml with distilled water. The inverted sugar was determined as described in A.O.A.C. 1975, 31.026(c).

2.3.3. Texture Measurements on Plantain

2.3.3.1. Apparatus

Instron Universal Testing Instrument (Model UTI with Standard modifications * M-12 for increased crosshead travel).

Magness Taylor Probe

Cork Borer

Knife

The above apparatus including the chart recorder are shown in plates 2.1 and 2.2 below.

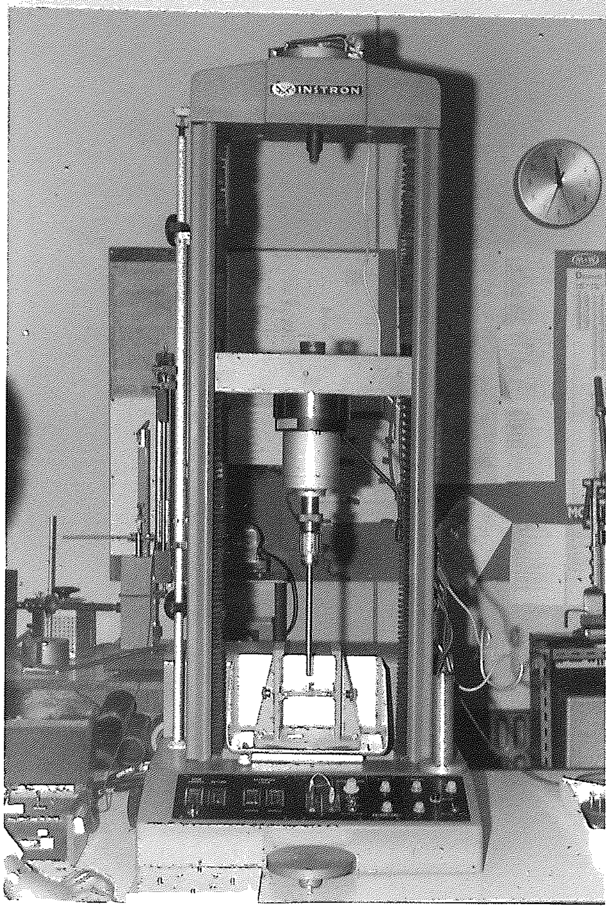


Plate 2.1

Table Model Instron
(Model TM-M)

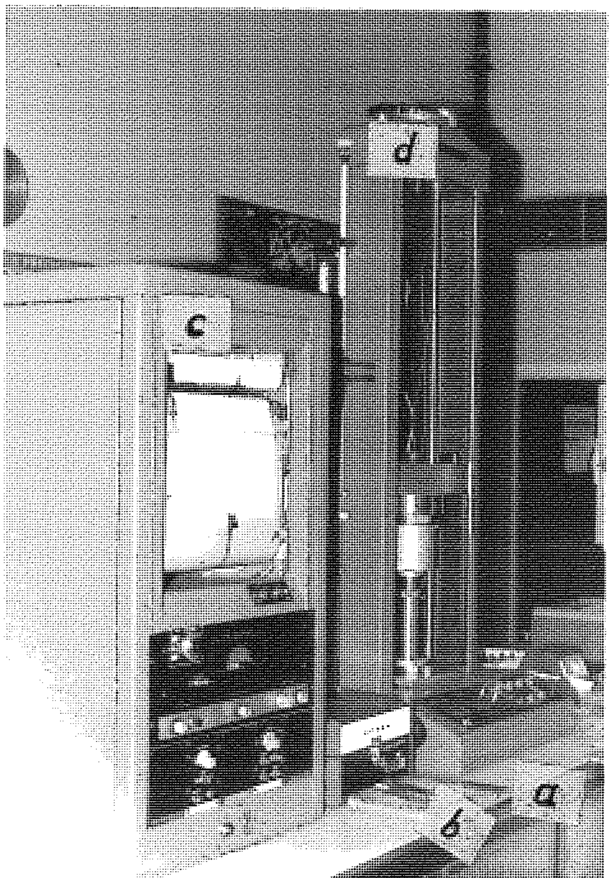


Plate 2.2

Knife (a)
Cork borer (b)
Chart recorder (c)
Instron UTI (d)

2.3.3.2. Principle and Operation of the Instron

This is a precision testing instrument capable of recording deflection curves from 2g full scale on the recorder to more than 100kg at synchronous cross-head speeds from 0.5 - 125cm/min. The full details of the operation of the Instron (UTI) together with the standard modifications and accessories are described in the Catologue of the Instruments and Equipment for advanced materials testing, Instron Ltd, Halifax Road, High Wycombe, Bucks, England.

Briefly, the apparatus consists of two sections:

(i) The tensometer and controls

(ii) The chart and calibration controls.

The Tensometer

This comprises an upper fixed cross-head and a lower cross-head which can move up and down at various speeds. Different load cells and probes can be fixed into the lower cross-head for compression and puncture tests. The lower cross-head is driven downwards at constant speed, thus exerting a force on the specimen. The signal created by the force is transmitted through the load cell to the previously calibrated chart recorder.

Speed of Lower Cross-head

Various cross-head speeds may be selected by using appropriate pairs of gears. The two gears in use are housed at the right of the rear casing on the base of the apparatus.

The Load Cell

Several load cells are available depending upon the forces to be measured.

A cell with a range of	10g	-	500g
B cell " " " "	100g	-	2,000g
CTM cell " " " "	2g	-	100kg

The Chart Recorder

The chart recorder is a potentiometric pen recorder with various chart speeds. The speeds can be selected in exactly the same way as for the cross-head drive mechanism. The chart and pen drives were operated by placing the appropriate switches on the control panel at the base of the recorder into the UP position.

Calibration of the Chart

A load on the load cell produced a deflection on the chart. In order that an observed deflection could be correlated with a load, the apparatus was calibrated. The chart was first zeroed and then adjusted to give a known (usually full scale) deflection for a known weight placed on the load cell. This weight was such that full scale deflection was obtained on maximum sensitivity.

The time axis of the chart was either a direct measure of, or a simple multiple of, the movement of the cross-head, depending upon the gear used. This attribute of the machine arises from the fact that both the recorder chart and the moving cross-head are sychronously driven from the same power supply.

2.3.3.3. Selection of Gear and Chart Speeds

The gear speed of 5cm/min. (i.e. Drive HX low HY) and a chart speed of 0.5cm/min. were found to be a suitable combination for the textural measurements of both unripe and ripe plantain pulp. The faster gear speed gave too short a time for any measurement to be made, while the slower gear speed took too long a time to give scope for accurate measurement.

2.3.3.4. Sample Preparation

A 3 cm cross-sectional length was cut out from a peeled plantain of average diameter. The cork borer was used to pierce longitudinally through the centre to produce a cylindrical shaped sample of height approximately 3cm. The sample was then reduced to a uniform height of 2.5cm and diameter of 2.5cm. Samples of these dimensions were used in all compression tests. For the penetration and puncture tests, a whole plantain was always used so that the tests could be carried out at the centre of the fruit.

2.3.3.5. Uniaxial Compresssion and Puncture Tests

The load cell and compression head (Magness Probe for puncture test) were inserted into the moving cross-head and the sample was positioned so that the surface of the plunger was vertically above and congruent with the sample. The plunger was made to compress or pierce the test sample at a cross-head speed of 5cm/min. until rupture or puncture and penetration of up to 8mm in depth was achieved. The direction of motion of the cross-head was then reversed until the plunger was completely withdrawn from the sample. Plates 2.3 and 2.4 illustrate both the compression and puncture tests.

2.3.4. The Physical and Chemical Changes of Plantain during Storage

2.3.4.1. Apparatus

Triton Constant Humidity Cabinet and Incubator

Humidity range 30 - 100%

Temperature range 25 - 100°C

(The room temperature, which was constant, was 26°C).

Knife

Gallenkamp Oven BS, Size One, Model OV-160

Perforated Aluminium Trays 400 x 300 x 40mm

End-Runner Mill

Sieve Shaker and Sieve Mesh No. 100 (150um)

EEL Reflectance Spectrophotometer

2.3.4.2. Method of Storage

Green plantains were stored in an incubator at 30°C and 97 per cent relative humidity, a condition normally obtained in the humid tropics of Nigeria. Samples consisting of 8

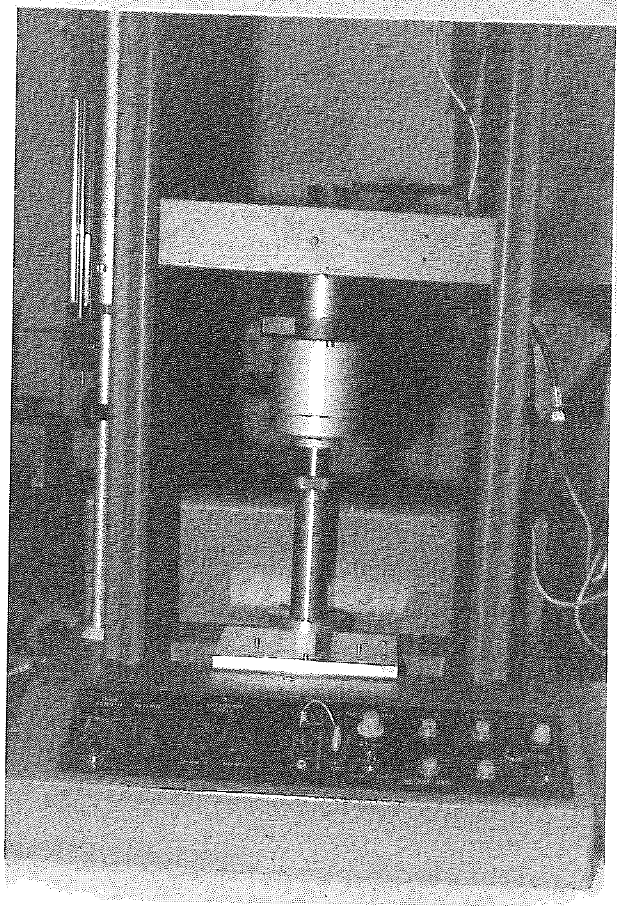


Plate 2.3.

Shows plantain sample being compressed.

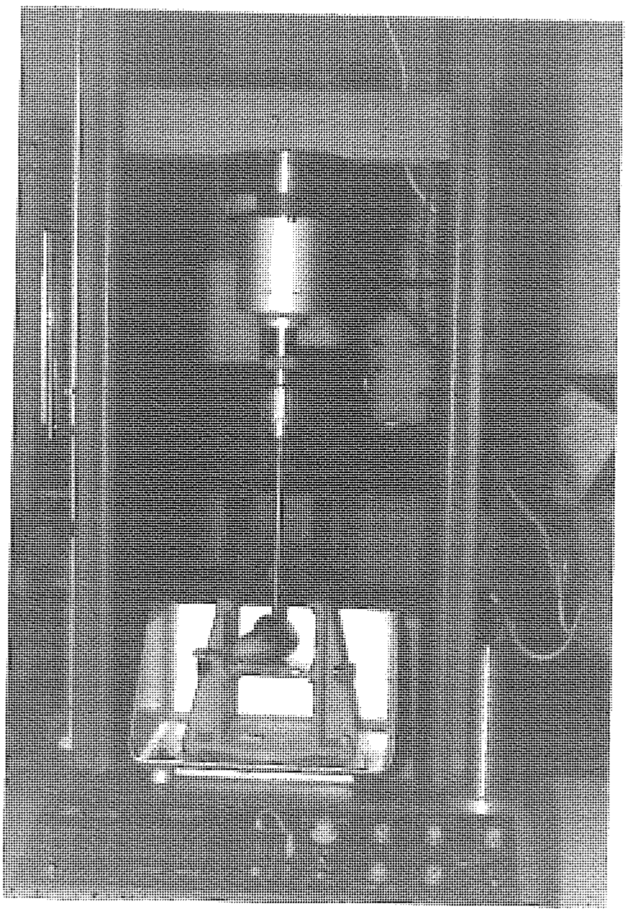


Plate 2.4.

Shows plantain fruit being pierced.

plantains were taken at 2 or 3 daily intervals for the physical and chemical measurements until they were overripe after 10 days.

2.3.4.3. Testing Procedures

On removal of the plantains from the incubator, they were peeled with a knife, cubed and divided into two lots and dried at 50°C and 93°C respectively, using a fan dryer - Gallenkamp Oven BS, Size One, Model OV-160. All the dried samples were milled in end-runner Mill to produce flour. Flours of particle size under 150μm from each sample were produced by sieving with Sieve Mesh No. 100 with a Sieve shaker.

Chemical analysis of the sieved flours was carried out to determine the moisture, alcohol insoluble solids, acidity, pH and sugar content (reducing and non-reducing) as described in sections 2.3.2.1, 2.3.2.4, 2.3.2.5, 2.3.2.6 and 2.3.2.9, above,

The physical measurement of the forces required to rupture a given sample of plantain pulp (section 2.3.3.4) and to puncture the skin was carried out as described in section 2.3.3.5.

2.3.4.4. Colour Measurement of the Plantain Flour

For wheat flour, the Kent Jones and Martin Flour Grader series 11 instruments are frequently used to judge the grade of colour or brightness. The numerical figures obtained are not affected by any artificial treatment like bleaching. In principle, the grade of the flour is related to the extent to which the endosperm has been contaminated with powdered bran and this is called the extraction rate.

Plantain flour contains no bran and as a result the colour of the flour could not be graded using the above flour grader. In this case, the system of colour specification suggested by the Commission Internationale de l'Eclairage for standardising colour measurements was used to quantify the difference in the colours of the plantain flour produced. The full detail of the method of measurement and analysis of results are described in the EEL Reflectance Spectrophotometer Operating Instructions Manual.

Briefly the process involves a measurement of three functions referred as X, Y and Z which have spectral distributions and their reflectance values for a given sample may be calculated mathematically from the full spectrophotometric curve. With photocell-filter combinations, the reading may be taken to a reasonable practical approximation with the "EEL" Reflectance Spectrophotometer by using the special "XYZ Filter Wheel" and taking readings of the sample which give directly the X, Y, Z values. The coefficients are obtained from the values as follows:

$$x = \frac{X}{X + Y + Z}\ ; \quad y = \frac{Y}{X + Y + Z}\ ; \quad z = \frac{Z}{X + Y + Z}$$

Since the Y function has the same spectral distribution as the "average eye" response, the percentage reflectance of a sample when measured using this filter is a measure of percentage "visual brightness".

2.4. RESULTS AND DISCUSSION

Table 2.5. Results of the Proximate Analysis of Green Plantain Pulp (Dry Basis)

Pulp : peel ratio	=	1.88:1	Fibre	=	1.15% W/W
Pulp Content	=	64.35% W/W	Ash	=	1.12% W/W
Moisture Content	=	60.46% W/W	Reducing Sugar	=	6.37% W/W
Protein Content	=	2.85% W/W	Non-reducing sugar as invert	=	1.85% W/W
Fat Content	=	1.06% W/W	Total Sugar	=	8.22% W/W
Alcohol Insoluble Solids	=	83.56% W/W	pH of Flour	=	5.6
Flour Acidity (0. IN NaOH)	=	2.88ml	Carbohydrate (by difference method)	=	94.97% W/W

2.4.1. Proximate Analysis of Green Plantain Pulp

The figures listed in table 2.5. are the average of three readings and are in close agreement with those observed by Sanchez Nieva et al (1970), Ketiku (1973) and Awan Ndubizu (1978). The values may vary with the state of maturity. The plantains that were available in the market in London were shipped from West Indies and South America. One could reasonably assume that the plantains were mature before they were harvested.

2.4.2. The Physical and Chemical Changes of Plantain during Storage

Table 2.6 details the physical and chemical properties at different stages of maturation. The state of maturation was judged visually by the colour of the peel. Traditionally plantain fruits have been judged to be mature when the buds were fully open and dried. At this stage the fruits would still be green. As the fruits start ripening, the degree of softness was judged traditionally by pressing the fruits with fingers. This method would not be suitable for industrial processing of plantain into flour when large quantities would be purchased from local farmers.

A criterion used for selecting peas for canning or freezing depends on the percentage of "alcohol insoluble solids" obtained after refluxing the peas for 30 minutes in 80% ethyl alcohol. In the case of plantain pulps, the alcohol insoluble solids dropped from 86.23% in the green state to 72.6% at the turning state (i.e. when both green and yellow colours were observed on the fruit). At the ripe stage, the value was 63.13%. Subsequent decreases were very small. Since plantain pulp could be dried fairly easily up to the turning stage, one could set a minimum limit of 70% as the value for the alcohol insoluble solid for plantain pulp to be selected for dehydration. However, this method cannot be regarded as simple and variations in fruits may require modification of the limit adopted.

For commercial processing of fruits, a rapid and convenient

Table 2.6.

The Physical and Chemical Changes of Plantain During Storage

Characteristic Measured					
Days in incubator	NONE	3	5	7	10
State of Maturity*	Green	Turning Green/yellow	Ripe (yellow)	Ripe (yellow)	Overripe (yellow)
Wt. of whole fruit (g)	299.6	364	296.6	339	237.6
Wt. of pulp (g)	198.0	233.9	194.0	233.2	173.2
Pulp content %	63.08	64.26	65.4	68.79	72.89
Pulp: peel ratio	1.74:1	1.8:1	1.9:1	2.2:1	2.7.:1
Texture (Force required for sample rupture) (kg)	28.40	9.5	3.7	3.0	1.75
Texture (Force required to puncture the skin)(kg)	15.20	10.3	5.7	5.2	3.62
Moisture Content of plantain pulp %	61.62	61.98	65.35	65.30	83.13
Reducing sugars of plantain pulp %	4.42	18.60	27.99	38.15	37.46
Non-reducing sugars as Invert of plantain pulp %	0.32	2.35	2.09	1.04	0.73
Total sugars as Invert of plantain pulp %	4.74	20.95	30.08	39.19	38.19
Alcohol Insoluble Solids of plantain pulp %	86.23	72.60	63.13	61.51	59.63
Acidity (0.1N NaOH) ml of plantain pulp	0.40	10.00	13.60	17.60	10.80
pH of plantain pulp	5.90	5.40	5.25	5.10	5.62
Ratio of Reducing/Non-reducing Sugars	13.73	7.92	13.39	36.68	51.32

* Judged from the colour of the peel.

method is required. The pulp: peel ratio of plantain has been suggested for use as a maturity index for harvesting mature green plantain. Sanchez Nieva et al (1968) recommended that plantains be harvested for processing when pulp: peel ratio is over 1.5:1. The pulp: peel ratio of the plantain used for this experiment was 1.8:1 at the turning stage and 1.9:1 at the ripe stage. Since the plantain pulp could be dried easily at the turning stage but not when ripe, because of the difficulty in handling, it may not be practicable to set an accurate ratio limit above which the plantain would not be suitable for drying. The difference between 1.8 and 1.9 is very small and when carrying out factory tests, any error would be within experimental limits.

Texture measurement of plantain fruits (sample rupture or puncture) represents a very accurate and rapid means of selecting plantain for drying on a commercial scale. The process, although capital intensive is fast and reproducible. The force required to puncture the skin at the turning and ripe stages was 10.3kg and 5.7kg respectively. One could set a force limit of about 9kg below which drying the fruits would pose some difficulties. Also a force of about 8kg could be set as a limit if the rupture process is used.

The knowledge of the sugar content in a given sample of plantain is very important if the appropriate choice of drying temperature is to be made. Green plantain can be likened to the potato as starch staples. In potatoes, there are processes which occur during storage:

(a) respiration which utilises sugars by converting them into carbon dioxide and water.

(b) conversion of starch to sugar by amylolytic enzymes

(c) conversion of sugar to starch, presumably by starch-synthesizing enzymes.

As sugars increase at low temperatures, starch decreases and at high temperatures sugars decrease as a result of respiration and starch synthesis, (Appleman 1912). During storage at low temperature, reducing sugars accumulate more rapidly than sucrose, (Schwimmer, et al 1954).

The total sugar content of plantains used in this experiment increased from 4.74% to 20.95% from green to the turning stage and to 30% at the first ripe stage. The sugar content of 39.19% at the second ripe stage was greater than 38.19% at the overripe stage. The slight decrease in sugar content at the overripe stage could be explained by the fact that during fermentation, some of the sugar was utilised in the process. The result obtained in table 2.6 showed a similar trend as those reported by Sanchez Nieva et al (1970) but the rate of starch hydrolysis was slower as the reported total sugar content increased from 4.40% at the green stage to 14.92% at the turning stage and to 21.39% at the ripe. Since starch hydrolyses faster at higher temperature, the difference could arise from the difference in temperature of storage which was 30°C in this experiment and 22°C as reported.

The colour of the plantain flour produced is considered critically by the consumers in their choice for the preparation of gruel or amala and confectionery products.

A light coloured plantain flour is most acceptable. Plates 2.5 and 2.6 show the colour of plantain flour produced after drying at the temperatures of 50° and 93°C and at different stages of maturity. Plate 2.7. compares the flours produced from plantains at green and turning stages which had been dried at 50° and 93°C respectively. The colour of the flours produced at both the green and turning stages at the processing temperature of 50°C was light brown. The colour darkened progressively to dark brown at the second ripe stage. The flour produced from the overripe plantain was less dark than the flour from the fully ripe plantain due to the decrease in the sugar content. The flours produced at a higher temperature of 93°C were progressively darker from the green to the fully ripe stage.

The difference in colour was quantified using the system of colour specification by the Commission Internationale de l'Eclairage (C.I.E.) for standardising colour measurement. The figures detailed in table 2.7 were obtained from the measurement and used to calculate the percentage brightness. The percentage brightness of the flour obtained from the green plantain pulp dried at 50°C was 70.5 and the value decreased to 64 at the overripe stage. The freeze dried plantain pulp at -24°C was brightest with 79.7. The values obtained after drying at 93°C was lower, ranging from 61.9 at the green stage to 41.2 at the full ripe stage.

The value of 70.5 for the green plantain pulp dried at 50°C was reasonably close to the 74.1 obtained fro the ground rice purchased from the market. Plantain flour is used for the preparation of gruel which is also prepared with ground rice.

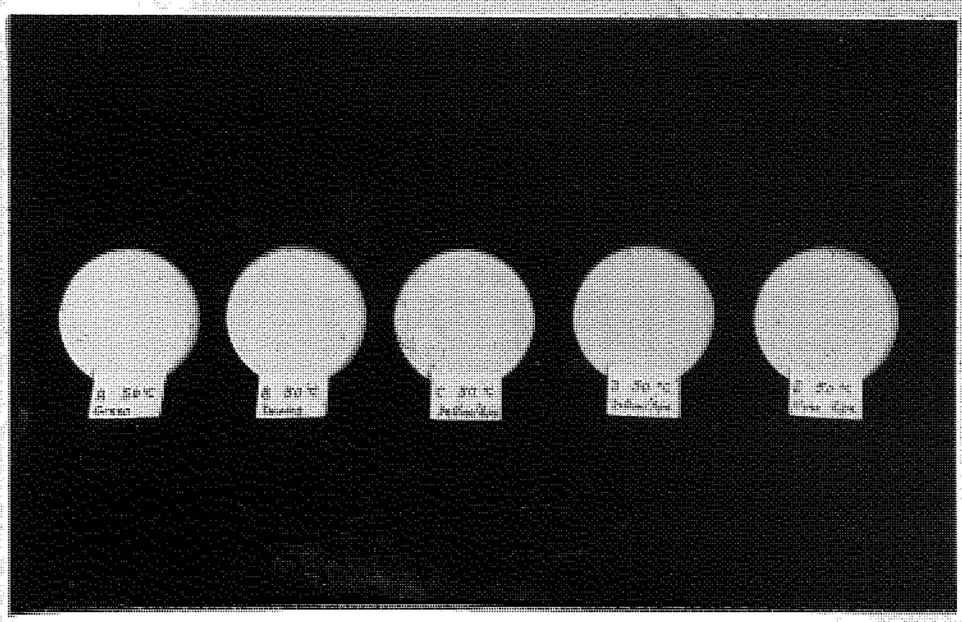


Plate 2.5

Plantain flour produced at different stages of maturation after drying at 50°C.

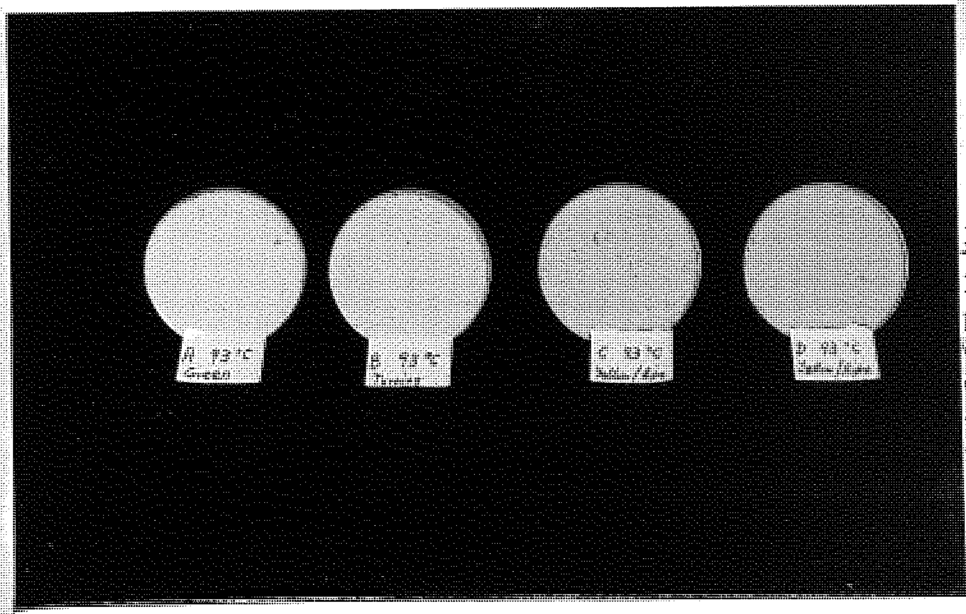


Plate 2.6

Plantain flour produced at different stages of maturation after drying at 93°C.

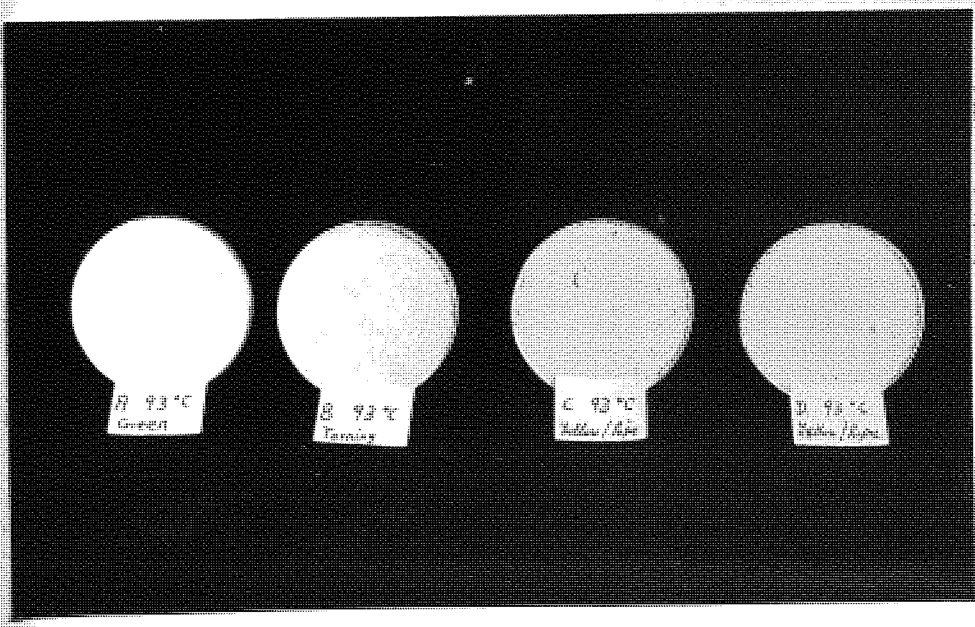


Plate 2.7

Plantain flour produced at different stages of maturation after drying at 50°C and 93°C are compared.

Table 2.7 Figures obtained from colour measurement using EEL Reflectance Spectrophotometer

* Judged from the colour of the peel.

Temperature of Drying	50 °C					93 °C				
Days in Incubation at 30°C	NONE	3	5	7	10	NONE	3	5	7	
Stage of Maturity*	Green	Turning Yellow/ Green	Yellow	Yellow	Overripe Black	Green	Turning Yellow/ Green	Yellow	Yellow	Freeze dried from green plantain
Total sugars as Invert %	4.74	20.95	30.08	39.19	38.19	4.74	20.95	30.95	39.19	4.74
X 1st readings	76.0	76.8	77.8	75.1	76.2	72	64.4	60.3	57.2	89.1
2nd "	74.7	76.7	78.0	75.0	75.0	72	64.2	60.1	53.3	88.8
3rd "	75.0	76.9	77.8	75.2	73.7	72	64.3	60.2	53.3	89.0
X Average	75.2	76.8	77.8	75.1	75.0	72	64.3	60.2	54.6	89.0
Y 1st readings	70.9	68.3	65.3	65.0	64.1	61.8	53.3	46.8	41.2	80.0
2nd "	70.5	67.2	65.8	63.3	64.0	61.9	53.3	45.8	41.3	79.3
3rd "	70.0	67.2	65.6	64.0	63.8	61.9	53.3	45.0	41.2	79.8
Y Average	70.5	67.6	65.6	64.1	64.0	61.9	53.3	45.9	41.2	79.7
Z 1st readings	23.0	20.8	19.0	17.8	18.7	16.9	13.9	11.2	9.9	25.2
2nd "	22.9	20.7	19.1	17.9	18.8	16.9	13.8	11.2	10.0	25.2
3rd "	23.0	20.8	19.1	17.8	18.7	16.9	13.8	11.2	9.9	25.2
Z Average	23.0	20.8	19.1	17.8	18.7	16.9	13.8	11.2	9.9	25.2
X + Y + Z Total	168.7	165.2	162.5	156.9	157.7	150.8	131.4	117.3	105.7	193.9
Coefficient x -	0.445	0.465	0.478	0.478	0.475	0.477	0.489	0.513	0.517	0.459
" y	0.418	0.409	o.404	0.408	0.406	0.410	0.406	0.391	0.390	0.411
" z	0.136	0.126	0.117	0.113	0.118	0.112	0.105	0.095	0.093	0.130
Total value of coefficients	0.999	1.0	0.999	0.999	0.999	0.999	1.000	0.999	1.000	1.000
% Brightness	70.5	67.6	65.6	64.1	64.0	61.9	53.3	45.9	41.2	79.7

However, the colour of the gruel prepared with plantain flour is usually dark while the one prepared with ground rice is fairly white in colour. The dark colour of the gruel prepared with plantain flour is due to high sugar content of the flour which favours maillard reaction. Maillard reaction occurs when a mixture of amino-acids and reducing sugars are heated resulting in a darkened product.

Colour changes in food are brought about by enzymic browning, non-enzymic browning or bleaching. The enzymic browning reaction occurs when the enzyme catalysed reaction of oxygen with certain phenolic compounds produces quinone structures and their polymerisation products which are responsible for the brown colour. This browning action can be controlled by bleaching or use of antioxidants. The maillard reaction reported above is an example of non-enzymic browning.

With the high sugar content of plantain at the latter stages of maturation, it is thought that drying at temperatures above 70^{o}C resulted in the production of a dark brown product mainly through the maillard reaction. At temperatures well below 70^{o}C the maillard reaction is less important and light coloured flour has been produced even with plantains at their turning stage of maturation.

Since the moisture content of plantain increased from around 62% at the green stage to about 66% at the ripe stage, more energy will be required to dry a given quantity of plantain as it matures from the green to the ripe stage. In addition, ripe plantains present a handling problem due to their softness and much difficulty was experienced in the milling and sieving of the dried ripe plantain pulp due to the clogging effect.

From the preliminary drying and milling tests the following conclusions have been drawn:

Plantain pulp could easily be handled, dried and milled if processed when the state of maturation did not exceed the stage from green to the turning point when both green and yellow colours appear on the fruit. A light coloured flour will be produced from plantain pulp if dried at a temperature well below 70°C. Drying at temperatures above 70°C produces a dark brown flour. The use of a Magness Taylor Probe attached to an Instron UTI offered a very rapid and convenient method of selecting plantain fruits for commercial drying. A minimum force of 9kg was required to puncture the skin of suitable fruit.

The respective total sugar content of plantain at green (5%) and turning point stage (20%) should be taken into consideration in the manufacture of bakery products. Less sugar would be required in a product produced from high sugar plantain flour, thus lowering the cost of production.

The C.I.E. brightness figure of the plantain flour to be used for either gruel or bakery product preparation should not be below 66 since the value obtained for the turning point stage was 67.2. Thus in the commercial production of plantain flour, the use of a physical method, like the EEL Reflectance Spectrophotometer for measuring, would give a fairly accurate and reproducible result.

CHAPTER 3

Dehydration of Plantain

3. DEHYDRATION OF PLANTAIN

3.1. INTRODUCTION:

There are different methods available for drying fruits. Each method has an effect on the quality and the physical properties of the product. Traditionally, plantain fruit is peeled, sliced and sun-dried for an average of six days, the actual drying time depending on the intensity of the sun and the season. The rate of drying depends on the thickness of the slices. During the rainy season, pre-drying directly over fire for twenty four hours is necessary for quick drying in the sun. The degree of dryness is judged by the ease with which the slices are broken. The drying is carried out on a mat or a hard surface like stone or cement.

The quality of the dried product is usually poor and the colour of the flour milled from the dried product is dark brown making it not very acceptable to the consumers. For commercial dehydration of plantain pulp, a controlled drying process and good understanding of the drying mechanism of the plantain slices or cubes are very important for a better and economic factory process.

A study of how a solid dries may be based on the internal mechanism of liquid flow and on the effect of the external conditions of temperature, humidity, air-flow, state of subdivision on the drying rate of the solid. The former procedure generally requires a fundamental study of the internal conditions. The latter procedure, although less fundamental is more generally used because the results have greater immediate application in equipment design and evaluation.

Understanding the drying behaviour of plantain cubes over a range of temperature, and cube size and air velocity is necessary in order to design or select a suitable dryer for commercial production of plantain flour.

3.2 Some Theoretical Considerations

Nonhebel and Moss (1971) considered some general principles governing the drying of a solid material. When a wet solid is dried by passing a stream of heated gas across or through it, the hot gas serves to transfer heat to the solid by convection and to remove the evaporated vapour. If the hot gas is supplied to the system at a constant temperature and humidity, it is observed that the drying process occurs in two distinct stages. Initially the rate of drying is constant and then, at a fairly definite moisture content it begins to diminish and continues to do so progressively until it is zero when the material is completely dry.

The moisture content at which the drying rate begins to diminish is known as the critical moisture content but the change generally tends to occur gradually over a range of moisture contents as shown by point B in the typical drying curves of figure 3.2.1.

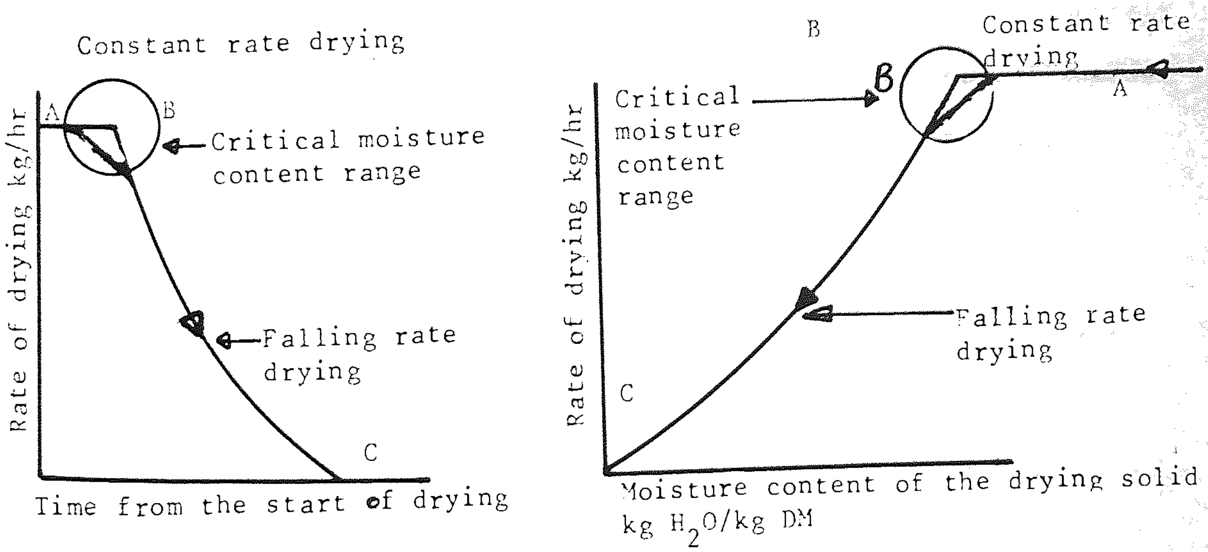


Figure 3.2.1 Typical drying rate curves in convection drying at constant external conditions.

In some cases the initial moisture content may be below the critical value and the drying will then be entirely falling-rate, with no constant rate. The falling-rate curves themselves may be concave or convex or may approximate to a straight line.

Stage AB in figure 3.2.1 represented the constant rate period when the surface of the solid remains saturated with liquid water because movement of water within the solid to the surface takes place at a rate as great as the rate of evaporation from the surface. Drying takes place by movement of water from the saturated surface through a stagnant air film into the main stream of the drying air. The rate of drying is dependent on the rate of heat transfer to the drying surface and is controlled entirely in the case of pure convection drying by velocity, temperature and humidity of the drying gas. Thus if these are constant, the rate of drying is constant. It is dependent on the rate of migration of liquid from inside to the surface at which evaporation occurs.

Stage BC represents the falling-rate period when the rate of migration of liquid to the surface has decreased so that it controls the rate of drying. The effects of external heat and mass transfer resistances progressively diminish. From point B, on-wards, the surface temperature begins to rise approaching the dry-bulb temperature of the air as the material approaches dryness. Often the falling rate period is described by two stages known as first and second falling rate periods.

Perry and Chilton, (1973), considered some basic drying theories, and considered the concept of the constant and falling rate periods of drying. When the heat for evaporation in the constant rate period is supplied by a hot gas, a dynamic equilibrium is established between the rate of heat transfer to the material and the rate of vapour removal from the surface.

$$-\frac{dw}{d\theta} = \frac{hA\ (Ta - Ts)}{\lambda} \quad \ldots\ldots\ldots\ 3.2.1$$

where $-\frac{dw}{d\theta}$ = drying rate (kg water per second)

h = heat transfer coefficient ($W/m^2\,^{\circ}C$)

A = surface area for heat transfer and evaporation (m^2)

Ta = air temperature $^{\circ}C$

Ts = surface temperature of the drying material $^{\circ}C$

λ = latent heat of evaporation at surface temperature (J/kg)

In equation 3.2.1. it is assumed that heat is supplied solely by the sensible heat of the drying gas.

The velocity of the drying gas affects the values of the heat and mass transfer coefficients through the two relations given in equation 3.2.2. for a single sphere (Bird 1960; Sherwood et al 1975).

$$\frac{hd}{k} = 2.0 + 0.6\ Re^{1/2}\ Pr^{1/3}$$

$$\text{and} \quad \frac{k_c d}{D_{AB}} = 2.0 + 0.6.\ Re^{1/2}\ Sc^{1/3} \quad \ldots\ldots\ldots\ 3.2.2.$$

where $\frac{hd}{k}$ = Nusselt number (Nu)

$\frac{k_c d}{D_{AB}}$ = mass transfer Nusselt number

$\frac{\rho v d}{\mu}$ = Reynolds number (Re)

$\frac{\mu}{\rho D_{AB}}$ = Schmidt number (Sc)

$\frac{Cp\mu}{k}$ = Prandtl number (Pr)

d = diameter of the sphere (m^2)

k = thermal conductivity (W/m °C)

k_c = mass transfer coefficient (m/s)

D_{AB} = Diffusion coefficient (m^2/S) for water vapour in the air

ρ = Average Density kg/m^3

V = air velocity m/s

μ = air viscosity kg/ms

Cp = mean specific heat of dry air J/kg °C

Nonhebel and Moss (1971) established that if a fluid is composed of air and water vapour at relatively low concentrations of water vapour, the Prandtl and Schmidt numbers are approximately equal, the mean molecular weight of the fluid is approximately equal to that of air and the specific heat of the fluid is the humid-heat of the air/water vapour. They also noted that the quantity or velocity of the gas stream passing over the surface is not always sufficient to ensure that true equilibrium at the wet-bulb temperature is achieved (e.g. a minimum velocity of 3 m/s is recommended in wet-bulb hygrometry for air/water system) but in practical drying problems it can be assumed that the actual surface will approximate to the wet-bulb temperature for constant - rate drying with heat transfer by pure convection.

Perry and Chilton, (1973,) found that when flow occurs over immersed bodies such that the boundary layer is completely laminar over the whole body, laminar flow is said to exist even though the flow in the main stream is turbulent. The following relationships are applicable to single bodies immersed in an infinite fluid and are not valid for assemblages of bodies. In general the average heat-transfer coefficient on immersed bodies is predicted by

$$N_{Nu} = Cr\,(N_{Re})^{m}\,(N_{Pr})^{1/3} \quad \ldots\ldots\ldots 3.2.3.$$

where the constant Cr = 0.648 and the notation m = 0.5 and for the situation where flow is parallel to object and $N_{Re} = 10^3$ to 3×10^5 and $N_{Pr} > 0.6$

The characteristic length is used on both the Nusselt and Reynolds numbers and the velocity in the Reynolds number is the undisturbed free stream velocity.

When liquid diffusion controls in the falling-rate period, the general form of equation for diffusion of a liquid in a solid based on the Fick's 2nd law which for unidimensional flow, is

$$\frac{\partial W}{\partial \theta} = D\frac{\partial^2 W}{\partial x^2} \quad \ldots\ldots\ldots\ldots 3.2.4$$

With negligible surface resistance to mass transfer, the solution expressed as average moisture content for the slab is:

$$\frac{W_\theta - W_e}{W_c - W_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left\{-(2n+1)^2\pi^2\, D\theta/4L^2\right\} \ldots\ldots 3.2.5$$

where W_θ = average moisture content(dry basis) at any time θ, (kg)

W_c = critical moisture content (kg)

W_e = equilibrium moisture content (kg)

D = Liquid diffusivity of the evaporating material in the drying solid m^2/S

θ = time from start of falling rate period (s)

L = one half the thickness of the solid layer through which the diffusion occurs (m).

The summation in 3.2.5. is rapidly convergent and for

$\frac{D\theta}{L^2} > 0.06$ only the first term n = o is needed, giving:-

$$\frac{W_\theta - W_e}{W_c - W_e} = \frac{8}{\pi^2} e^{-D\theta (\pi/2L)^2} \quad . \ . \ . \ . \ . \ . \ . \ . \ 3.2.6$$

Equation 3.2.6 assumes D constant. However, D is rarely constant but varies with moisture content and temperature and humidity. 3.2.6. may be differentiated to give the drying rate as

$$\frac{dW_\theta}{d\theta} = \frac{-\pi^2 D}{4 \ L^2} (W_\theta - W_e) \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ 3.2.7.$$

where $\frac{dW_\theta}{d\theta}$ = drying rate (i.e. decrease in moisture content) (kg water per second)

Thus from equation 3.2.4, when internal diffusion controls for long times, the rate of drying is directly proportional to the free-water content (W_θ-We) and the liquid diffusivity D and the drying time varies inversely as the square of the material thickness. When equation 3.2.6. is plotted on semilogarithmic graph paper, a straight line is obtained for values of

(W_θ- We) / (Wc-We) $<$ 0.6 when the approximate form of equation 3.2.7. applies also.

<u>External and Internal Diffusion Resistances in Cube</u>

The passage of one gas component through another is called diffusion or mass transfer and the rate is proportional to k_c in equation 3.2.2. The measure of the external resistance is the reciprocal of mass transfer coefficient k_c : External Resistance = $1/k_c$

The diffusivity or diffusion coefficient D_{AB} of a constituent A in a second component B is a measure of its diffusive mobility. A measure of the internal resistance is as follows:

$$\text{Internal Resistance} = \frac{\text{Diffusional Path Length}}{\text{Diffusional Coefficient } (D_{AB})}.$$

3.3. Review of Literature

Many authors have studied the effect of external variables (the air temperature, velocity, the humidity, the size of solid being dried) on the drying rate and mechanism of a range of food crops. The main difficulty in describing transport of heat and mass inside porous food materials is that the geometry of the structure is not easily described quantitatively during the drying process and that the rates of heat and mass transfer depend on local values of temperature, pressure and composition, (Mazza and LeMaquer, 1980).

3.3.1. Effect of Velocity: By studying the effect of different velocities of air on the moisture content of a given sample during drying it is possible to determine which resistance (internal or external) controls the rate of drying. Jason(1958) dried fish muscles and found that at low air velocity, the rate of heat transfer by convection is considerably reduced and becomes comparable with the rate of heat transfer by radiation. He noted that, although the temperature of the surface initially falls steeply with increasing air velocity, it remains slightly higher than the wet-bulb temperature even at the highest velocity of 3.7 m/s. Vaccarezza et al, (1974) found that for sugar beet root 9mm thick, increase in rate of drying with increase in air velocity was not appreciable but for a 4mm sample the rate of drying increased initially with increase in velocity from 2 - 6.5m/s. Palumbo et al(1977) dried sausages and found that onset of the diffusion-controlled falling rate period occurred almost immediately after drying started. Air velocity should have no effect on the drying rate. Townsend et al(1975), however, have reported statistically significant increases of about 1% in the percent shrinkage of sausages dried in high air velocities compared with sausages dried in low air velocities. Chirife,(1970), studied the effect of air flow rate for the range 0.5 - 1.4 m/s and found that up to a velocity of 1.1 m/s, the increase of flow causes appreciable decrease of drying time for tapioca root but further increases are no longer as effective since the drying time appears to tend to a limit for an air flow greater than 1.38 m/s. The drying of tapioca root is diffusion controlled from the start. He explained the fact by considering that at low flow rates, the drying rate is controlled by a mixed mechanism: the mass transfer at the solid gas interphase and the internal diffusional mass transfer. As the flow rate increases the superficial mass transfer coefficient increases until for a given value, the superficial resistance is negligible compared to the internal resistance. Roman et al (1979) found that increasing air velocities from 0.35 - 1 m/s in the drying of 1mm thick apple resulted in increase in heat and mass transfer coefficients. This caused faster drying rate at all but the very low moisture content. Saravacos and Charm, (1962) found that increasing air velocity from 1 - 3 m/s increased the drying rate of potato 6.5mm thick during the constant rate period but had no effect on the falling rate period. Mazza and LeMaquer(1980) conducted drying experiments with onion slices 1.5mm thick at constant temperature and variable air flow rate and found that external resistances contributed significantly to overall resistance. Since the internal resistance is unaltered by change in the flowrate, the increase in drying rate is totally attributable to the improvement in heat and mass transfer at the surface of the product.

The overall effect is that at low air velocity the rate of heat transfer by convection is reduced and this effect is more pronounced when smaller cubes are dried. There is an optimum velocity required to overcome the resistance to mass transfer at the solid gas interphase. When this resistance is overcome, further increase in air velocity does not effectively increase the rate of drying. When the rate of drying is diffusion controlled, external conditions like air velocity should not have any influence on the rate of drying. However, the experimental results of all quoted authors except, Saravacos and Charm (1962), acknowledged the fact that in a diffusion controlled drying process increase in air velocity could affect the rate at the initial phase when evaporation from the surface controls the rate. The velocity of the drying gas affects the magnitude of both heat and mass transfer coefficients through some established relations between Nusselt, Reynolds, Schmidt and Prandtl numbers (section 3.2, equation 3.2.2.). This will be discussed further during the analysis of the experimental results obtained in this work.

3.3.2. Effect of Size: The overall effect of size on the rate of drying is that smaller size requires shorter time to dry than a bigger size as can be shown in the relation $\frac{dW}{d\theta} = -\frac{\pi^2 D}{4L^2}(W_\theta - We)$ reported in section 3.2. Saravacos and Charm (1962) found that the drying time of the falling rate period during the drying of potato slabs followed the rule of the square of thickness when the above equation is used. The critical moisture content was found to vary to a small degree with the thickness of the food material and the external drying conditions. The graph of log $(W_\theta - We)/(Wc-We)$ versus time gave generally a straight line for the region of moisture content 1.0 - 0.1 kg H_2O/kg DM. The value of the drying constants calculated from the slopes depended on the thickness of the food piece, the nature of the material and air temperature. Vaccarezza et al (1974), however, found that sugar beet root drying time showed a thickness dependence which was not exactly proportional to the square of the thickness. Jason (1958) found that the effect of evaporative cooling varies inversely with the square of the thickness of the fish fillet and directly with the effective diffusion constant in accordance with the equation:

$$\frac{dH}{d\theta} / (W-We) = \frac{\lambda \pi^2 D}{4L^2} \qquad \text{. . . . . 3.2.8}$$

where $dH/d\theta$ is rate of cooling per unit weight of free water (W-We). The effect was more on the thinner samples which resulted in the reduction of diffusion constant.

The rule of the square of thickness does not always follow , (Vaccarezza et al 1974). When a solid is being dried, the heat transfer process involves both latent heat transfer owing to vaporization of a small portion of water and sensible heat transfer owing to the difference in temperature of water and air. 80% of this heat transfer is due to latent heat and 20% from sensible heat (Perry and Chilton, 1973). The extraction of this latent heat results in evaporative cooling.

3.3.3. Effect of Air Temperature

Charm (1971) stated that the effect of temperature on reaction rate is expressed through effect of the temperature on the reaction velocity constant. The most satisfactory method for expressing the influence of temperature on reaction velocity is that used by Arrhenius (1889),

$$\ln K = \ln A - \Delta E/RT \quad \ldots\ldots\ldots\ldots 3.2.9$$

where K = reaction velocity constant

A = constant

R = gas constant

ΔE = energy of activation J/mole

T = absolute temperature ^{o}K

Arrhenius suggested that in every system there is a distribution of energy among the molecules at any time. In order to enter into reaction it is necessary for the molecule to possess at least a certain minimum amount of energy distribution changes and the number of molecules possessing energy greater than the energy of activation increases.

The temperature dependence of the diffusion and the activation energy can be represented by the Arrhenius type of relationship which is of the form $D(T) = A \exp(-\Delta E/RT)$ where D(T) is the diffusion coefficient at temperature of drying $T^{o}K$. Palumbo et al, (1977), reported that theoretically when the activation energy is known, the diffusion coefficient at any temperature can be determined from its value at a single temperature. Thus by incorporating the actual diffusion coefficient for a particular temperature, the moisture level at any stage of drying could be calculated . Charm(1971) stated that the constants $\Delta E/R$ and A may be evaluated from the velocity rate constant K determined at two different temperatures. In the case of diffusion coefficient (D) instead of velocity rate constant, two values are required to be plotted against the reciprocal of absolute temperature to give a straight line. Corresponding values of diffusion coefficient and absolute temperature can be obtained from any point on the line, while the activation energy can be calculated from the slope of the line (i.e. slope = $-\Delta E/R$). These values could be substituted in equation 3.2.9 to obtain the value of A so that D(T) can be obtained at any temperature of the material being dried. Mazza and LeMaguer (1980) in drying 1.5mm thick onion slices found that because of higher rate of diffusion at higher temperature, the drying times necessary to achieve the same residual moisture content in the onion was twice as long at $40^{\circ}C$ than at $65^{\circ}C$. They also showed that at 40, 50, 65 $^{\circ}C$, diffusivities in the first phase of drying were about 20, 25 and 35 times higher respectively, than for the second phase. This indicates that during the higher dehydration rate period, the rate was sensitive to changes in temperature while during the second period of drying, which corresponds to low moisture contents, the rate was not sensitive to external factors. Jason(1958) in drying 5mm thick fish muscle established that the value of the diffusion coefficients for the second phase of drying were approximately one-fifth of the values obtained in the first phase.

The temperature of food materials increase rapidly at the beginning of drying towards the air dry bulb temperature. The internal temperature gradient is small and food temperature can be described as being uniform at each instant of time, (Saravacos and Charm(1962); Jason,(1958); Chirife,(1971); Vaccarezza et al, 1974). Saravacos and Charm, (1962), determined the heat transfer coefficient of potato slabs dried in air as 14.44 W/m^2K (8.34 Btu/hr sq ft $^{\circ}F$) using equation 3.2.1. The value of heat transfer coefficient obtained when single layer of cubes in a tray are dried might be a bit higher than when more layers of cubes are dried. This is because a considerable amount of heat is transferred by conduction from the trays to the cubes, in addition to the convection of heat by the air stream. As a result the temperature of the product tends to rise above the wet bulb temperature and overall heat-transfer rates are higher. This effect is minimal with more layers of cubes.

The overall effect of temperature is that the rate of drying is higher at higher temperature due to higher rate of diffusion and higher heat transfer rate, (equation 3.2.1.). The temperature of the drying material is assumed uniform at any given time eventhough there is a slight temperature difference of about 2°C between the centre and surface temperatures of the drying material, (Alzamora et al 1979). The appropriate value of diffusion coefficient should be that corresponding to the mean temperature of the material. This temperature will be approximately that of the surface temperature. The values of diffusion coefficients and energy of activation of some food products published in the literature are shown in table 3.1.

From the above review, it is evident that nothing has been reported on the drying characteristics of plantain pulp with respect to effect of air temperature, velocity and cube size. Therefore experiments are needed to establish the drying behaviour of plantain cubes.

PRODUCT	TEMPERATURE RANGE °C	SAMPLE THICKNESS m m	AUTHORS AND YEAR	ACTIVATION ENERGY (1st Phase) J/mole H_2O	DIFFUSION COEFFICIENT (1st Phase) m^2/s
Fish Muscle	5 - 100	15	JASON (1958)	30054	$3.09 - 3.23 \times 10^{-10}$ @ 30°C Shrinkage taken into account
Wheat	-	-	BECKER and SALLANS (1955)	62700	-
Scalded Potatoes	54.5 - 65.5	3	Saravacos and Charm (1962)	53335	$2.5 - 6 \times 10^{-10}$
Scalded Potatoes	25	-	Fish (1958)	-	2×10^{-10}
Tapioca Root	55 - 100	3	Chirife (1971)	22609	$3.3 - 8.6 \times 10^{-10}$
Sugar Beet	47 - 85	4 - 10	Vaccarezza et al (1974)	28889	$4 - 14 \times 10^{-10}$
Pepperoni	12	-	Palumbo et al (1977)	-	$0.47 - 0.57 \times 10^{-10}$
Apple	30	1 - 3	Roman et al (1979)	-	2.56×10^{-10}
Onions	40 - 65	1.5	Mazza and LeMaquer (1980)	19800 - 21666	$0.76 - 1.39 \times 10^{-10}$

TABLE 3.1: SUMMARY OF REPORTED ACTIVATION ENERGY AND DIFFUSION COEFFICIENTS

3.4 EXPERIMENTAL METHODS:

The objectives of the experiments were:

(i) to establish drying curves for plantain and determine the effects of size, air flow-rate and temperature

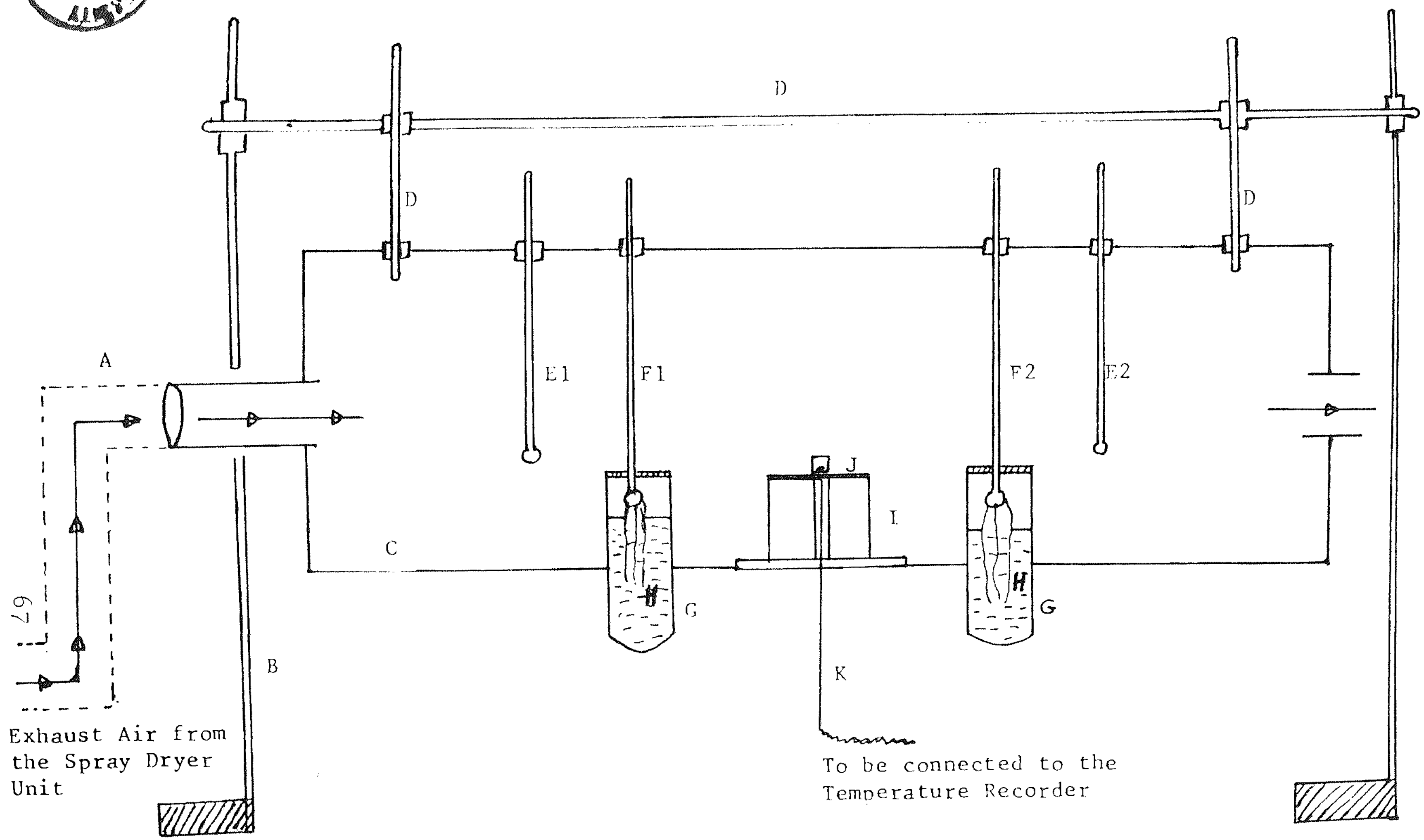
(ii) to determine the variation of cubes surface temperature with time

(iii) to determine the diffusion coefficient and activation energy in the drying of plantain cubes

(iv) to attempt to predict the drying time using a modified form of Ficks 2nd law of diffusion (3.2.4).

3.4.1. Apparatus:

Figure 3.4.1. shows an elevation of the perspex chamber used in the study of the drying behaviour of plantain cubes. The chamber contains dry - and wet - bulb thermometers (E.F.) fitted at both the inlet and exit side of the chamber. The chamber was held firmly by two stands(B) and three supporting rods(D). Two openings at the ends of the chamber were for the passage of the drying air into and out of the chamber. An opening with a tight screwed perspex cover (10 x 10 cm) was constructed so that it could be fitted or removed easily. All the drying samples were put into the chamber through the opening. Drying sample rested on a wooden block, 7 x 6.5 x 4.5 cm, at the centre of the chamber. The height of the wood is such that the sample would be in good contact with the passing stream of dry air. Plate 3.4.1 illustrates the connection of the drying chamber with the spray dryer. Plate 3.4.2. is a plain view of the drying chamber and the temperature chart recorder. A 1.5 mm thick chromel-alumel thermocouple was connected to the chart recorder and the instrument calibrated using a calibration unit together with ice and boiling water to read the temperatures between 0° and 100°C. Plate 3.4.3. illustrates the connection of the spray dryer and the chart recorder with the drying chamber.



A = Connecting Tube

B = Stand

C = Perspex Case

D = Supporting Rod

E1= Dry Bulb Thermometer Inlet

E2= Dry Bulb Thermometer Outlet

F1= Wet Bulb Thermometer Inlet

F2= Wet Bulb Thermometer Outlet

G = Distilled Water Container

H = Wick

I = Wooden Block

J = Sample

K = Thermocouple

Figure 3.4.1 Evaluation View of an Apparatus for Plantain Drying:

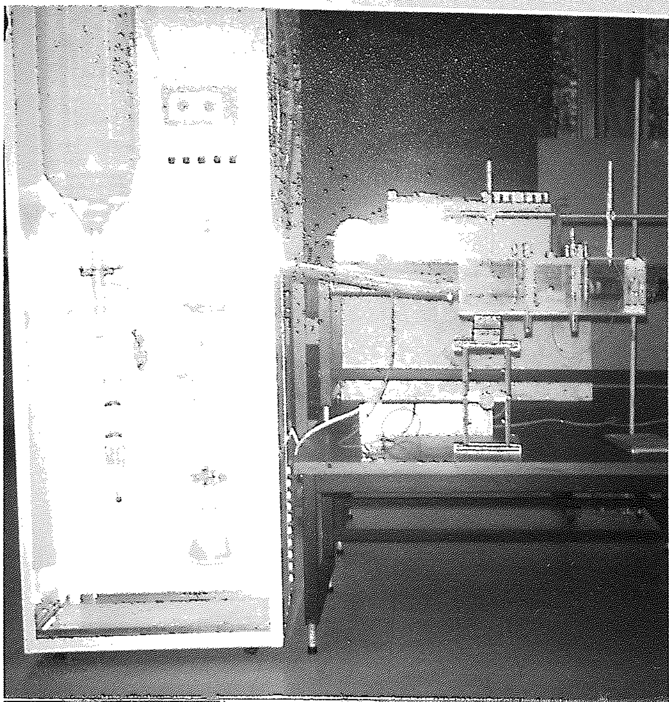


Plate 3.4.1

illustrates the connection of the drying chamber with the spray dryer

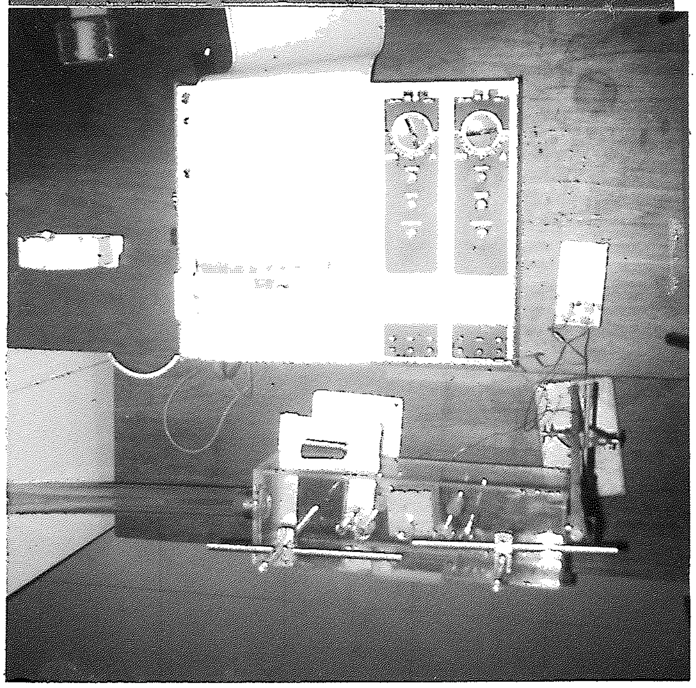


Plate 3.4.2

illustrates the bird's eye view of the temperature recorder

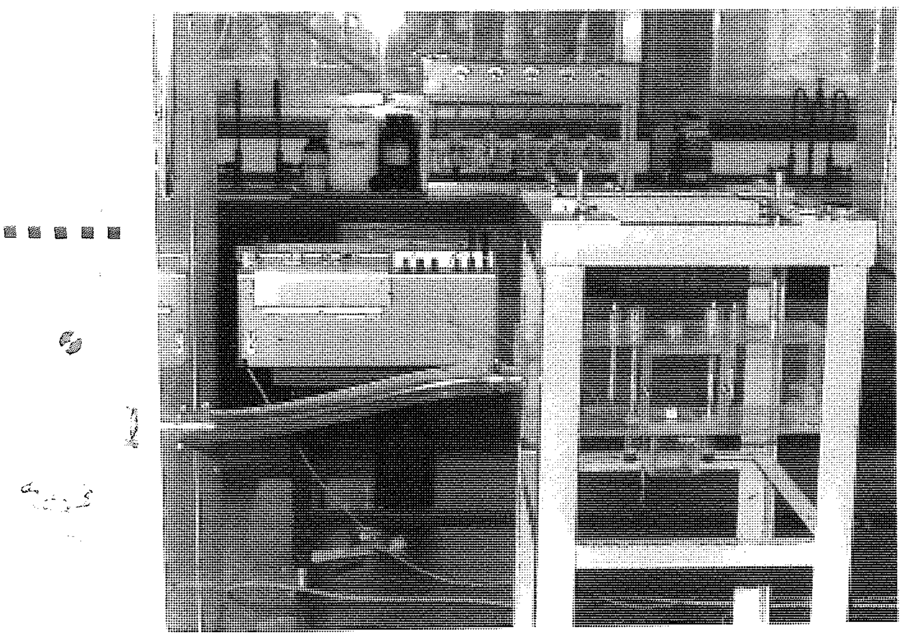


Plate 3.4.3

illustrates the connection of the spray dryer and the chart recorder with the drying chamber

The chamber was supplied with heated air from a centrifugal fan heated by a thermostatically controlled heater of a laboratory spray dryer. The temperature range was 0° - $250^{\circ}C$. The air velocity was varied by a manual butterfly valve and measured with an AM5000 Digital Anemometer. The velocity range was 0 - 3.5 m/s.

3.4.2. Drying Procedure:

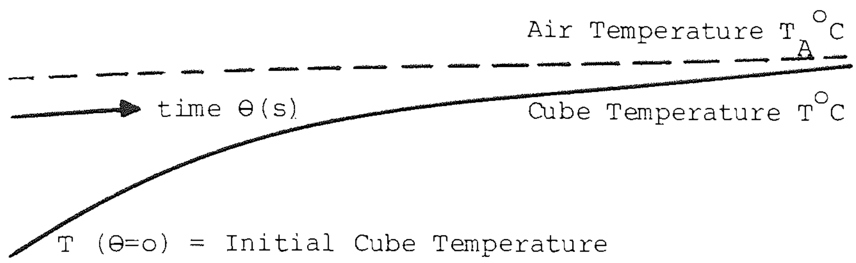
Green plantain pulp was cut into 10mm and 15mm cubes and used as samples for the drying tests. A 5mm cube was also dried at $54^{\circ}C$ in order to establish the second falling rate period as 10mm or 15mm cube would require a long time of drying to exhibit the second falling rate period. When the operating temperature and air velocity have been selected, the readings of the dry- and wet-bulb thermometers were taken for the inlet and outlet air. Samples were weighed on a standard laboratory electronic balance reading 0-200g $\pm$ 0.001g. The balance was placed as near as possible to the drying chamber so as to minimise loss of drying time. The weighed sample was placed on the wooden block inside the chamber through the specially constructed opening. Samples were withdrawn at desired intervals and weighed. The readings of the thermometers were taken at the same intervals. Drying tests were carried out at air temperatures of 40°, 49°, 54°, 60°, 65° and at air velocities of 2.4, 2.9 and 3.4m/s.

3.4.3. Measurement of the Centre Temperature of 15mm Aluminium Cube so as to determine the heat transfer coefficient for 15mm cube under the experimental drying conditions

A hole 1.5mm diameter was made in the 15mm aluminium cube to the depth of 7.5mm (i.e. to the centre of the cube). When an equilibrium condition was established in the chamber, the cube was placed on the wooden block and the thermocouple inserted through the wooden block into the aluminium cube until the centre was reached. The temperature chart recorder was switched on immediately. The size of the thermocouple was very important because heat conduction along the wire would be negligible only if very thin thermocouple was used. In the experiment the thermocouple was not exposed to the drying air so that the temperature of the centre in the chart was solely the temperature of the centre of the cube. When the chart reading became constant, the experiment was terminated and the centre temperature of the cube at any time read from the chart. The aluminium cube was weighed before and after the experiment.

3.5 RESULTS AND ANALYSIS OF DATA

3.5.1. Heat Transfer Coefficient From Aluminium Cube Heating



The heat transfer coefficient is function of air velocity and geometry of the material being dried. Therefore, if the heat transfer coefficient is determined using an aluminium cube, the value will hold for a plantain cube of the same dimension dried under the same conditions.

Rate of heat transfer to cube $Q = hA(T_A - T)$ 3.5.1

$Q = mc\ dT/d\theta$ 3.5.2

where Q = rate of heat transfer to cube J/s

$\frac{dT}{d\theta}$ = change in temperature of cube $^{o}K/s$

m = mass of the cube (kg)

Thus $hA(T_A - T) = mc dT/d\theta$ .... 3.5.3.

$$\int_{T_o}^{T} \frac{dT}{T_A - T} = \int_{o}^{\theta} \frac{hA}{mc}\, d\theta \quad \text{........ 3.5.4.}$$

$$\text{i.e.} \quad -\ln e\left(\frac{T_A - T}{T_A - T_o}\right) = \frac{hA\theta}{mc} \quad \text{......3.5.5.}$$

$$\therefore \quad \ln(T_A - T) = \ln(T_A - T_o) - \frac{hA}{mc}\theta \quad \text{...3.5.6.}$$

plot of values of $(T_A - T)$ versus θ should produce a straight line of slope $- hA/mc$.

The cube temperature was considered uniform but time dependent. Air Temperature was the same at all exposed faces and cube specific heat (c_p) was not a function of temperature.

In the experiments, the area A in 3.5.6 was that of 5 cube faces, the sixth being in contact with the wooden block, and thus not heated by the air stream.

Table 3.5.1

Data from chart for the evaluation of heat transfer coefficient.

Time θ (Seconds)	T_A	T	(T_A-T)	$\ln(T_A-T)$
0	46	26.5	19.5	2.97
60		33.7	12.3	2.51
120		37.8	8.2	2.10
180		40.6	5.4	1.69
240		42.3	3.7	1.31
300		43.5	2.5	0.92

A graph of $\ln(T_A - T)$ versus time in seconds figure 3.5.1 gave a slope of $-0.0069\ s^{-1}$

$$\therefore \quad -0.0069 = \frac{-hA}{mc}$$

$$h = \frac{0.0069 \times m \times c_p}{A}$$

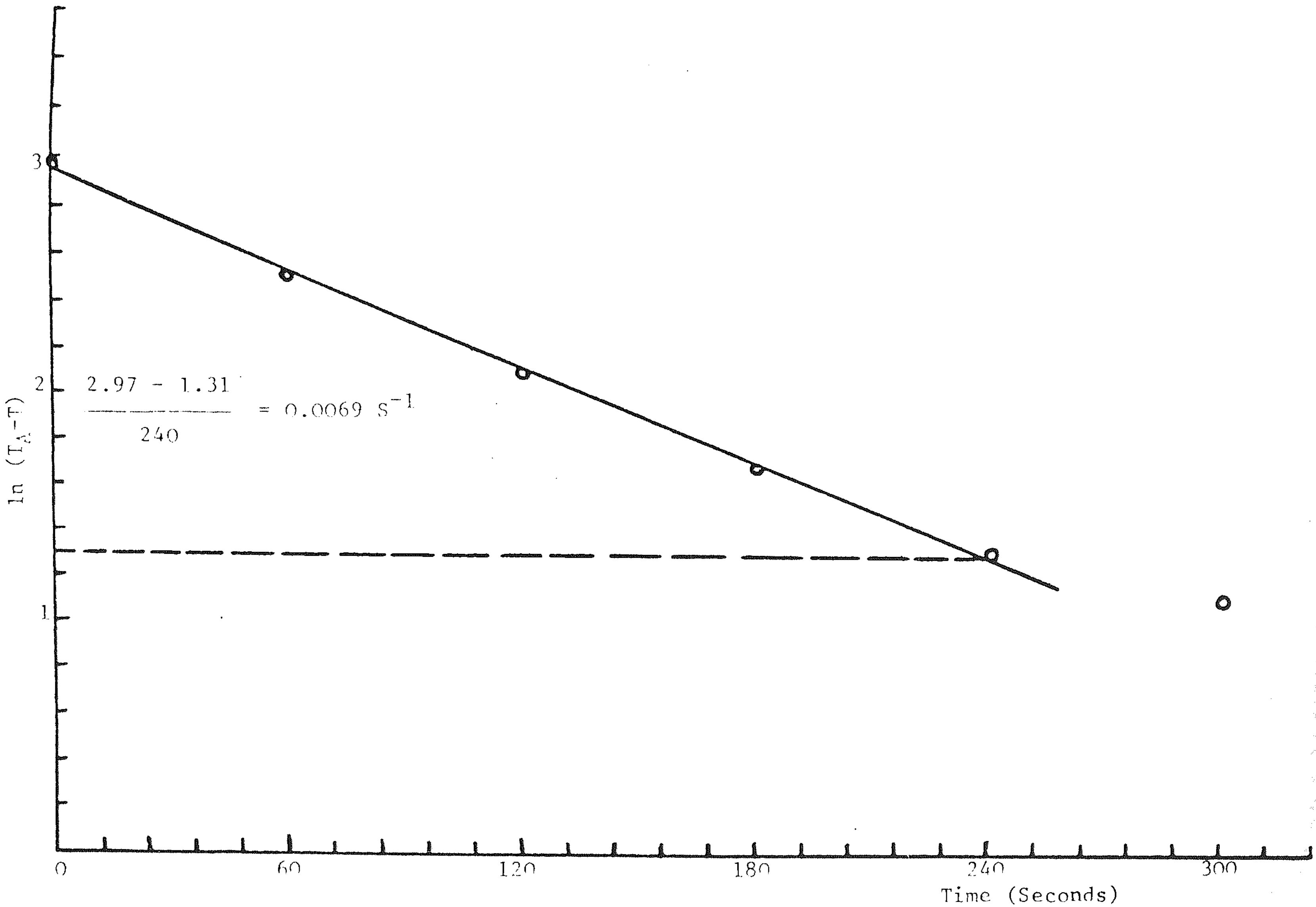
$$= \frac{0.0069 \times 9.127 \times 0.224 \times 4.185}{5 \times \left(\frac{1\cdot5}{100}\right)^2}$$

(Assuming that 5 faces are being heated)

$h = 52.5\ W/m^{2\,o}C$.

Air velocity = 2.9m/s in experiment.

Figure 3.5.1 Graph of ln $(T_A - T)$ against time for aluminium cube heating



Approximate Check on h value

For flow around spheres, correlations exist of Nu versus Re & P_r.

$$\frac{hd}{k} = 2.0 + 0.6\, Re^{\frac{1}{2}}\, P_r^{\,1/3}$$ (Section 3.2, equation 3.2.2).

For air velocity 3 m/s at $60^{o}C$ passing over a sphere of diameter 0.015m and taking viscosity of air $= 2.0\times10^{-5} m^2/s$, $P_r = 0.7$, $k=0.030$ W/m°k

$$Re = \frac{3x\ 0.015}{2.0x10^{-5}} = 2250$$

$$\frac{hd}{k} = 2.0 + 0.6\ (2250)^{0.5}(0.7)^{0.333} = 27.27$$

$$h = \frac{0.030\ x\ 27.27}{0.015}$$

$$= 54.5\ W/m^2\ {}^{o}C$$

To check if the assumption of uniform cube temperature is valid.

True if Biot Number $\frac{hV}{Ak} < 0.1$ (Vaccarezza et al 1974)

with $h = 52\ W/m^2\ {}^{o}C$ and $\frac{V}{A} = L^3/6L^2 = {}^{L}/6$ (assuming 6 faces)

$$\therefore\ Bi = \frac{L}{6}\ \frac{h}{k} = \frac{0.015\ x\ 52\ x\ 1}{6\ x\ 229}$$ (k=229 W/m°K for pure aluminium)

$$= 6\ x\ 10^{-4}$$

Therefore Biot number criterion easily met.

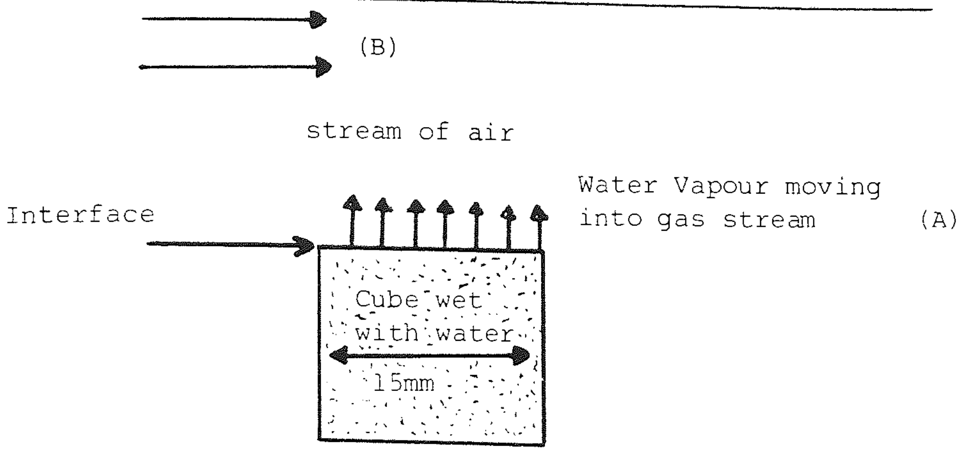
Similarly the heat transfer coefficients for 10mm cube is $45.3W/m^2\,{}^{o}C$.

The result of the experiment is in reasonable agreement with the theory for a sphere.

A sphere of diameter 0.015m has a smaller surface area of $7.1\ x\ 10^{-4}\ m^2$ compared to $11.0\ x\ 10^{-4}\ m^2$ for a cube of 0.015 m side.

For a given heat load, the theoretical heat transfer coefficient will be less for the cube according to the relation $h = \frac{mc\,dT/d\theta}{A(T_A - T)}$

3.5.2. Mass Transfer Coefficient at 15mm Plantain Cube Surface



Example of Mass-Transfer Across a Phase Boundary:

Diffusion of water vapour into the air stream occurs as shown in the above figure. The Mass-Transfer coefficient (k_c) determines the rate of diffusion normal to the interface (Bird et al 1960). The correlation for mass transfer coefficient at the surface of a sphere is as follows:

$$\frac{k_c d}{D_{AB}} = 2.0 + 0.6\, R_e^{1/2}\, S_c^{1/3} \quad \text{(section 3.2 equation 3.2.2)}$$

For air velocity 3m/s past a 0.015m diameter sphere and for D_{AB} (m^2/s) $= 3.6\ 10^{-5}$ at $60^{\circ}C$

$$S_c = \frac{\mu}{D_{AB}} = \frac{2.0 \times 10^{-5}}{3.6 \times 10^{-5}} = 0.55$$

R_e = 2250 (section 3.5.1)

$$\therefore \frac{k_c d}{D_{AB}} = 2.0 + 0.6\ (2250)^{1/2} (0.55)^{1/3} = 25.36$$

$$k_c = \frac{25.36 \times 3.6 \times 10^{-5}}{0.015}$$

$$= 0.061 \text{ m/s}$$

3.5.3. Internal and External Diffusion Resistances in Plantain Cube:

At air velocity 3m/s the mass-transfer coefficient is 0.061m/s.

At 60°C D (Internal Diffusion Coefficient) = 1.612×10^{-9} (see page 97).

External Resistance $= \frac{1}{K_c} = \frac{1}{0.061} = 16.4$ s/m

Internal Resistance $= \frac{\text{Diffusion Path Length}}{\text{Internal Diffusion Coefficient}}$

$$= \frac{0.005}{1.612 \times 10^{-9}}$$

$$= 3.1 \times 10^{6} \text{ s/m}$$

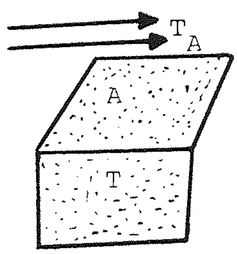
Conclusion

The heat transfer coefficient is 52 W/m^2°C for five faces of 15mm aluminium cube and agrees well with the empirical formula for a 15mm diameter sphere. The mass transfer coefficient for a 15mm diameter sphere is 0.061 m/s and this is taken to be a good approximation to the value for 15mm plantain cube by anology with the agreement of the experimental and calculated h values in the previous section 3.5.1. The internal resistance of 3.1×10^{6} s/m is far greater than external surface resistance of 16.4 s/m. Thus the external resistance and air velocity should not affect the drying rate during the falling rate period in the drying of plantain cubes.

3.5.4. Surface Temperature of the Drying Cube

The rate of evaporation of water from the drying material depends on the surface temperature of the material. For a diffusion controlled drying process, the rate of evaporation will also depend on the rate of diffusion of water vapour from the inside of the material to the surface. The rate of diffusion is dependent on the material temperature. However, the material temperature increases rapidly at the beginning of the drying towards the air dry bulb temperature but the difference between the material and dry bulb temperature becomes negligible only when about 90% of the initial water has been evaporated, (Vaccarezza et al 1974). The internal temperature gradient is small and the food temperature can be described as being uniform, (Alzamora et al 1979).

The low material temperature and consequently low rate of diffusion will affect the amount of water being evaporated from the surface throughout the drying process. It is intended in this section to establish theoretically the surface temperature of plantain cubes (i.e. cube temperature) when dried at $60^{o}C$ at 3m/s using the rate of moisture loss from the experimental drying curve.



Assuming uniform cube temperature (T), the energy balance for heat flow when a plantain cube is being heated can be represented simply as:

$$hA(T_A - T) = -\lambda \frac{dW}{d\theta} + mc\frac{dT}{d\theta} \quad \ldots\ldots\ldots \; 3.5.7.$$

Neglecting sensible heat, the equation reduces to the form;

$$hA\,(T_A - T_\theta) = -\lambda \frac{dW}{d\theta}$$

where $\frac{dW}{d\theta}$ = rate of moisture loss kg/s

For the drying operation carried out with 10mm and 15mm plantain cubes at 60°C, sample calculation is given below:

$T_A = 60^{\circ}C$ $\qquad$ $T_{(\theta)}$ = surface temperature

$\lambda = 2355\ kJ/kg$ (Mayhew and Rogers, 1972)

$h = 50\ W/m^2\,{}^{o}C$

For 10mm cube $\qquad$ $A = 5 \times 10^{-4}\ m^2$ (5 faces exposed to heating)

For 15mm cube $\qquad$ $A = 5 \times (1.5)^2 \times 10^{-4}\ m^2$ (5 faces exposed to heating)

$$T_A - T_\theta = \frac{\lambda\, dW_W/d\theta}{hA}$$

Surface temperature after 5 minutes of heating

10mm cube

$$T_A - T_\theta = \frac{2355 \times 4.75 \times 10^{-4}}{50 \times 5 \times 10^{-4}} = 45$$

$$T_\theta = 15^{\circ}C$$

15mm cube

$$T_A - T_\theta = \frac{2355 \times 8.87 \times 10^{-4}}{50 \times 5 \times (1.5)^2 \times 10^{-4}} = 37$$

$$T_\theta = 23^{\circ}C$$

The theoretically calculated cube surface temperature rose continuously until the dry bulb temperature was reached as shown in figure 3.5.2. Thus there is no constant drying period since the surface temperature was never constant. The surface temperature was found to be below 50°C during the first 60 minutes of the drying operation for both 10mm and 15mm cube. An average mean surface temperature of 55°C was assumed to be most appropriate for the calculation of the diffusion coefficient, to be used for the prediction of moisture loss with time.

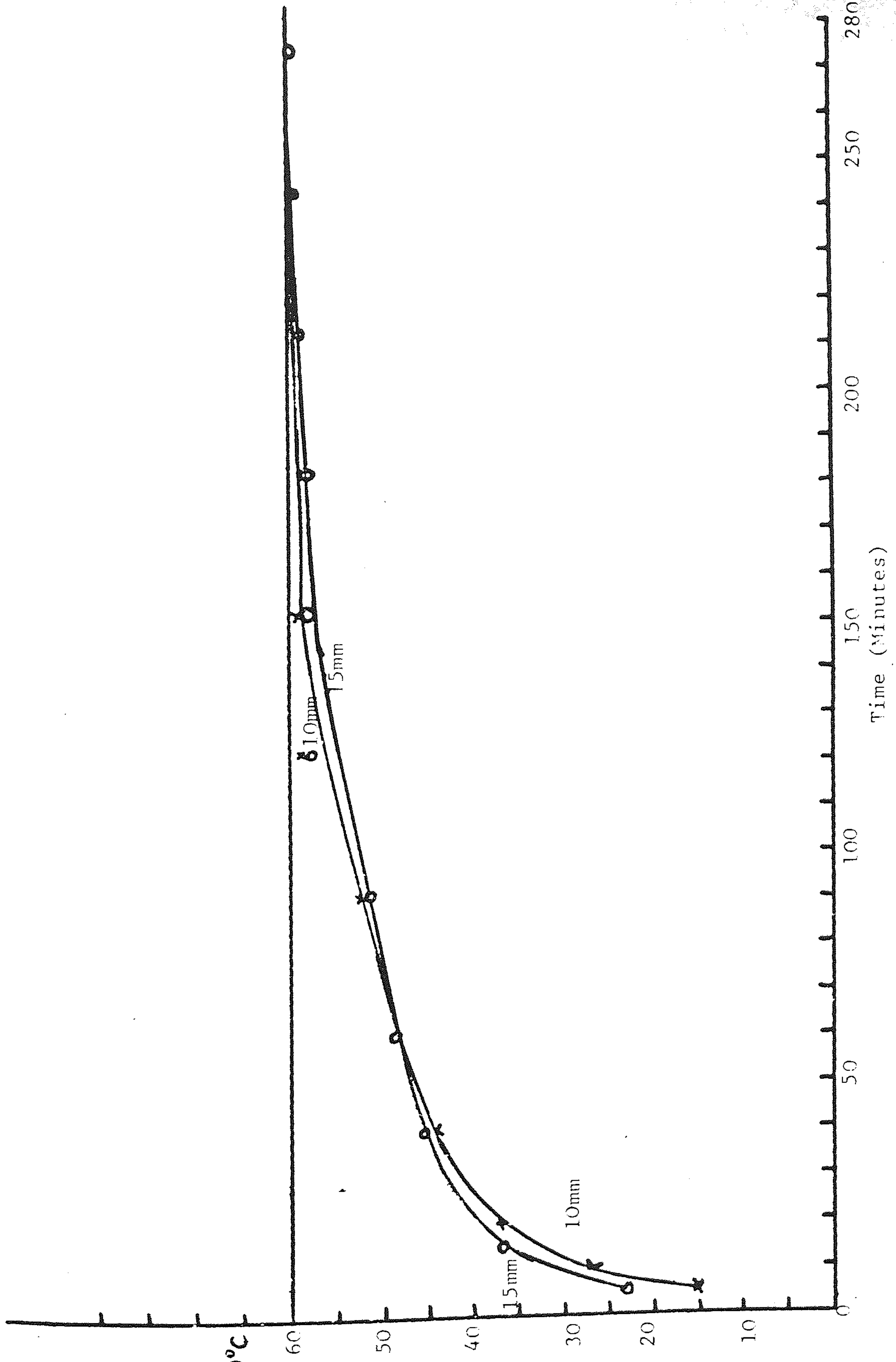


Figure 3.5.2 Calculated surface temperature of 10mm and 15mm plantain cubes versus time

The data and the calculated surface temperature for 10mm and 15mm plantain cubes dried at $60^{o}C$ are shown in the table APP-3.1

3.5.5. Diffusional Process in the Drying of Plantain Pulp

3.5.5.1. Equilibruim Moisture Content (W_e)

This is the lowest moisture content that can be achieved when moist material is dried under a given set of conditions of temperature and humidity. It can be determined by drying the material under the given condition until constant weight is confirmed by repeated weighings. A correct value of W_e is necessary for the accurate determination of the diffusion coefficient, D, for the first falling rate period, which depends on the slope of the graph $\ln(W_\Theta - W_e)/(W_O-W_e)$ versus time. When too high a value is used for W_e, the graph tends to curve downwards and when a low value is used, the graph tends to curve upwards as shown in figure 3.5.6. The value of W_e was found by graphs such as figure 3.5.6 and the graph that gave the best straight line was used to calculate the value of D. It was found that for almost all the cubes, the equilibrium weight was 37% of the initial weight of the cube.

3.5.5.2. Calculation of the Diffusion Coefficient (D)

From the graph of $\ln (W_\Theta - W_e)/(W_O-W_e)$ versus time (figures 3.5.3 - 3.5.7), the slope is measured to give $- 9\pi^2 D/16L^2$ (equation APP-3.2) The diffusion coefficient is then calculated as shown in the sample calculations below.

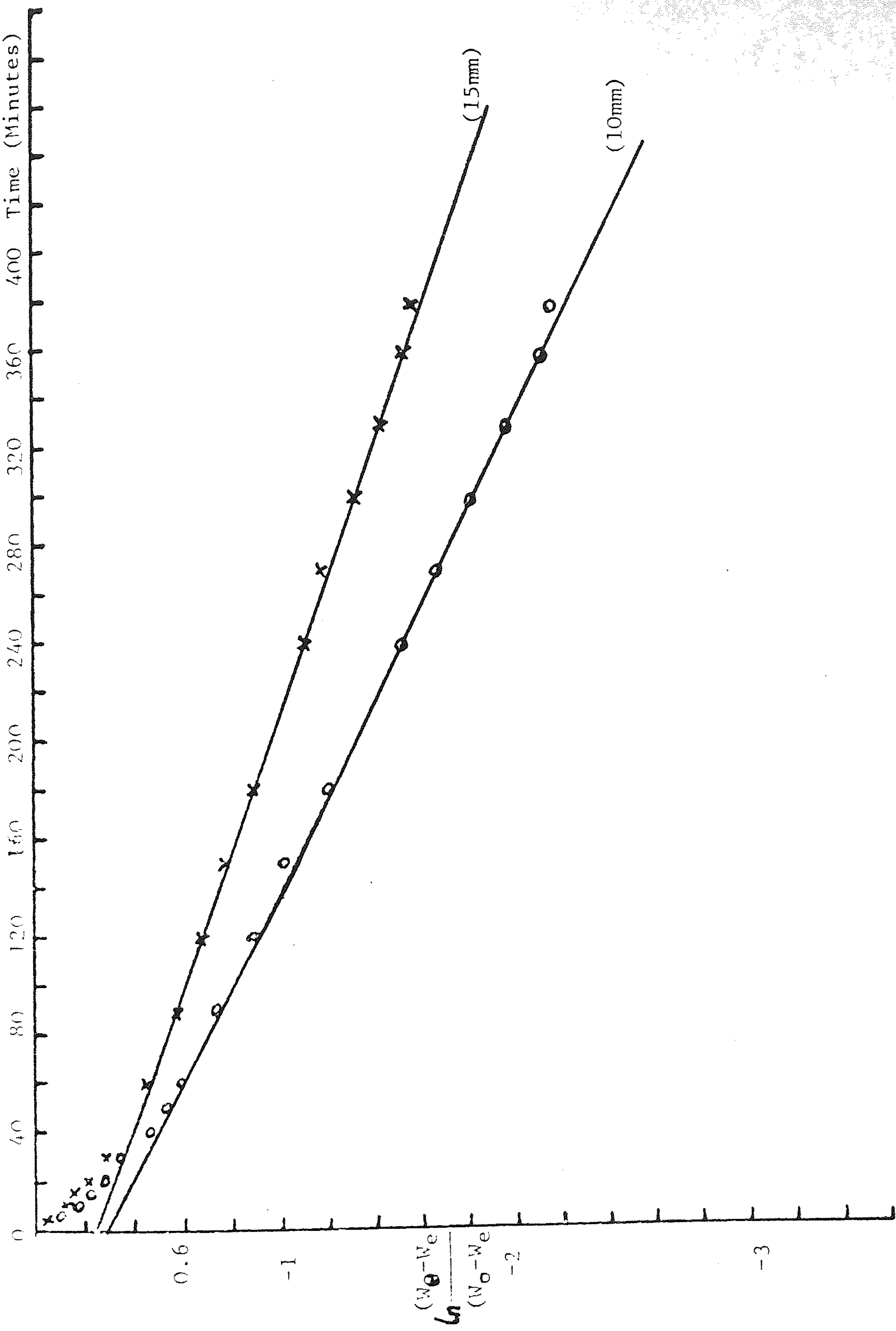


Figure 3.5.3 Fraction of evapor-able water remaining in plantain cube as a function of time 10mm and 15mm cubes dried at 40°C (DB).

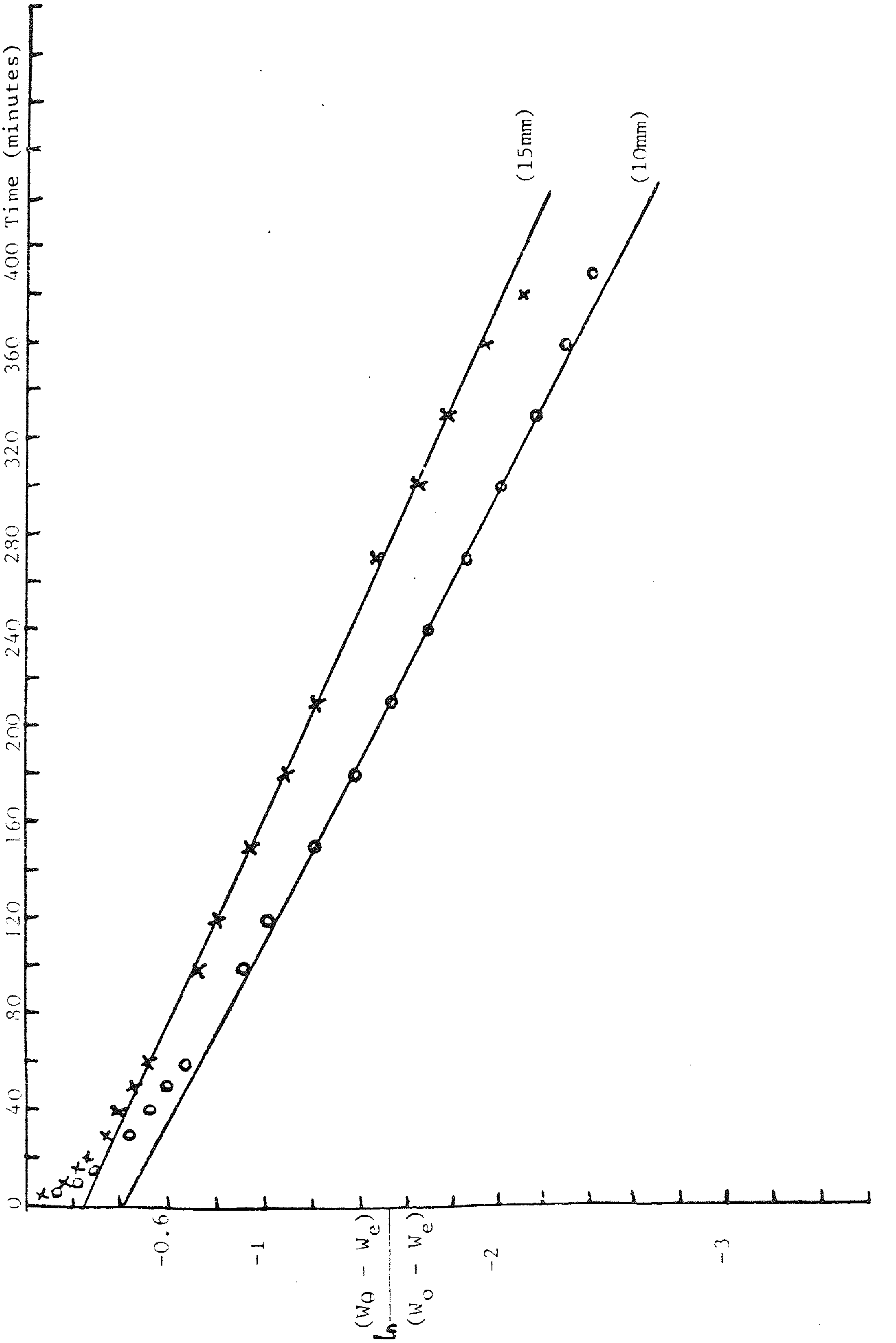


Figure 3.5.4 Fraction of evaporable water remaining in plantain cube as a function of time for 10mm and 15mm sizes dried at 49°C (DB)

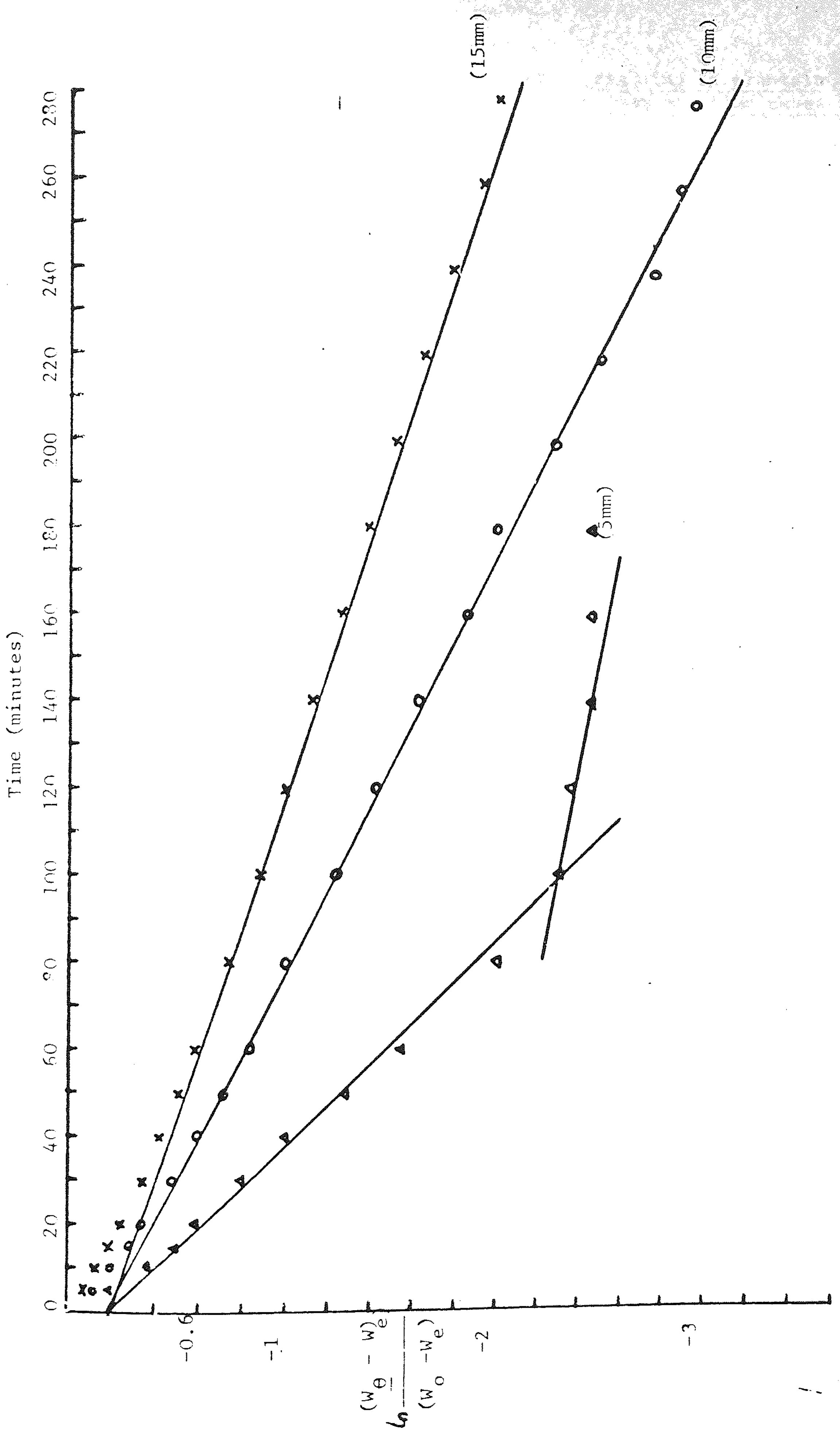


Figure 3.5.5 Fraction of evaporable water remaining in plantain cube, as a fraction of time for 5mm, 10mm and 15mm cubes dried at 54°C (DB)

Figure 3.5.6 Fraction of evaporable water remaining in plantain cube as a function of time for 10mm and 15mm cubes dried at 60°C

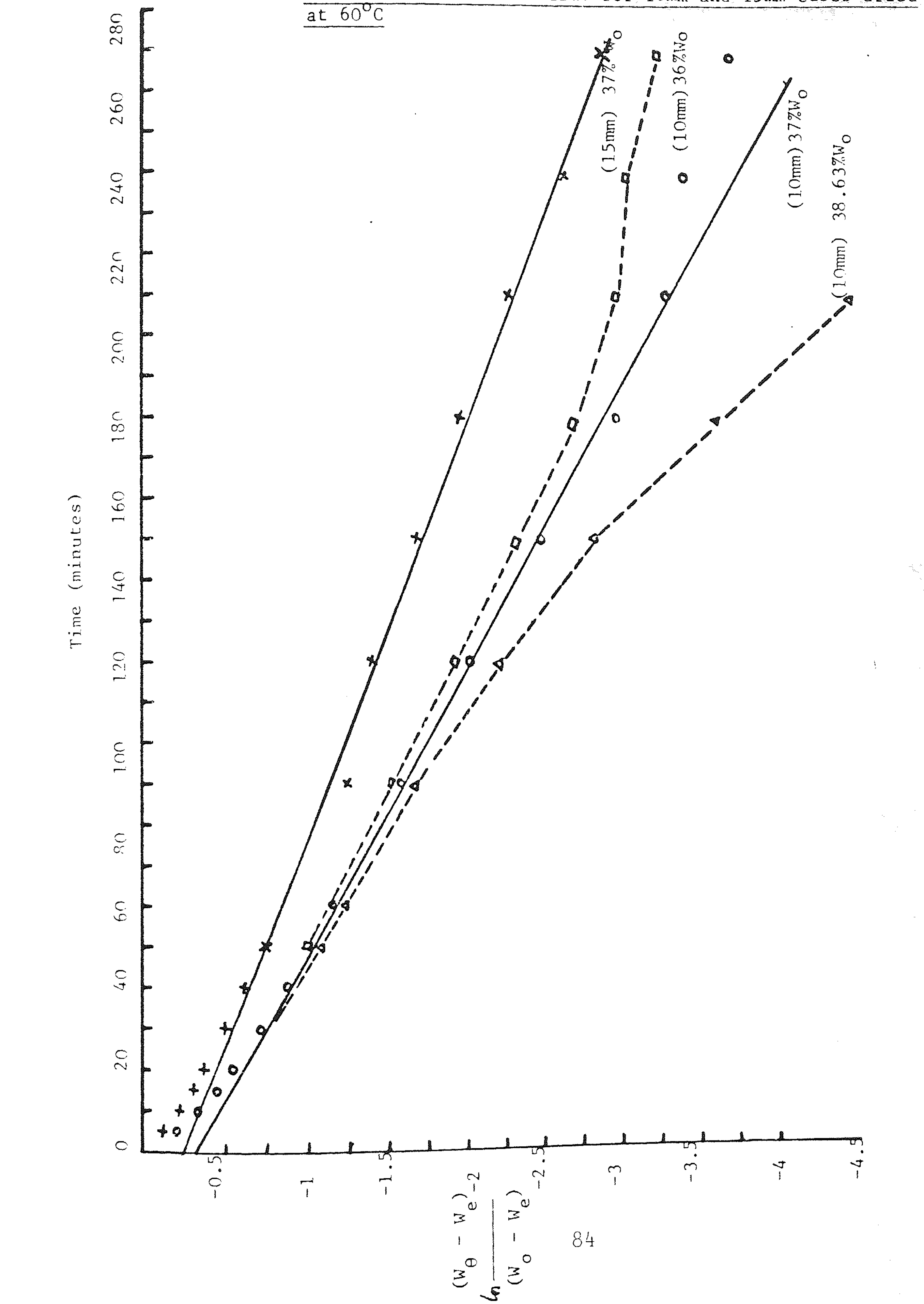
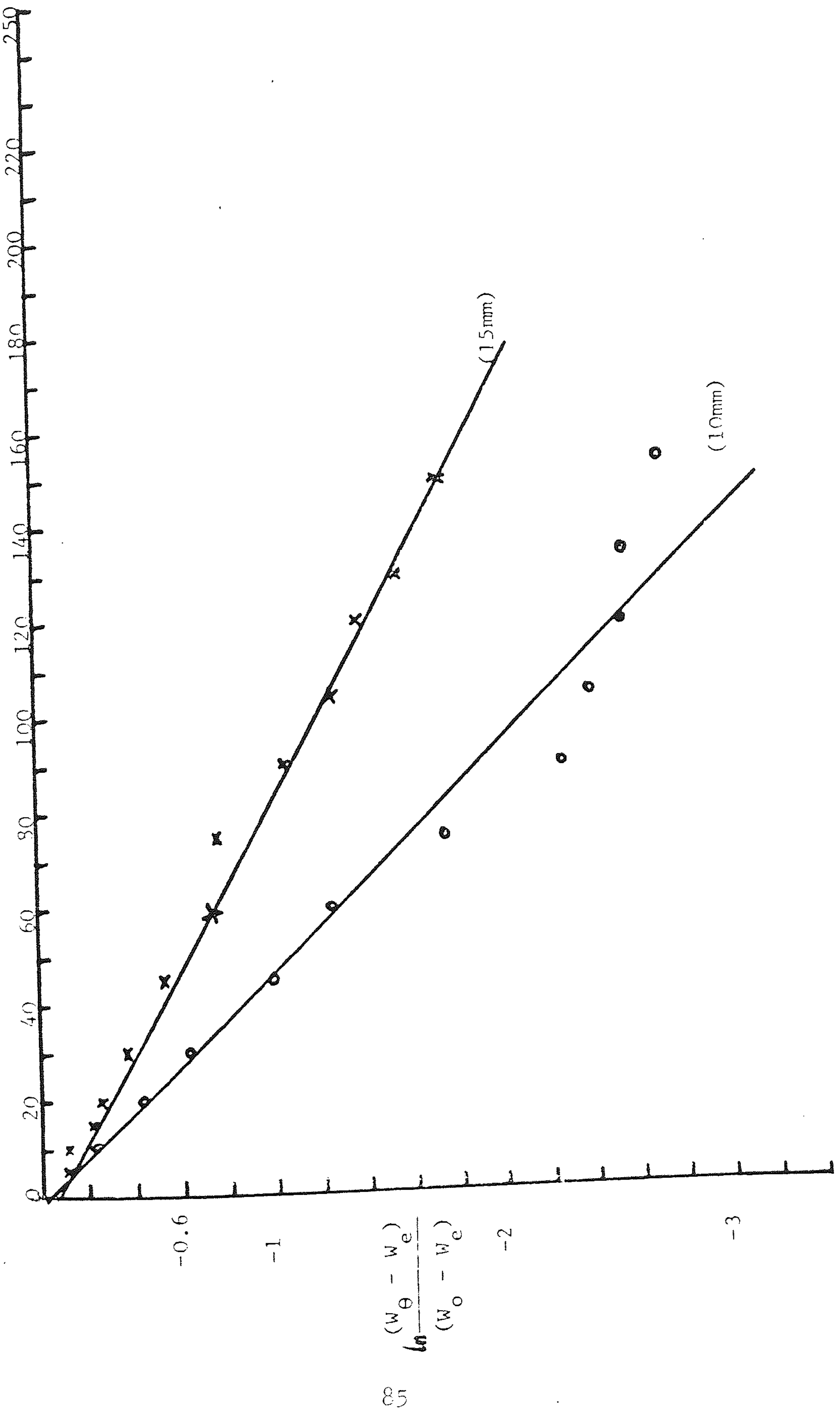


Figure 3.5.7 Fraction of evaporable water remaining in plantain cube as a function of time for 10mm and 15mm cubes dried at 65°C (DB)



Sample calculation for the 10mm and 15mm cubes dried at $54^{o}C$.

15mm Cube   1st Falling Rate Period   (Figure 3.5.5)

$$Slope = -\frac{9\pi^2 D}{16L^2} = -1.1110 \times 10^{-4} \quad s^{-1}$$

$$D = 1.111 \times 10^{-4} \times \frac{16}{9} \times \frac{1}{\pi^2} \times 5.625 \times 10^{-5}$$

$$= 11.26 \times 10^{-10} \quad m^2/s$$

10mm Cube   1st Falling Rate Period

$$Slope = \frac{-9\pi^2 D}{16L^2} = -1.750 \times 10^{-4} \quad s^{-1}$$

$$D = 1.75 \times 10^{-4} \times \frac{16}{9} \times \frac{1}{\pi^2} \times 2.5 \times 10^{-5}$$

$$= 7.88 \times 10^{-10} \quad m^2/S$$

3.5.5.3. Calculation of the activation energy (ΔE) for the temperature range $40^{o} - 65^{o}C$

From the graph of ln D versus $1/T^{o}K$ (figure 3.5.8) a straight line was obtained whose slope was equal to $-\Delta E/R$ (section 3.3.3, equation 3.2.9).

For 10mm Cube

$$Slope = \frac{1.9}{0.00033} = -5757 \cdot 5758 = -\frac{\Delta E}{R} \quad S^{-1}$$

$$\Delta E = 5757\ .5758 \times 8.314$$

$$= 47.8 \quad kJ/mole$$

For 15mm Cube

$$Slope = \frac{1.6}{0.00033} = -4848.4848 = -\frac{\Delta E}{R} \quad S^{-1}$$

$$\Delta E = 4848.4848 \times 8.314$$

$$= 40.3. \quad kJ/mole$$

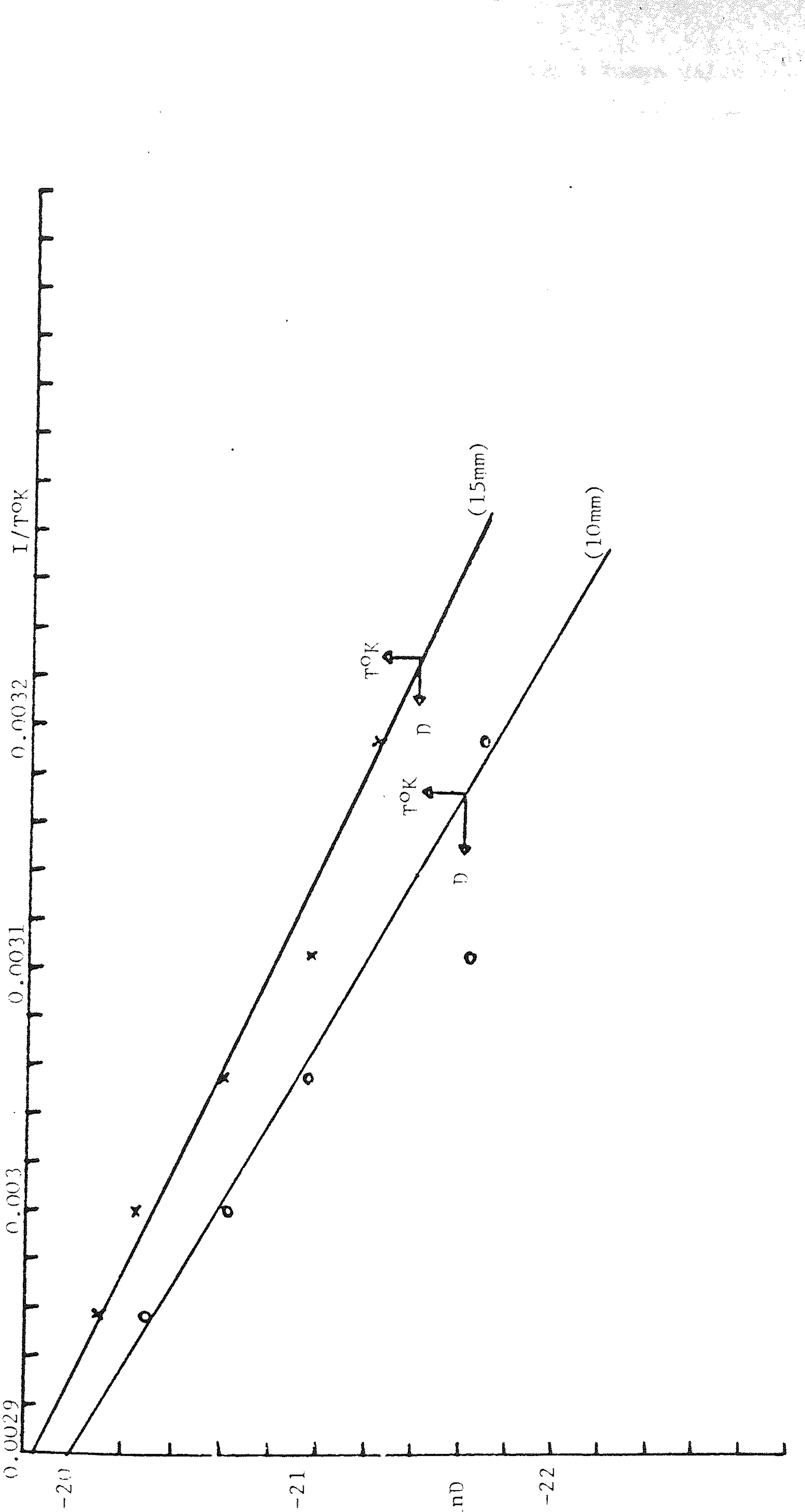


Figure 3.5.8 Graph of natural logarithm of diffusion coefficient against the reciprocal of the temperature of drying for 10mm and 15mm cubes

3.5.5.4 Calculation of the constant "A" using a known value of diffusion coefficient "D"

In order to obtain a value for the constant "A" in the relation $D(T) = A \exp(-\Delta E/RT)$ a value for the diffusion coefficient D is obtained from the graphs in figure 3.5.8. The values of the activation energy, diffusion coefficient and corresponding temperature are substituted in the relation $\ln D = \ln A - \Delta E/RT$ to obtain a value for "A".

For 10mm Cube

$\ln D = -21.6$ (From figure 3.5.8)

$T^{o}K = 314.4654$ (" ")

$E = 47868.500$ J/mole (Section 3.5.5.3)

$\ln D = \ln A - \Delta E/RT$

$-21.6 = \ln A - [-47868.600/(8.314 \times 314.4654)]$

$\ln A = 21.6 + 18.3091 = 3.2909$

$A = e^{-3.2909} = 0.03722 \; m^2/sec$

$D(T) = 0.03722e^{-\Delta E/RT}$

For 15mm Cube

$\ln D = -21.4$ (From figure 3.5.8.)

$T^{o}K = 309.5975$ (" " ")

$\Delta E = 40310.300$ (Section 3.5.5.3)

$\ln D = \ln A - \Delta E/RT$

$-21.4 = \ln A - [-40310.3/(8.314 \times 309.6)]$

$\ln A = -21.4 + 15.6571 = -5.7429$

$A = e^{-5.7429} = 0.0032 \; m^2/sec$

$D(T) = 0.0032e^{-\Delta E/RT}$

The summary of the calculated diffusion coefficients for different temperatures based on the activation energy is given in table 3.6.2.

3.5.5.5. Prediction of Cube weight with drying time

The weight of plantain cube at different time intervals during drying was calculated using computer programme for the relation:

$$W_\theta = (W_o - W_e)\left(\frac{8}{\pi^2}\right)^3 \left\{ \exp - \frac{9\pi^2 D(T)\theta}{16L^2} + \frac{1}{3} \exp - \frac{41\pi^2 D(T)\theta}{16\,L^2} + \frac{1}{27} \exp - \frac{105\pi^2 D(T)\theta}{16L^2} \right\} + W_e$$

(appendix APP-3.3 equation APP-3.1). The calculated values for 10mm and 15mm cubes are given in tables 3.6.3 and 3.6.4.

3.5.5.6. Prediction of Moisture changes during plantain cube drying

The fraction of evaporable water remaining in plantain cube as a function of time was calculated for both experimental and theoretical weights using the relation $\ln \frac{W_\theta - W_e}{W_o - W_e}$ for 10mm and 15mm plantain cubes dried at 40°, 49°, 54°, 60°, and 65°C. The calculated values are given in the appendix APP-3.4 to APP-3.8.

3.6. Discussion

3.6.1 Effect of Air Flowrate on the Rate of Drying

The data for the drying curves of 15mm plantain cube are given in table APP-3-9.

Figure 3.6.1 shows the effect on the drying rate of 15mm plantain cube for three air velocities. There was an appreciable increase in the rate of water desorption when the air velocity was increased from 2.4 - 2.9 m/s. The subsequent increase in drying rate when the velocity was increased from 2.9 - 3.4 m/s was less but significant. The graph of fractional rate of water desorption as a function of mean moisture content, figure 3.6.2 showed no evidence of constant rate period as there was a continuous fall in the drying rate. If there was a constant rate period, the graph would appear horizontal initially before decreasing as was the case in the drying of fish muscle (Jason 1958), and potato disc (Saravacos and Charm 1962).

When fruit and vegetables are dried using cabinet or tray drier the air velocity in the range of 2 - 5 m/s is usually employed. (Brennan et al 1976).

Air Velocity m/s	Reynolds Number	Heat tranfer Coefficient $W/m^2\ ^oC$	Mass transfer Coefficient m/s	External Resistance s/m
1	750	33.2	0.04	26.8
2	1500	45.3	0.05	19.7
2.4	1800	49.2	0.055	18.2
2.9	2175	53.7	0.06	16.6
3.0	2250	54.4	0.061	16.4
3.4	2550	57.8	0.065	15.5
4.0	3000	62.4	0.07	14.3
5.0	3750	69.3	0.077	12.9

Table 3.6.1 Effect of Air Velocity on the Heat and Mass Transfer Coefficient of 15mm plantain cube

Figure 3.6.1 Effect of Airflowrate on the Drying Rate of 15mm plantain cube

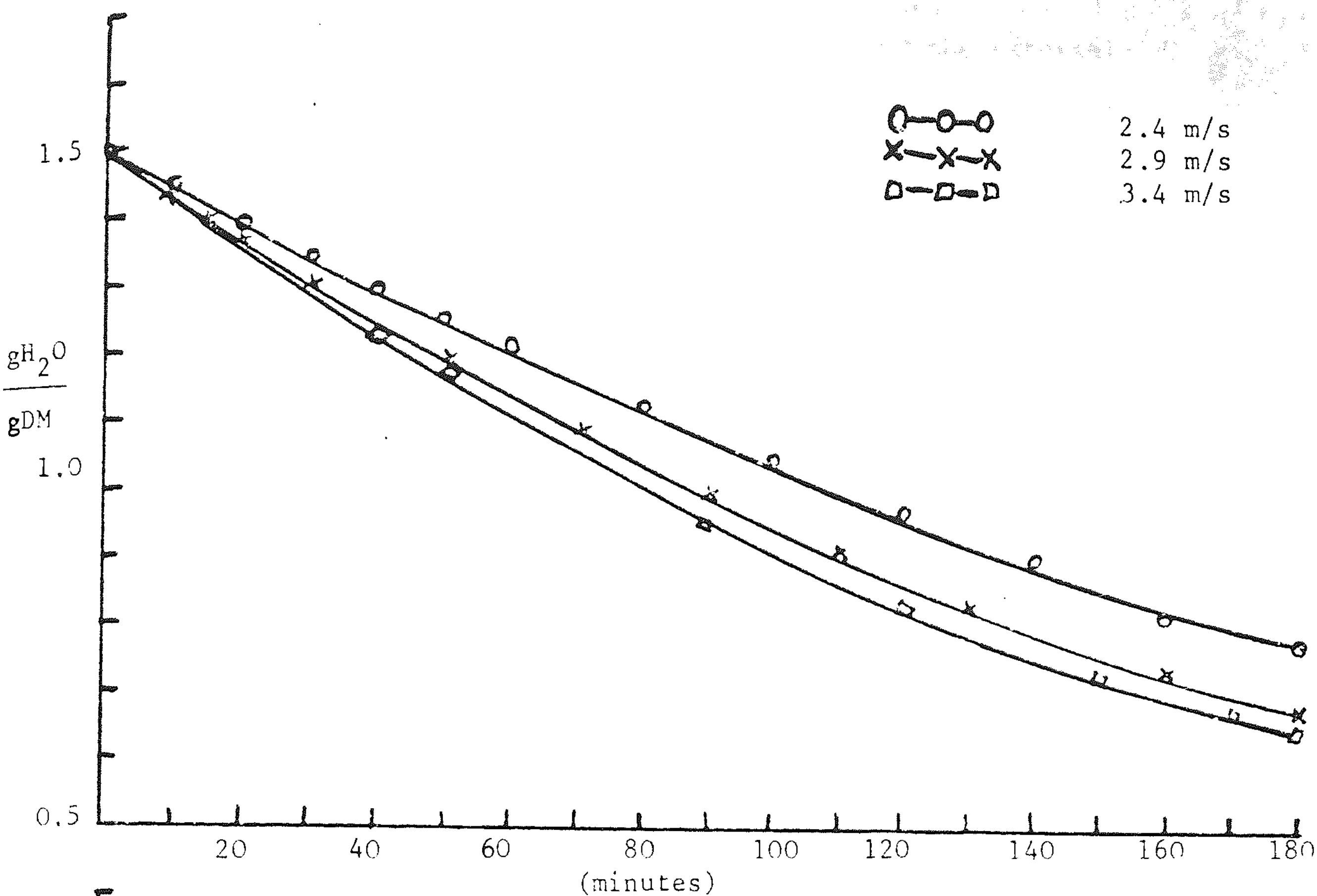


Figure 3.6.2 Fractional Rate of Water Desorption as Function of Mean Moisture Content

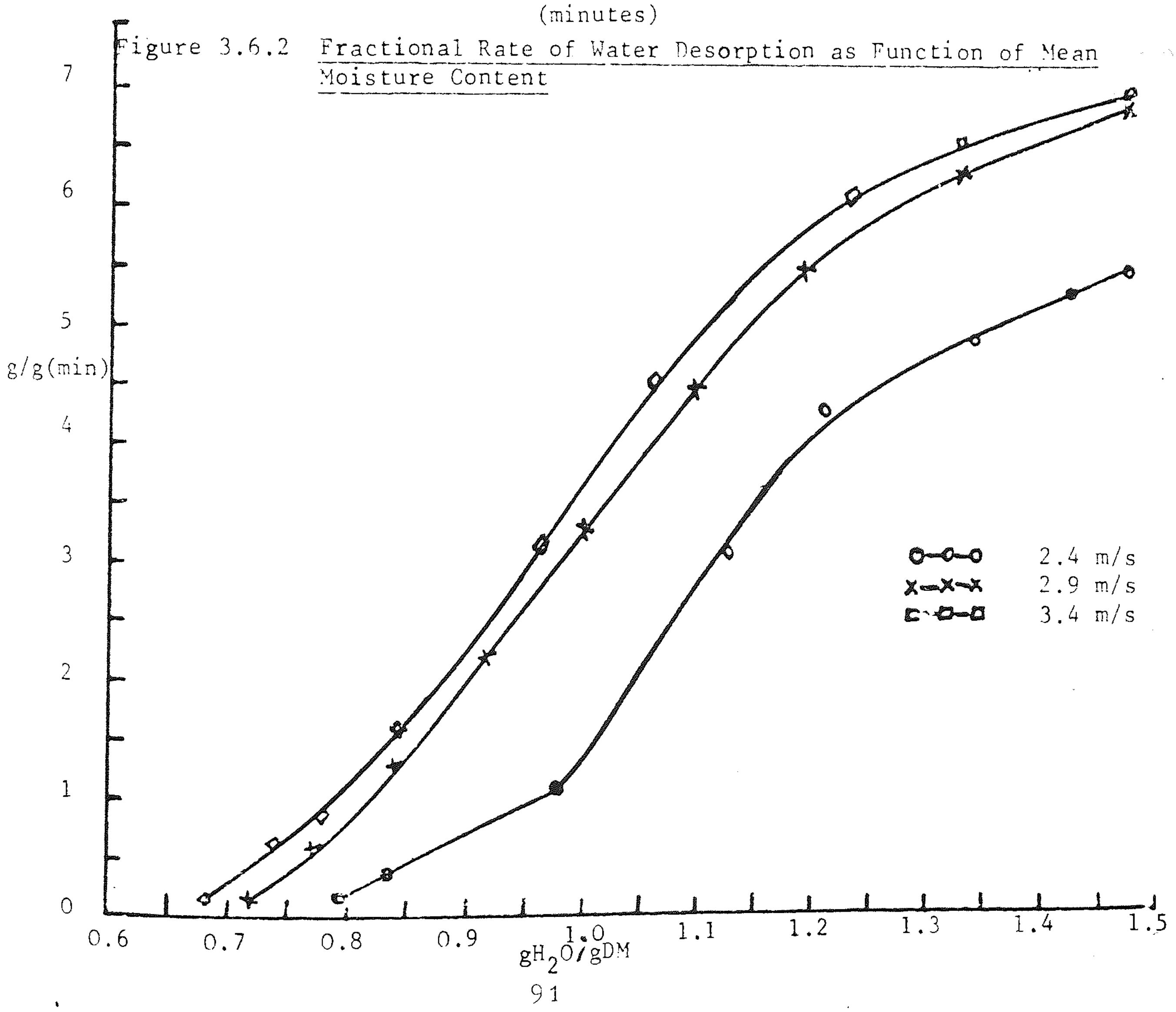


Table 3.6.1 shows the effect of increase in velocity in the drying of plantain cube on the heat transfer coefficient and the external resistance to mass transfer. However, the external resistance of 16.4. s/m is very small compared with the corresponding internal resistance of 3.1×10^6 s/m when 15mm plantain cube was dried at 60^oC and air velocity 3m/s, (section 3.5.3). In the falling rate period, increase in air velocity should not affect the internal movement of water vapour (i.e. internal diffusion) to the surface. The increase in the rate of drying with increase in air velocity in the falling rate period could be mainly due to the increase in heat transfer coefficient giving a higher cube temperature and consequent high diffusion coefficient. The drying of plantain cube could be described as taking place in two zones, the zone of unsaturated surface drying and the zone where internal moisture movement controls. The first zone lies within the moisture content of 100% - 80% and could be regarded as within the critical moisture content range (figure 3.2.1). In this zone not all of the surface can be maintained saturated by moisture movement within the solid. The drying rate decreases for the unsaturated portion and hence the rate of the total evaporation decreases with time. The zone where internal moisture movement controls starts from the mean moisture content 80% and this happens after about 50 minutes drying for 15mm plantain cubes.

3.6.2. Effect of Air Temperature on the Rate of Drying

The data for the drying curves of 10mm plantain cube are given in APP-3.10. Figure 3.6.3. shows the rate of drying for the air temperatures 40°, 49°, and 60°C. As expected, increase in temperature reduced the drying time. The time required to reduce the moisture content below 10% of the original content was shortest for the smallest cube size, APP-3.10. However, care should be taken to avoid case hardening effect at very high temperature of drying which results in a lower drying rate.

The biological changes occuring in a material at any point will be functions of the moisture content, temperature and time. A chemical change which could take place during the drying of plantain pulp is the gelatinisation of the starch granules. The average moisture content of green plantain pulp is 60%. The plantain starch could mix with the water when heated to form a viscous liquid. Meyer (1978), noted that for most starches, the granules begin to swell rapidly and take up a large amount of water at a temperature of approximately 65°C. The swelling of starch, which results in an increase in viscosity of starch-water mixtures and the formation, under proper conditions, of a gel is now believed to occur through the binding of water.

For plantain starch, the gelling point temperature was found to be 71°C using Brabender Viscograph equipment. The details of the experiment are given in chapter 5, section 5.5.2. Thus if plantain pulp is dried at a temperature above 75°C, the resultant flour will be pregelatinised but if dried at a temperature below 70°C, the dried pulp will yield non-gelatinised flour. Each type of flour is desirable for the production of particular dishes. Since the cube surface temperature of the drying cube is initially well below the dry bulb temperature,

Figure 3.6.3 Effect of temperature of drying on the rate of drying of 10mm plantain cube

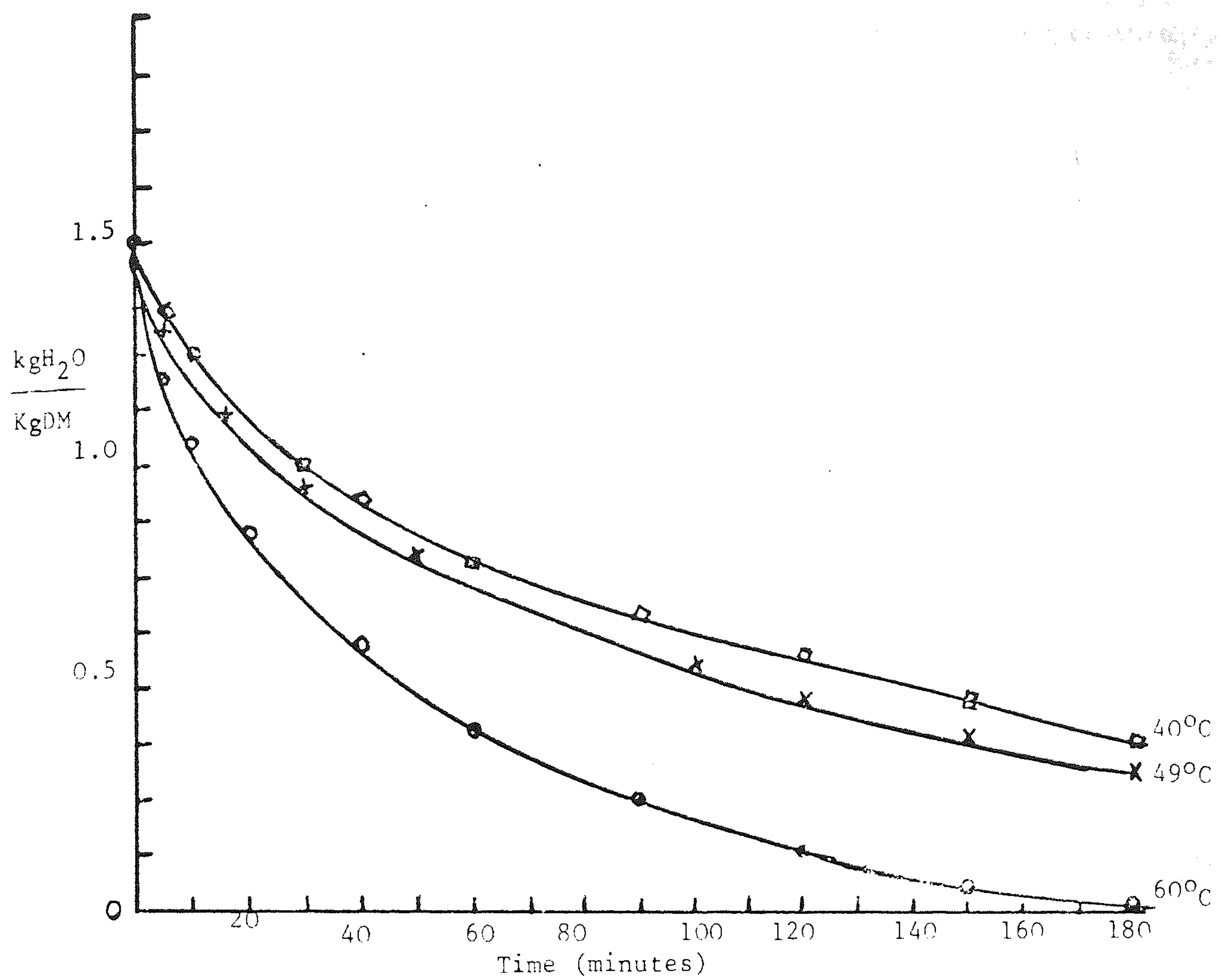
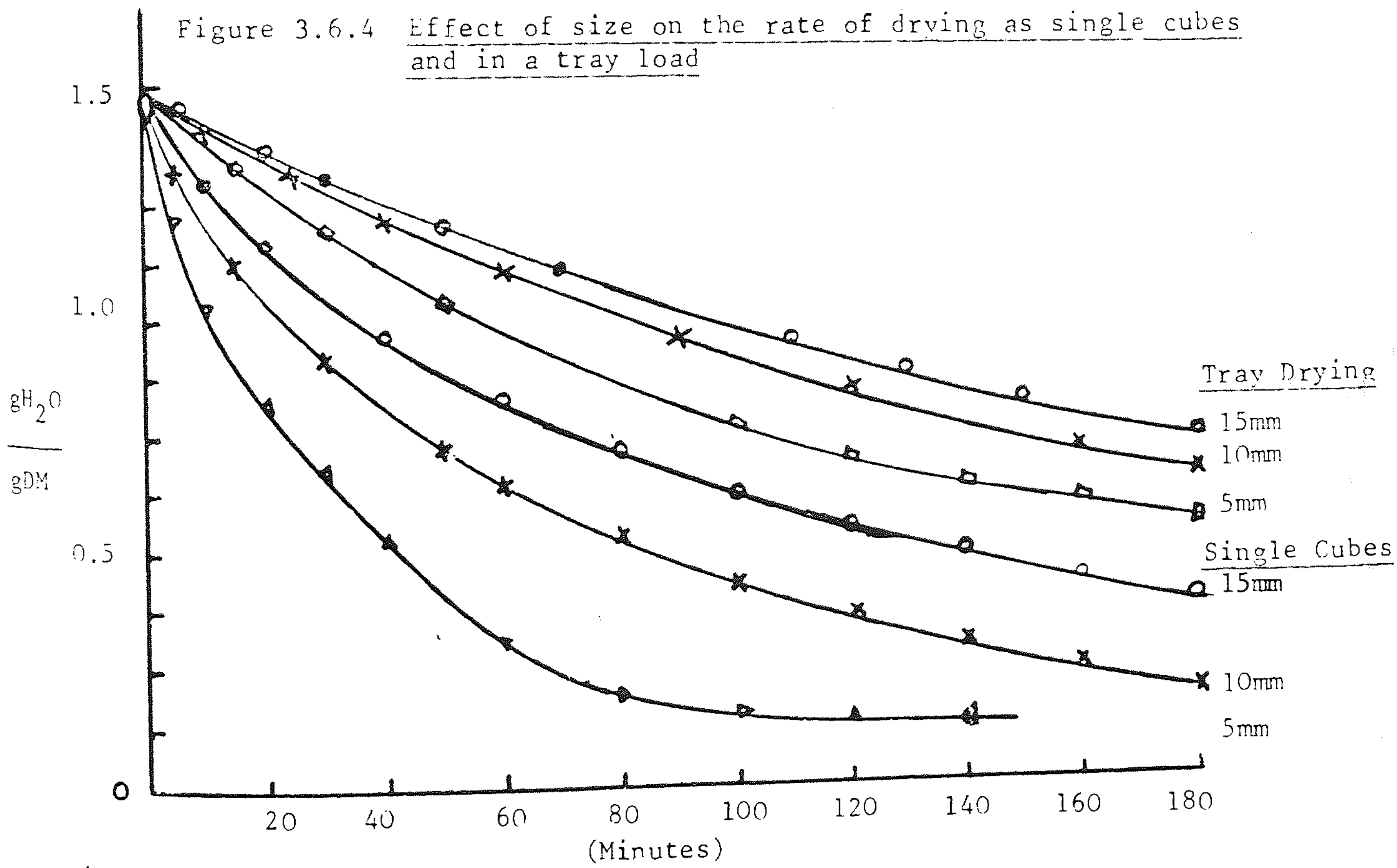


Figure 3.6.4 Effect of size on the rate of drying as single cubes and in a tray load



(section 3.5.4. figure 3.5.2), one could operate the dryer at a higher temperature initially and reduce it to the appropriate temperature after about 90 minutes of drying estimated from figure 3.5.2.

The temperature effect on the rate of diffusion and the value of activation energy for water vapour in plantain cubes is discussed in section 3.6.4.

3.6.3. <u>Effect of Size on the Rate of Drying</u>

The data for the drying curves are given in table APP-3.11 and APP-3.12 Plantain cubes of the size 5mm, 10mm and 15mm were used in the study of the effect of thickness on the rate of drying and figure 3.6.4 shows the results obtained after drying cubes in a petri dish inside the drying chamber (figure 3.4.1.). The rate of drying was fastest with the smallest cube in both cases and the drying time required to achieve a moisture content below 10% was shortest for 5mm cube as shown in table APP-3.12 Considering the equation $\ln(W-W_e) = \ln(W_o-W_e) - a\Theta/L^2$ where a is constant (section 3.2, equation 3.2.7), and using the data in table APP-3.12 one will get the following values.

thickness (L)	L^2	Time Θ	Θ/L^2
5mm	$25mm^2$	120min	0.48
10	100	210	0.21
15	225	>300	<0.13

Therefore the drying time for the three different sizes was not inversely proportional to the square of the thickness, and hence a constant "a" value independent of cube size, was not found.

The rate of drying was faster for single cubes than for single layer of similar cubes packed in Petri dish as shown in figure 3.6.4. With single cubes, the drying took place on the five exposed faces. But with the single layer cubes, they behaved initially as a single surface layer and drying took place from the top surface only. As drying proceeded ,the cubes shrank and the structure of the layer became more open and relatively thinner. Each cube then behaved as a single cube and drying took place throughout the whole layer. (See figure 4.4 page 131). The effect of thickness on the rate of diffusion is discussed in section 3.6.4.

3.6.4. The Diffusional Process in Plantain Pulp Drying:

It is assumed that the drying of plantain cubes is diffusion controlled for about 80% of the total time for the drying operation because the fractional rate of water desorption as a function of mean moisture content showed no evidence of constant rate period (Section 3.6.1, figure 3.6.2.). Also the cube surface temperature rose continuously until the dry bulb temperature was reached showing that there was no constant drying period, (section 3.5.4, figure 3.5.2).

The diffusion coefficient was calculated from the slope of the best possible straight line of $\ln(W_\Theta - W_e)$ vs Θ from the experimental data, (section 3.5.5.2.) . Most of the straight lines were obtained through the points obtained at $\ln(W_\Theta - We)/(W_o - W_e) < 0.6$. The diffusion coefficients increased with temperature for a particular cube size and also with cube size for a given temperature as shown in table 3.6.2. for the first falling rate period. The values of activation energy were 47.8 kJ/mole and 40.3 kJ/mole for 10mm and 15mm cubes respectively, (section 3.5.5.3) . The theoretical values of diffusion coefficients calculated using the appropriate activation

Table 3.6.2 Summary of the variation of diffusion coefficient with temperature and size of cube.

Temperature (^oC)	Cube Size (mm)	Diffusion Coefficient 1st Phase D_{exp} M^2/S	$\ln D_{exp}$	Intercept	Slope	Diffusion Coefficient D(T) (Calculated)
40	10	3.83×10^{-10}	-21.6842	0.29	8.49×10^{-5}	3.82×10^{-10}
49	"	4.03×10^{-10}	-21.6332	0.40	8.94×10^{-5}	6.39×10^{-10}
54	"	7.88×10^{-10}	-20.9615	0.20	1.75×10^{-4}	8.39×10^{-10}
55	"					8.86×10^{-10}
60	"	11.01×10^{-10}	-20.6270	0.25	2.45×10^{-4}	11.53×10^{-10}
65	"	15.36×10^{-10}	-20.2941	0.04	3.41×10^{-4}	14.89×10^{-10}
40	15	6.02×10^{-10}	-21.2314	0.24	5.94×10^{-4}	6.02×10^{-10}
49	"	7.84×10^{-10}	-20.9666	0.25	7.74×10^{-4}	9.27×10^{-10}
54	"	11.26×10^{-10}	-20.6049	0.20	1.11×10^{-4}	11.67×10^{-10}
55	"					12.21×10^{-10}
60	"	16.12×10^{-10}	-20.2458	0.20	1.59×10^{-4}	15.25×10^{-10}
65	"	18.38×10^{-10}	-20.1145	0.08	1.86×10^{-4}	18.91×10^{-10}

energy and air temperature for the cube size (section 3.5.5.4) are also shown in table 3.6.2. The values of the diffusion coefficients and activation energy agree reasonably with the figures published in the literature, (table 3.1).

The rate of drying of a wet material is directly proportional to the free-water content and the liquid diffusivity in accordance with the relation $dW/d\theta = -(W_\theta - W_e)\pi^2 D/4L^2$ (section 3.2). Also Jason (1958) found that the effect of evaporative cooling varied inversely with the square of the thickness of the fish muscle and directly with the effective diffusion constant according to the $\frac{dH/d\theta}{(W_\theta - W_e)}$ $= \frac{\lambda\pi^2 D}{4L^2}$ (section 3.3.2). He claimed that the effect of evaporative cooling was more on the thinner samples which resulted in reduction of diffusion constant.

Since the diffusion coefficient increases with increase in temperature, the lower diffusion coefficient of the smaller cube could be explained by the fact that the surface temperature of the smaller cube (10mm) falls below the surface temperature of the larger cube(15mm) for the first one hour of the drying operation. However, the surface temperature of the smaller cube starts to increase at a faster rate than the larger cube during the latter stage of the drying as shown in figure 3.5.2. The resultant effect could be the case hardening of the cube surface because the rate of water movement from inside the material to the surface can no longer maintain the rate of evaporation from the surface. Therefore a hard impermeable skin could form at the surface, thus reducing the rate of water diffusion.

The theoretical weights of plantain cubes calculated from equation APP-3.1 using the theoretical diffusion coefficients at the air temperature and at 5°C below the air temperature are compared with the experimental weights in tables 3.6.3 and 3.6.4 for 10mm and 15mm cubes respectively.

The experimental and theoretical values are plotted as shown in figures 3.6.5. - 8. The cube weights calculated with diffusion coefficient at 5°C below the air temperature agreed closely with the experimental weights after about one hour drying for 10mm and 15mm cubes dried at 60°C (figure 3.6.7). At lower temperatures of drying, the theoretical values were below the experimental values throughout the period of drying (figures 3.6.5 and 3.6.6). Any prediction of drying time based on the diffusion model equation 3.2.5 will be greatly under-estimated unless due consideration is given to the very low surface temperature of the cube at the initial stage of drying. Chirife, (1971), applied equation 3.2.5 in the drying of tapioca root and found that the experimental data does not follow exactly the theoretical pattern which indicates that the effective diffusivity cannot be considered constant. He also found that as the temperature increased, the constant diffusivity model approached the experimental values. Vaccarezza et al (1974) applied Fick's law in the analysis of the data obtained during air drying of sugar beet root and found that a good agreement was obtained between the theoretical and experimental internal moisture distributions during drying. He, therefore, claimed that Fick's law, might be used to predict the moisture distribution especially at his lower drying temperature (47°C). He attributed the disagreement at higher temperature of drying (81°C) to the probable structual and chemical changes in the drying beet and the existence of internal temperature gradients which were not observed at lower temperature.

Cube Size = 10mm

Time (mins)	seconds	$40^oC = 313^oK$, $D = 3.8253x10^{-10}$, $D_{40^o} = 3.8200x10^{-10}$ Cube Weight EXP	CAL D_{40}	$54^oC = 327^oK$, $D = 7.8805x10^{-10}$, $D_{54^o} = 8.3950x10^{-10}$, $D_{49^o} = 6.3870x10^{-10}$ Cube Weight EXP	CAL D_{54}	CAL D_{49}	$60^oC = 333^oK$, $D = 1.1010x10^{-9}$, $D_{60} = 1.1530x10^{-9}$, $D_{55} = 0.8858x10^{-9}$ Cube Weight EXP	CAL D_{60}	CAL D_{55}	$65^oC = 338^oK$, $D = 1.5360x10^{-9}$, $D_{65} = 1.4890 x 10^{-9}$, $D_{60} = 1.1530x10^{-9}$ EXP	CAL D_{65}	CAL D_{60}
0	0	1.715	1.589	1.404	1.262	1.279	1.605	1.406	1.429	1.31	1.128	1.148
2	120											
5	300	1.615	1.521	1.311	1.187	1.212	1.415	1.303	1.337		1.035	1.064
10	600	1.549	1.448	1.250	1.109	1.142	1.320	1.198	1.242	1.14	0.941	0.978
15	900	1.497	1.394	1.195	1.054	1.092	1.244	1.124	1.174	0.97	0.876	0.918
20	1200	1.448	1.351	1.152	1.010	1.052	1.185	1.067	1.120	1.02	0.827	0.871
30	1800	1.399	1.282	1.083	0.942	0.988	1.097	0.979	1.037	0.92	0.752	0.799
40	2400	1.322	1.227	1.024	0.890	0.939	1.021	0.914	0.974	0.79(45)	0.698	0.746
50	3000	1.275	1.181	0.974	0.849	0.899	0.957	0.863	0.924		0.657	0.704
60	3600	1.239	1.142	0.931	0.814	0.865	0.908	0.821	0.882	0.72	0.624	0.671
80	4800		1.076	0.864	0.759	0.811		0.758	0.816	0.63(75)	0.577	0.619
90	5400	1.152	1.048		0.737	0.788	0.806	0.734	0.789	0.57	0.560	0.599
100	6000		1.023	0.807	0.717	0.768		0.713	0.766	0.56(105)	0.546	0.582
120	7200	1.083	0.978	0.765	0.686	0.734	0.731	0.681	0.729	0.55	0.526	0.556
140	8400		0.941	0.728	0.661	0.706		0.657	0.699	0.55(135)	0.513	0.537
150	9000	1.017	0.924		0.651	0.694	0.681	0.648	0.687	0.55	0.507	0.529
160	9600		0.908	0.696	0.641	0.683		0.640	0.677			
180	10800	0.962	0.879	0.670	0.626	0.664	0.648	0.628	0.659			
200	12000		0.854	0.650	0.613	0.648		0.619	0.645			
210	12600		0.842		0.608	0.642	0.632	0.615	0.639			
220	13200		0.831	0.633	0.604	0.635		0.612	0.634			
240	14400	0.875	0.811	0.618	0.596	0.624	0.629	0.607	0.626			
260	15600		0.793	0.612	0.589	0.614		0.604	0.619			
270	16200	0.841	0.785		0.586	0.611	0.620	0.602	0.616			
280	16800		0.777	0.609	0.584	0.606		0.601	0.614			
300	18000	0.812	0.763	0.607	0.580	0.600	0.617	0.599	0.609			
330	19800	0.782	0.744									
360	21600	0.767	0.729									
380	22800	0.761	0.719									
390	23400											

Table 3.6.3. Experimental Cube Weight for 10mm cube compared with the theoretically calculated cube weights using the theoretical diffusion coefficients at appropriate air temperature and at 5°C below the air temperature.

Cube Size 15mm

Time (mins)	seconds	40°C EXP	40°C CAL	54°C EXP	54°C CAL D_{54}	54°C CAL D_{49}	60°C EXP	60°C CAL D_{60}	60°C CAL D_{55}	65°C EXP	65°C CAL D_{65}	65°C CAL D_{60}
		$40^oC = 313^oK$ $D = 6.0159x10^{-10}$ $D_{40^o} = 6.016x10^{-10}$		$54^oC = 327^oK$ $D = 1.1257x10^{-9}$ $D_{54^o}=1.1674x10^{-9}$ $D_{49^o}=0.9274x10^{-9}$			$60^oC=333^oK$ $D=1.612x10^{-9}$ $D_{60}=1.5249x10^{-9}$ $D_{55}=1.2214x10^{-9}$			$65^oC=338^oK$ $D=1.8381x10^{-9}$ $D_{65}=1.8912x10^{-9}$ $D_{60}=1.5249x10^{-9}$		
		Cube Weight		Cube Weight			Cube Weight					
0	0	4.555		4.455			4.055			4.87		
2	120		4.271		4.098	4.135		3.665	3.704		4.351	4.401
5	300	4.359	4.116	4.247	3.905	3.961	3.750	3.457	3.515	4.51	4.077	4.151
10	600	4.216	3.949	4.101	3.701	3.775	3.523	3.238	3.314	4.52	3.792	3.888
15	900	4.097	3.826	3.960	3.553	3.639	3.385	3.081	3.170	4.26	3.589	3.700
20	1200	3.999	3.725	3.857	3.434	3.529	3.242	2.955	3.053	4.17	3.429	3.55
30	1800	3.845	3.564	3.670	3.246	3.355	3.050	2.761	2.870	3.91	3.181	3.316
40	2400	3.725	3.434	3.527	3.099	3.217	2.871	2.609	2.727	3.59(45)	2.991	3.134
50	3000	3.607	3.325	3.377	2.977	3.103	2.713	2.486	2.609		2.839	2.986
60	3600	3.525	3.229	3.264	2.874	3.004	2.597	2.382	2.508	3.28	2.718	2.861
80	4800		3.070	3.065	2.705	2.841		2.215	2.344	3.23(75)	2.511	2.661
90	5400	3.319	3.000		2.634	2.771	2.235	2.147	2.276	2.86	2.431	2.579
100	6000		2.937	2.903	2.570	2.708		2.086	2.215	2.68(105)	2.360	2.506
120	7200	3.158	2.825	2.765	2.460	2.599	2.136	1.983	2.109	2.57	2.244	2.382
140	8400		2.727	2.655	2.368	2.506		1.899	2.021	2.46(135)	2.153	2.282
150	9000	3.020	2.683		2.328	2.464	1.984	1.864	1.983	2.35	2.114	2.238
160	9600		2.641	2.550	2.290	2.425		1.831	1.947			
180	10800	2.864	2.565	2.463	2.224	2.355	1.866	1.775	1.884			
200	12000		2.496	2.380	2.167	2.294		1.729	1.831			
210	12600		2.464		2.142	2.266	1.766	1.709	1.807			
220	13200		2.434	2.309	2.118	2.240		1.690	1.785			
240	14400	2.635	2.377	2.243	2.076	2.193	1.692	1.658	1.745			
260	15600		2.326	2.185	2.039	2.150		1.632	1.712			
270	16200	2.570	2.301		2.023	2.131	1.651	1.620	1.697			
280	16800		2.278	2.136	2.008	2.113		1.610	1.682			
300	18000	2.452	2.235	2.096	1.981	2.080	1.600	1.592	1.657			
330	19800	2.374	2.176									
360	21600	2.307	2.124									
380	22800	2.285	2.093									
390	23400											

Table 3.6.4. Experimental Cube weight for 15mm cube compared with the theoretically calculated cube weights using the theoretical diffusion coefficients at appropriate air temperature and at 5°C below the air temperature.

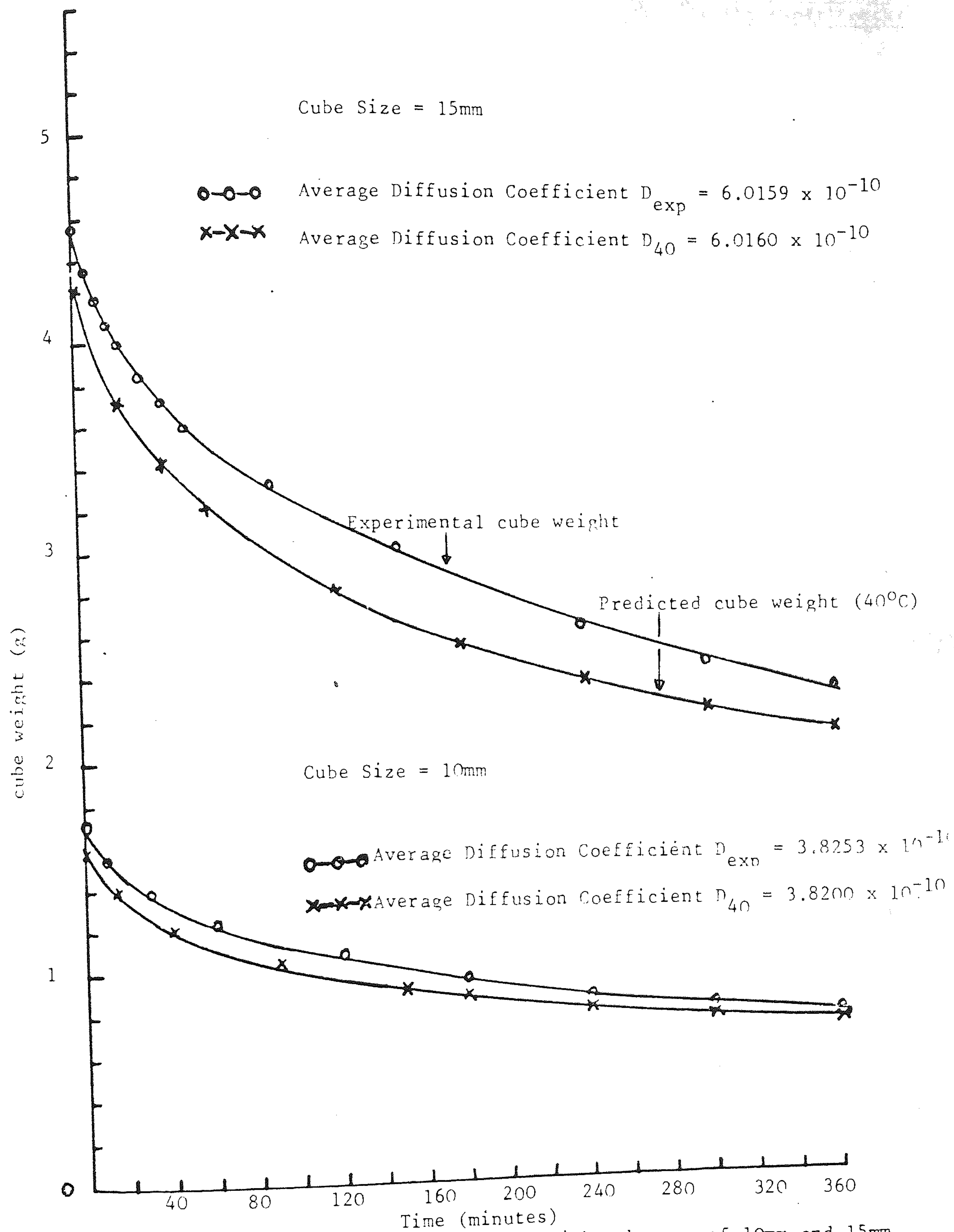


Figure 3.6.5 Comparison of predicted weight changes of 10mm and 15mm plantain cubes with the experimental results obtained at dry bulb temperature 40°C

Figure 3.6.6 Comparison of predicted weight changes of 10mm and 15mm plantain cubes using average diffusion coefficients calculated at temperatures 49° and 54°C with the experimental results obtained at dry bulb temperature 54°C

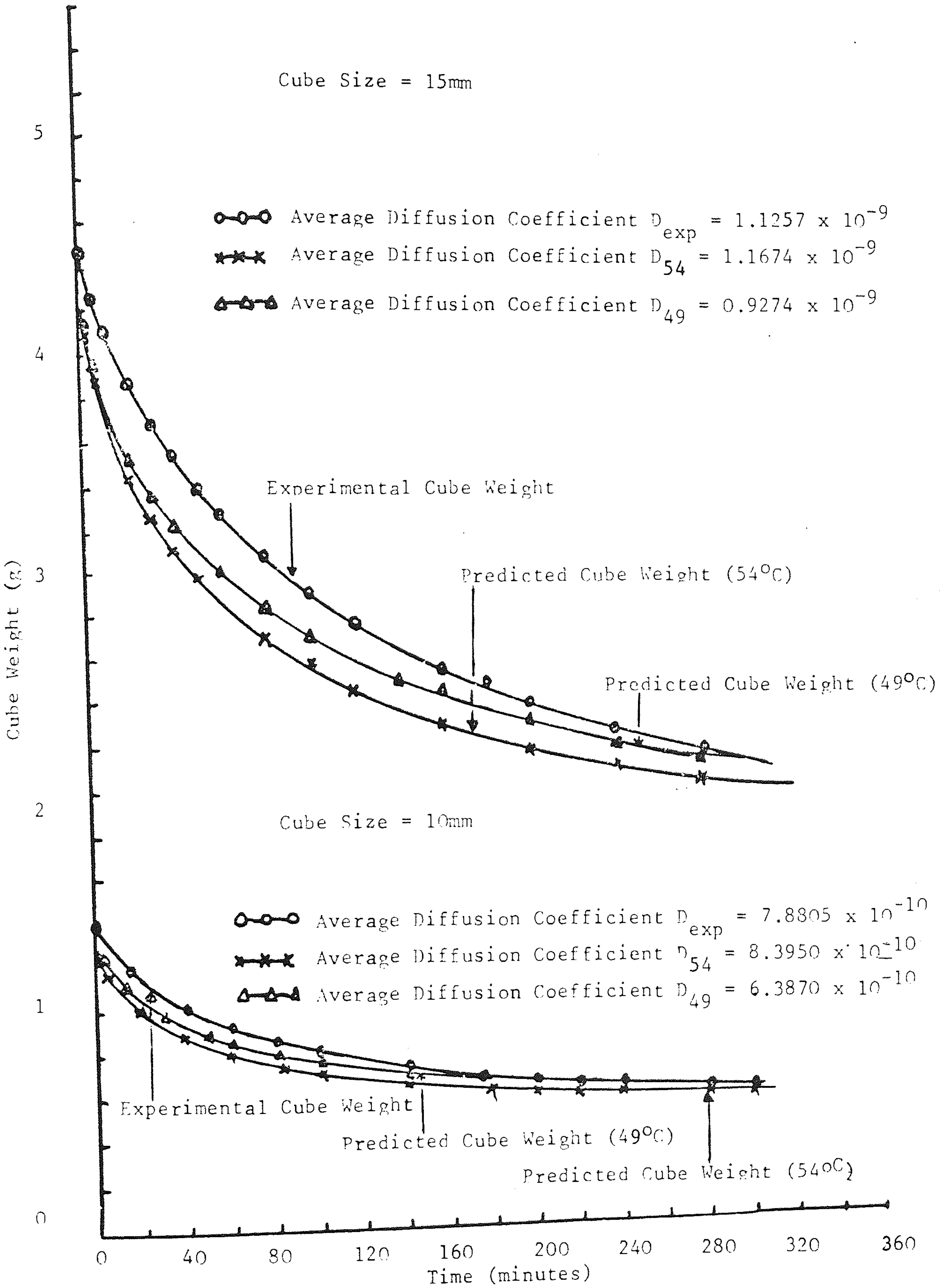


Figure 3.6.7 Comparison of predicted weight changes of 10mm and 15mm plantain cubes using average diffusion coefficients calculated at temperatures 55° and 60°C with the experimental results obtained at dry bulb temperature 60°C

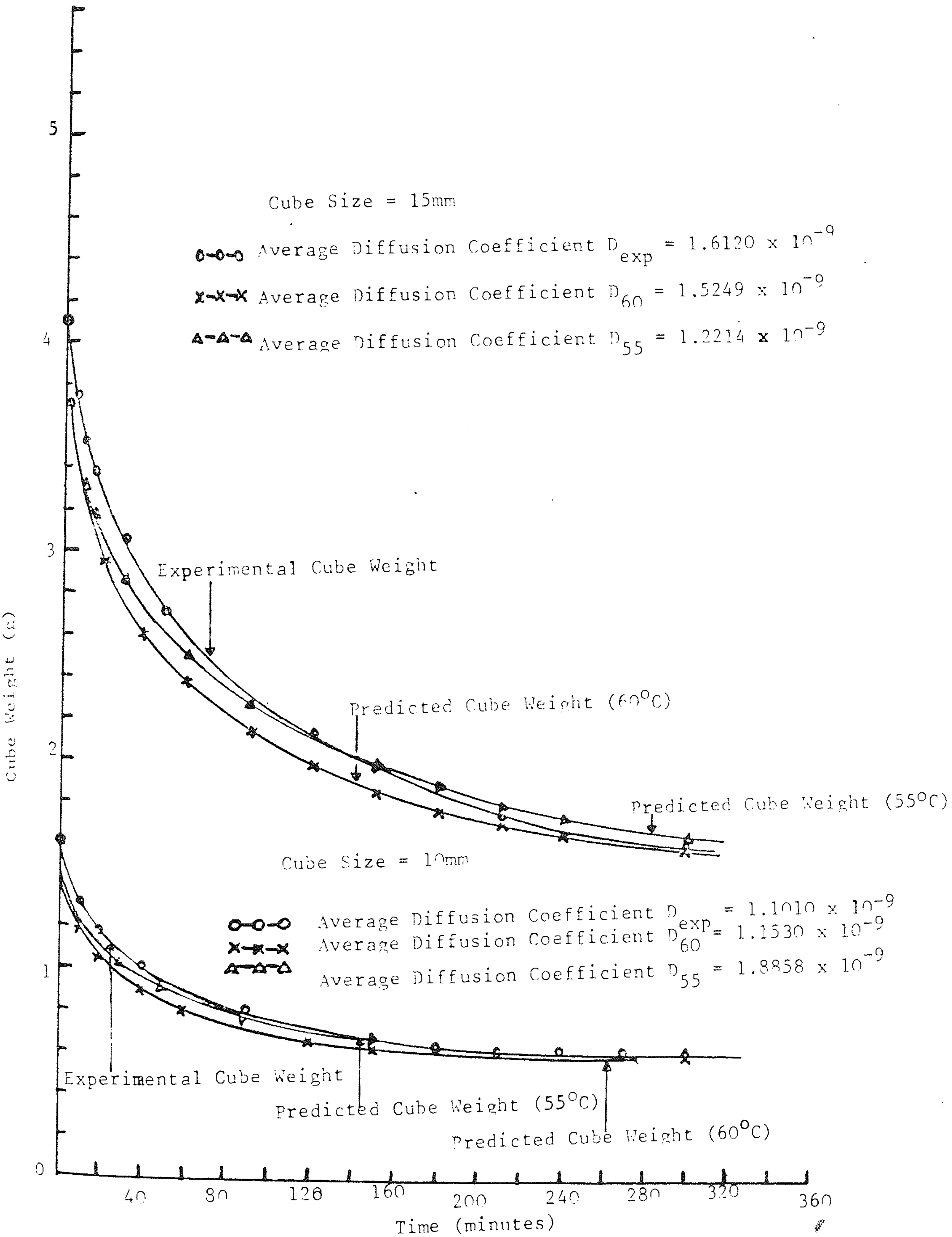
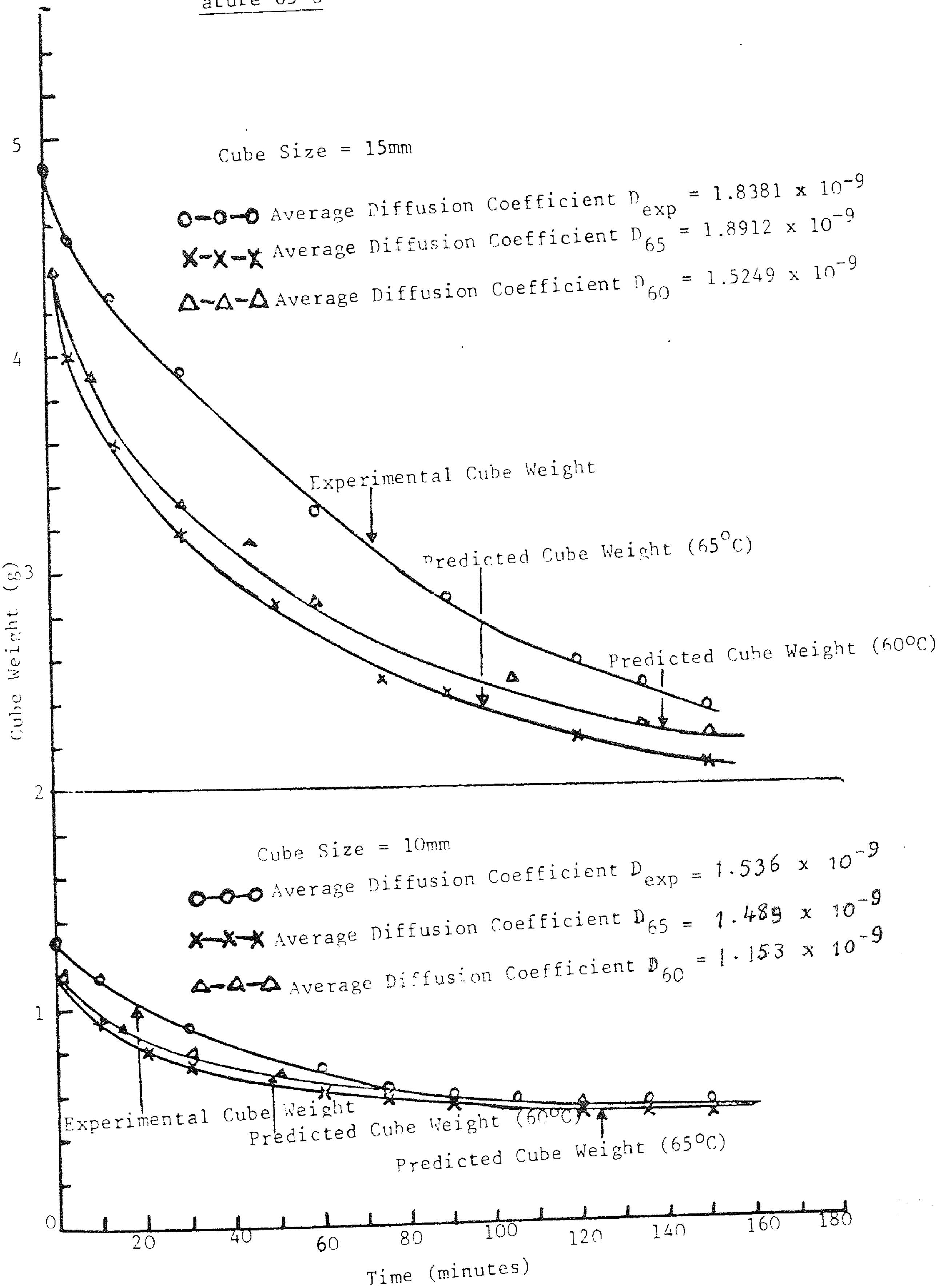


Figure 3.6.8 Comparison of predicted weight changes of 10mm and 15mm plantain cubes using average diffusion coefficients calculated at temperaturs 60° and 65°C with the experimental results obtained at dry bulb temperature 65°C



The apparent discrepancy in the findings of different authors may be due to the following:

1. The surface temperature of the drying material is lower than the air temperature until about 90% of the initial moisture content is evaporated (figure 3.5.2; Vaccarezza et al 1974). There is a need to use the average mean surface temperature for the calculation of the average diffusion coefficient instead of using the air temperature. Alzamora et al,(1979), calculated the diffusion coefficient at a mean average temperature of 67°C for 5.5mm thick apple slabs dried at air temperature of 71°C. When an average mean surface temperature of 55°C was assumed in the present work for both 10mm and 15mm cubes dried at 60°C, APP- 3.13 , better agreement was obtained, (figures 3.6.7, 3.6.9, 3.6.10). Vaccarezza et al,(1974), recognising this variation in the product temperature with time, introduced a variable equation in a dimensionless form which he solved numerically and incorporated in the diffusion model. However, it is beyond the scope of this work to investigate his equation.

2. In the development of equation 3.2.5, it was assumed that the diffusion coefficient is constant. However, table 3.6.3 shows that the diffusion coefficient decreases with time and hence with decreasing moisture content. This agrees with the finding of Chirife (1971). The use of an average diffusion coefficient for the moisture range 1.0 - 0.1, (Saravacos and Charm 1962) means that at the initial stage of drying, the diffusion coefficient would be underestimated and over estimated at the last stage of drying. This was shown in figures 3.6.7, 3.6.9 and 3.6.10, where the diffusion coefficient at 55°C was used

Figure 3.6.9 Comparison of predicted and experimental moisture changes of 10mm plantain cube dried at dry bulb temperature 60°C

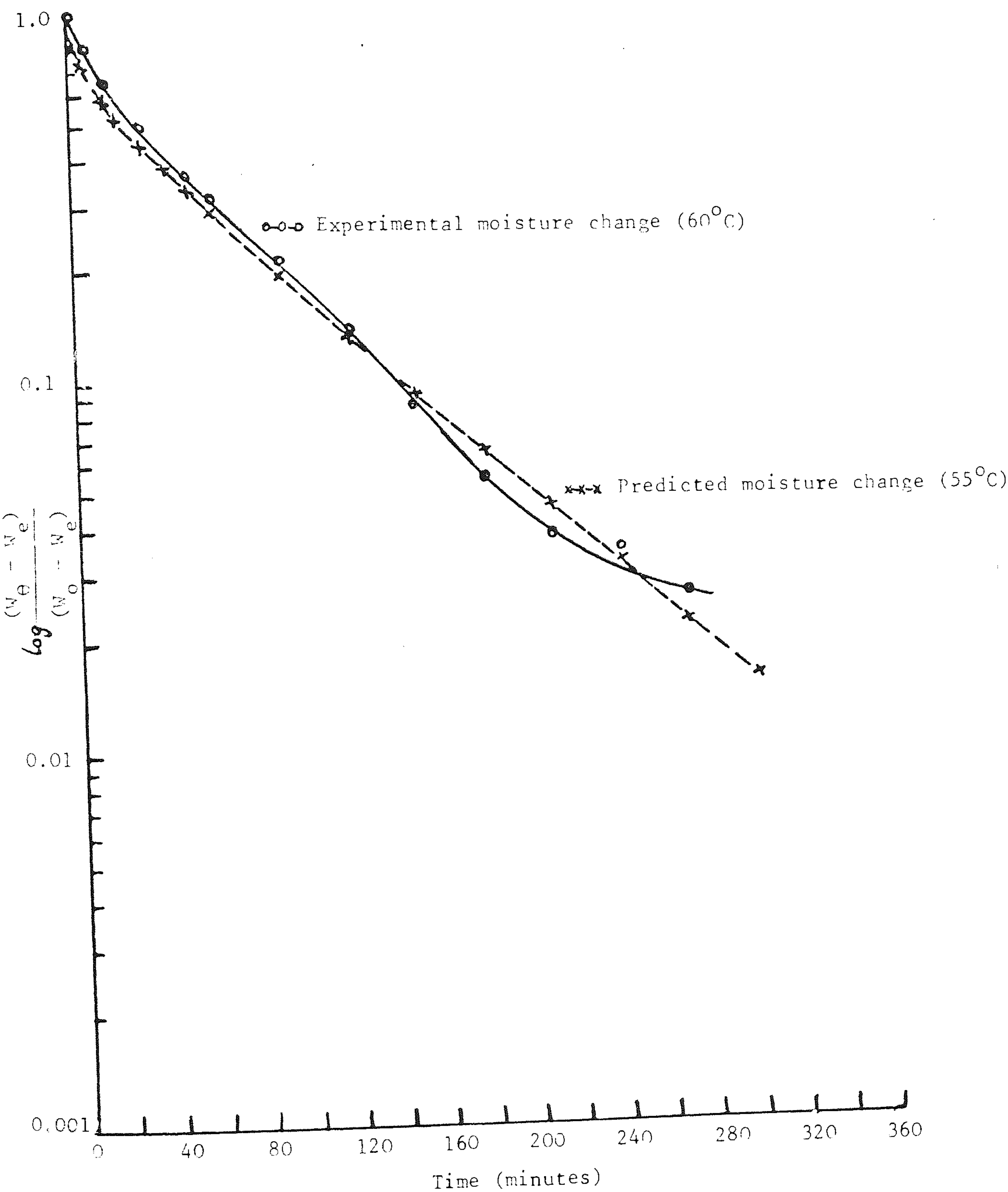
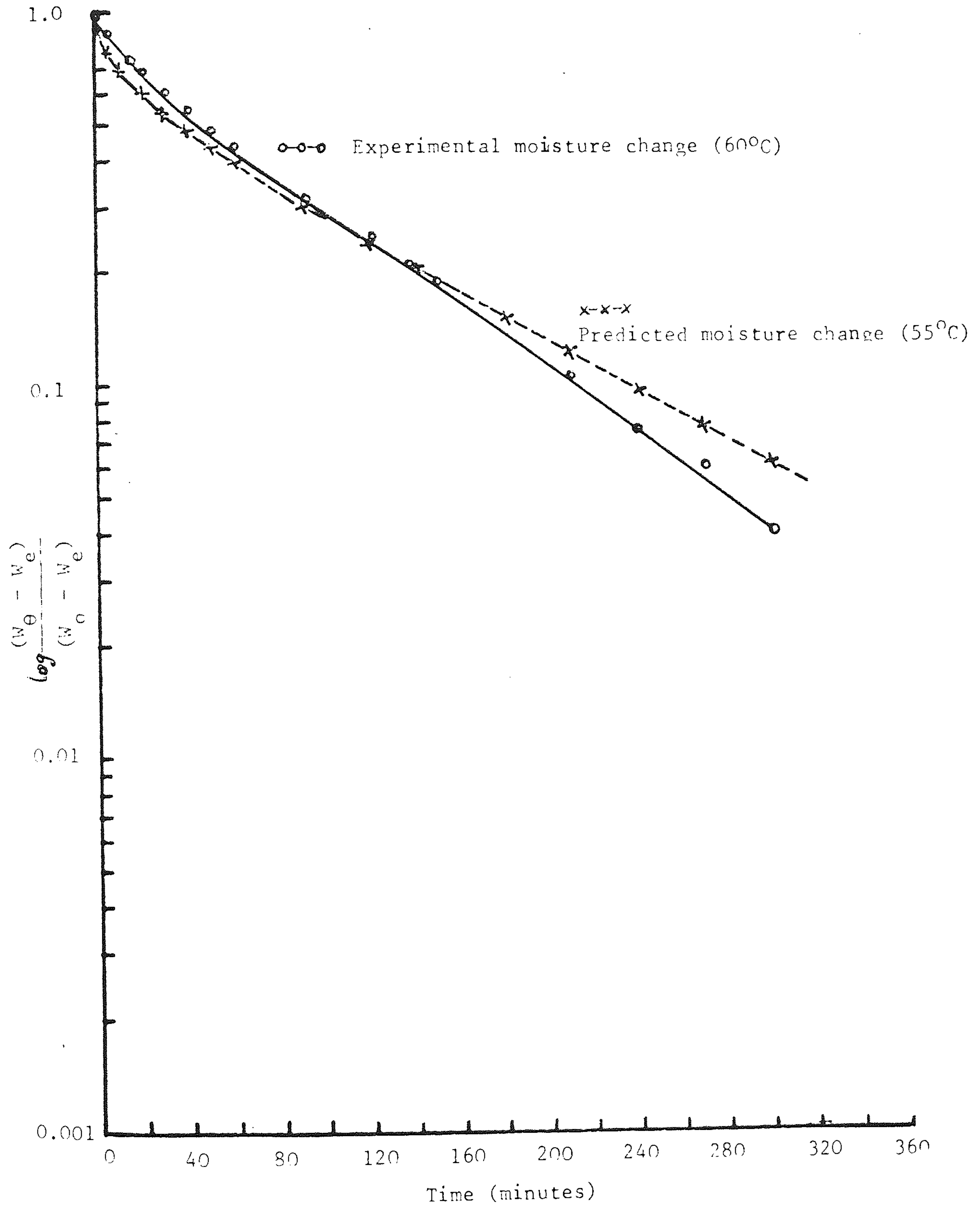


Figure 3.6.10 Comparison of predicted and experimental moisture changes of 15mm plantain cube dried at dry bulb temperature 60oC



instead of at the air temperature of 60°C.

3. The use of wrong value for the material weight at the begining of the falling rate period. (ie the critical moisture content W_c) when a mixed drying mechanism is obtained at the beginning of the drying operation could result in disagreement between the experimental and theoretical values. In the drying of plantain cubes, the surface of the cube was wet for a very short period which was not enough time to constitute a constant rate period, (section 3.6.1, figure 3.6.2). The critical moisture content range was therefore prolonged, (figure 3.2.1) and the actual falling rate period started when the material weight was below the initial weight. Therefore the use of initial material weight (Wo) in the equation 3.2.5 instead of the appropriate critical weight (W_c) will definitely introduce some error.

4. When the drying time becomes large, a limiting form of equation 3.2.5. is obtained when n = o giving rise to equation 3.2.6. The use of the first term only of the series has been found in this project to be the cause of the initial disagreement between the experimental and theoretical weight. Therefore more than one term would be needed for the calculation of the theoretical weight which the summation $\ln(W_c-W)/(W_c-W_e)$ in equation 3.2.5. predicts as shown in the sample calculation done manually for 10mm and 15mm cubes dried at 60°C, (APP-3.2) In the computation carried out for plantain cubes, all the terms having values up to 10^{-7} were included and presented in tables 3.6.3, and 3.6.4.

All the reports in the literature compared the fractions of evaporable water remaining in wet material being dried as a function of time. Figures 3.6.9 - 10 compare the experimental and theoretical values for plantain cubes and they show good agreement after about one hour of drying.

It is now evident that the diffusion model based on the Fick's law cannot be used to predict the drying time correctly during the early part of the drying period without due consideration given to the time dependence of temperature and temperature dependence of the diffusion coefficient, (Vaccarezza et al 1974). In a commercial drying operation, however, the total drying time is one of the most important factors to be considered in the design or selection of dryers.
In the case of plantain cube drying, if an average mean surface temperature is used for the calculation of the average diffusion coefficient, the total drying time required to reduce the moisture content to about 9% of the initial moisture content can be accurately predicted using the modified form of Fick's law (equation APP-3.1)
Also a better agreement would be obtained at air temperature above 60°C.

3.7. CONCLUSION

1. The heat transfer coefficient for aluminium cube heating was found to be 52 $W/m^2{}^oC$ and 45.3 $W/m^2{}^oC$ for 15mm and 10mm respectively at 2.9 m/s air velocity and the value for 15mm cube agrees well with the empirical formula for a 15mm diameter sphere. The values should also hold for the plantain cube heating having the same geometry. Any reduction in the rate of heat transfer can be quantitatively attributed to the rise in surface temperature of the cube alone. The mass transfer coefficient for a 15mm plantain cube is 0.061 m/s at 2.9m/s air velocity. The external surface resistance of 16.4.s/m is negligible when compared with the internal resistance of 3.1×10^6 s/m. The external surface resistance should not affect the drying rate during the falling rate period.

2. The surface temperature of the plantain cubes was found to be below the air temperature at the early part of drying and rose continuously as drying progressed until the dry bulb temperature was reached. There was no constant rate drying period as the surface temperature was never constant and the graph of fractional rate of water desorption as a function of mean moisture content showed a continuous fall in the drying rate.

   The effects of increase in air velocity are the increase in the heat transfer coefficient and the continuous decrease in the external resistance to mass transfer. Increase in surface temperature of the cube will increase the rate of water evaporation from the cube surface. Since the effective external resistance to mass transfer for water vapour is small when compared with corresponding internal resistance for the velocity range 1-5 m/s, the choice of optimum air velocity will depend on the cost of energy required for the fan power.

Increase in temperature reduces the drying time but care should be taken to avoid case hardening effects at very high drying temperatures, which result in a lower drying rate. Plantain starch has a gelling point temperature of 71^{o}C. If plantain pulp is dried at a temperature above 75^{o}C, the resultant flour will be pregelatinised but if dried at a temperature below 70^{o}C a non-gelatinised flour is produced. Since the surface temperature of the drying cube is initially well below the dry bulb temperature, the dryer could be operated at a higher temperature initially and the temperature reduced to the appropriated level after about 90 minutes of drying.

3. Smaller plantain cubes have a faster rate of drying but the drying time was not inversely proportional to the square of the thickness when 5mm, 10mm and 15mm were dried simultaneously. The rate of drying was faster for single cubes than for a single layer of similar cubes packed in a tray.

4. The drying of plantain cubes is diffusion controlled for about 80% of the total time for the drying operation and there is no effective constant rate period. The diffusion coefficients increased with temperature for a particular size and also with cube size for a given temperature in the first falling rate period. The values for 10mm cube lie between 3.8×10^{-10} and 14.9×10^{-10} m^2/s for a temperature range between 40^{o} and 65^{o}C. The values for 15mm cube for the same temperature range

lie between 6 x 10^{-10} and 18.9 x 10^{-10} m^2/s. The values of activation energy were 47.8 kJ mole and 40.3 kJ/mole for 10mm and 15mm cubes respectively. The values of the diffusion coefficients and activation energies agree reasonably with the figures published in the literature (table 3.1).

The effect of evaporative cooling is greater on the thinner sample and a smaller sample has higher activation energy than a larger sample. This results in the rate of diffusion being faster in the larger cube. Choice of the optimum cube size for commercial drying would aim to maximise material throughput and is discussed in chapter 4.

5. Observed variation in the diffusion coefficient values during the course of a drying experiments may be caused in part at least, by changes in the cube temperature accompanying the progressive fall of the drying rate. For the best prediction of drying rates the diffusion coefficient should not be calculated at the air temperature but at the average surface temperature which is assumed to be about 5°C below the air temperature for plantain cubes.

The cube weights calculated from diffusion coefficient determined at a temperature 5°C below the air temperature agreed closely with the experimental weight after about one hour drying at air temperature of 60°C. At lower drying temperatures the theoretical values were below the experimental values throughout the period of drying. Any predicted drying time made using the modified diffusion equation APP-3.1 which was based on Fick's law could be a serious underestimate unless due consideration is given to the very low surface temperature of the cube at the initial stage of drying.

6. There are discrepancies in the findings of different authors as to the adequacy of the drying model for food drying rates and temperatures. Possible causes of disagreement in the findings have been given in points 1 -4, section 3.6.4.

In a commercial drying operation the total drying time can be fairly accurately predicted using the modified diffusion equation,

$$\frac{W_\theta - W_e}{W_c - W_e} = \left(\frac{8}{\pi^2}\right)^3 \left\{ \exp - \frac{9\pi^2 D\theta}{16L^2} + \frac{1}{3} \exp - \frac{41\pi^2 D\theta}{16L^2} + \frac{1}{27} \exp - \frac{105\pi^2 D\theta}{16L^2} + \right\}$$

for plantain cubes when the mean surface temperature is used for the calculation of the average diffusion coefficient and air temperature above 60°C.

CHAPTER 4

Plant Design for Plantain Flour Production

4. Plant Design for Plantain Flour Production.

4.1. INTRODUCTION

Plantain processing to produce flour involves the processes represented in figure 4.1. There are three routes through which plantain could be processed into flour. Route 1 involves peeling, slicing, tray or cabinet drying, milling and sieving to produce flour. Route 2 involves blanching with hot water, to loosen the peel, and fluidised bed drying; otherwise the process is the same as in route 1. The processes in routes 1 and 2 could be combined by drying the plantain pieces for about 2 hours in a tray dryer followed by fluidised bed drying to the desired final moisture content. In route 3 the plantain is steam blanched and expressed. Water is added to homogenise the slurry which could be dried using either a spray dryer, votator, drum dryer or extruder. For the extrusion process, no water need be added, as plantain contains about 60% water by weight and this lies within the minimum concentration of water necessary for the formulation of extrudate. The drying in route 3 is a high-temperature short-time process, operating above 100°C. The technology involved in the processes encountered in route 3 may be classified as advanced. Steam production is necessary and the operation of the capital equipment requires trained technicians. In the case of any breakdown, spare parts may not be easy to obtain. The initial capital cost may be high as all the equipment may have to be imported. The technology involved in routes 1 and 2 may be classified as intermediate. The operation of either a tray or fluidised bed dryer is fairly simple and most of the equipment could be constructed locally. The fluidised bed route will require a larger blower with a greater

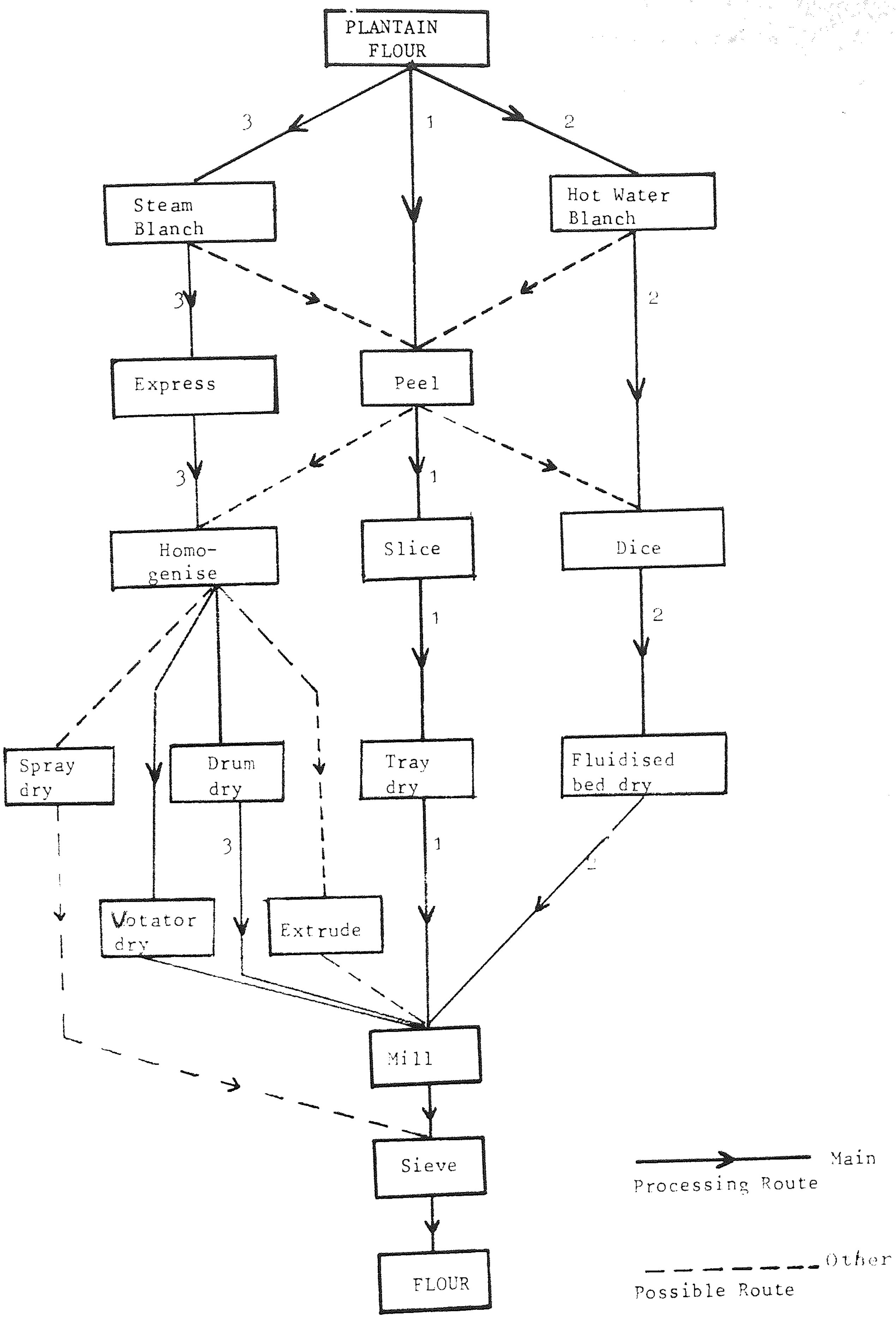


Figure 4.1 Alternative Routes to Process Plantain to Flour

throughput than the tray dryer and would be seriously affected by breakdown of the blower. Either process is labour intensive and could reduce unemployment in the rural areas. The drying process affects directly the quality of the flour produced. Pregelatinised flour is produced when processes in route 3 are employed. Drying plantain cubes in either tray or fluidised dryer could yield pre- or non-gelatinised flour.

The selection of an appropriate dryer for the drying of plantain requires equipment trials under conditions closely related to the heating and handling conditions to be encountered in practice. In addition to the difficulty of predicting drying rate curves, questions arise concerning variation of drying conditions through dryer, air flow pattern and effect of operating variables and choice of equipment upon the condition of the dried product. Also the usual economic factor of processing cost must be considered in relation to the most desirable product condition from a sales point of view, (Foust et al 1980).

Where possible, moisture contents and temperatures should be measured at various points within the dryer. The completeness of the information which is sought in any given test depends on the ultimate use of the data. In any case data for at least two sets of operating conditions are needed if a good analysis of dryer performance is to be made. The following factors should be considered in the preliminary selection of dryers,

1. Properties of the material being handled

2. Drying characteristics of the material

3. Flow of material to and from the dryer

4. Product quality

5. Facilities available at site of proposed installation

The physical nature of the material to be handled is the primary item for consideration. A slurry will demand a different type of dryer from that required by a solid which in turn will be different from that required by a sheet of material, (Perry and Chilton, 1973).

For plantain pulp drying, plant trials were carried out on drum and cabinet dryers. For the drum dryer, the factors affecting the drying rate and the final moisture content of the flour were investigated. These include the speed of rotation of the drum which controls the contact time, the steam pressure, and the film thickness on the drum. For the cabinet dryer, the effects of temperature, tray loading and sample geometry on the rate of drying were investigated. From these trials, the overall performance data were obtained. The results will be used to establish the optimum operating conditions, product quality and characteristics and dryer size.

4.2 Literature Review

Pretreatment and Peeling

Green Plantain and banana pulp are similar in texture and are both starchy staples. Roudier and Lavollay,(1945) described the modern methods used in French Africa in which the plantain and banana fruits were dried in tunnel dryers operated at temperatures between 58° and 69°C. They recommended sulphuring the fruits to prevent discoloration, using 200 mg of sulphur dioxide per 100g of fruit. Da Silveira (1946) studied the discoloration of the ripe banana flour prepared by a drum-drying method and recommended dipping the fruit in a solution of one percent citric acid instead of sulphuring before dehydration. Von Loescke,(1955), pointed out that ripe bananas have been sun-dried, drum-dried, spray-dried and dried in cabinet dehydrators. Of these, drum-dried banana flakes seemed most commercially promising. Rahman,(1963) dried plantain cubes using trays in a Proctor and Schwartz cabinet dehydrator at dry bulb temperatures varying from 93° to 71°C. He established that hand peeling and slicing yielded between 25 and 28 percent of flour after drying. The unpeeled fruit yielded , after treatment with potassium metabisulfite, 31 to 32 percent of flour. Inspite of the higher yield obtained with the unpeeled fruit, one would expect to process peeled fruits for the production of flour of acceptable colour.

Samish and Coussin,(1965), studying the production of dehydrated flakes as a means of utilising surplus banana, found that blanching bananas before drying improved the product and the addition of SO_2 improved its colour.

Effect of Temperature:

Chirife(1971) dried tapioca beds in a temperature range 55-100°C and found that increase in temperature reduced drying time but stressed that the choice of optimum working temperature must be made considering the effect of temperature on the physico-chemical characteristics of the dried product. Slices of tapioca, a starchy staple like plantain, were scorched at temperatures of 84° or higher. Archapong and Wieneke(1977) reported that drying of 15 mm plantain cubes at temperatures above 85°C resulted in considerable shrinkage and hardening of cube surfaces.

Effect of tray loads

Van Arsdel and Copley(1964) studied the drying rates in well designed cross-flow tray dryers and found that once a single layer of pieces is spread on a tray, the active evaporating surface is increased only slightly by adding to the load so that it is 2,3 or 4 pieces deep. Consequently, increasing the total loading per square metre reduces the gross drying rate materially during the early stages of drying. As the drying proceeds, the material on the trays shrinks and the structure of the layer on the trays becomes more and more open and relatively thinner so that drying takes place throughout the whole layer. The maximum dry output when shredded cabbage was dried in a counterflow tunnel was obtained at a tray load of about 7.3 kg/m^2. Chirife and Cachero(1970) found that, although the maximum bed depth was 120mm, the output was highest at the bed depth of 70mm. Edelmiro et al (1977) studied the effect of tray loading on the time required to reduce the moisture of 12 x 10 x 6.5 mm green banana cubes to 10% of the original value. He found that it took 3 hours to dehydrate the cubes when placed in a single layer (9kg/m^2) and 6 hours when the tray was completely filled with the cubes($33kg/m^2$) . In other words, the overall rate of drying based on weight loss for 6 hours operation was 5.5 kg/m^2hr which was greater than the rate of $3kg/m^2hr$ for 3 hours operation. He claimed that initially the problem was with the difficulty of hot air in passing and water escaping through the successive layers of banana cubes. However, as dehydration progressed, the shrinkage of banana cubes reduced their volume, increasing air spaces and permitting the hot air to pass more easily through the layers of cubes, thus facilitating the removal of water.

Therefore, increase in tray loading increases the throughput to a certain limit after which further increase will not result in significant increase in output. It is important to establish the optimum tray loading for optimum output of dried product.

The literature contains little about the commercial dehydration of banana or plantain pulp with a view to designing or selecting a suitable dryer. It is a wide practice to blanch fruits or use additives to help improve the colour of the end product. In the present work, it was found that hot water blanching for about 10 minutes facilitates peeling by softening the peel for easy removal and that good quality flour could be produced without additives.

4.3. Plant Trials

4.3.1. Pilot-Scale Production of Plantain Flour Using Roller, Double Cylinder (Nip Fed) and Tubular Dryers:

The trial was carried out at Richard Simon & Sons, "Dryer Division" No.8. Factory, Private Road No. 3, Colwick Industrial Estate, Nottingham, NG4 2BT, UK. Tel: 0602-249881; Telex 37454. The objectives were to study the effects of the speed of rotation of drum and steam pressure on the drying of green plantain slices to produce flour.

Experimental Procedure and Results:

15 kg of green plantain was used for the trial and detailed report on the individual equipment trial is given in the appendix (APP-4.1). Table 4.1 summarises the experimental conditions and the results.

Conclusions from the trial:

Thin plantain slices could be dried in a double cylinder dryer to produce dried bands which could be milled to flour of desired particle size. For the production of a good product with required moisture content, there is need for proper adjustment of the cylinder speed and pressure. For every kilogram of water evaporated, 1.4kg of steam is used and to obtain good performance, economically it is necessary to run it for a minimum of 14 hours a day. Blanching the plantain in hot water for about 15 minutes resulted in much darker product while unblanched green plantain slices gave a light coloured plantain flour.

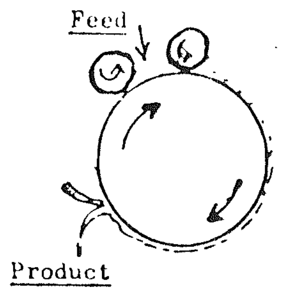
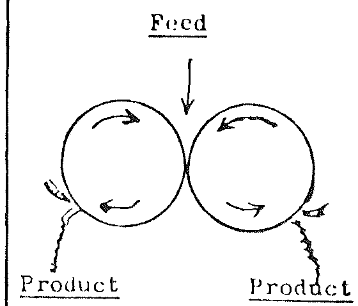
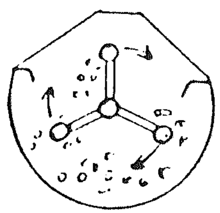
Dryer Name	Diagram	Roller Speed (rpm)	Steam Pressure (psi)	Feed Rate (kg/h)	Feed State.	Inlet moisture content	Outlet m.c.	Remarks
(Twin) Roller Dryer		4.5	90	4.9	Slices	58 %	10 %	Uneven film on drum, uneven drying.
		2.6	80	5.8	Lightly Mashed	58	7	Improved, but still uneven film and drying.
Double Cylinder Dryer. (Nip Feed)		13.3	90	7.4	Slices	58	5	Well formed, light yellow band. Rather too dry.
		13.3	90		Slices, 15 min blanch	58		Too dry
		15.7	90	about 12	Slices, 15 min blanch	58	8	Well formed, yellow band. Good throughput
Tubular Dryer.		-	75	1.2kg Feed	Thin Slices	58	-	Sticking to metal surfaces. Dark, uneven product

TABLE 4.1. SUMMARY OF DRYING TESTS

4.3.2. Pilot-Scale Drying of Plantain Pulp Using Cabinet and Simulated Band Dryers

The trial was carried out at APV Mitchell Dryers Ltd, Denton Holme, Carlisle, Cumbria, England, CA2 5DU. UK: Tel: 0228 34433; Telex: 64139.

The objectives were to assess the drying performance of both Cabinet and Simulated Band Dryers for plantain cubes and slices in order to establish the best operating conditions that will give good quality product.

Experimental Proceedure:

30 kg of green plantain was used for the tests and the detailed report on the individual equipment trial is given in the appendix (APP-4.2). The data collected from the trial runs on the Cabinet Dryer will be analysed in section 4.3.3.

Conclusion from the trial:

A Cabinet Dryer is the best equipment to handle the proposed throughput of 3500kg plantain pulp per day. Dicing of plantain pulp produces more uniform 10mm cubes than slicing. Drying two or three layers of slices resulted in slices sticking together to form single thick layer, thereby reducing vapour diffusion.
The use of perforated trays greatly reduced the tray wetness and improved the rate of drying. There was no significant difference between the colour of the products obtained after drying at 67° and $77^{\circ}C$ for single and second layer tray of cubes and slices. Inspite of the obvious significant improvement in the colour of the products produced in a simulated band dryer, the capital cost of the equipment as well as the throughput requirement for economic operation are thought to be too high for the proposed

throughput for plantain drying.

4.3.3. Data Analysis and Discussion of Results from Drying Tests in Cabinet Dryer

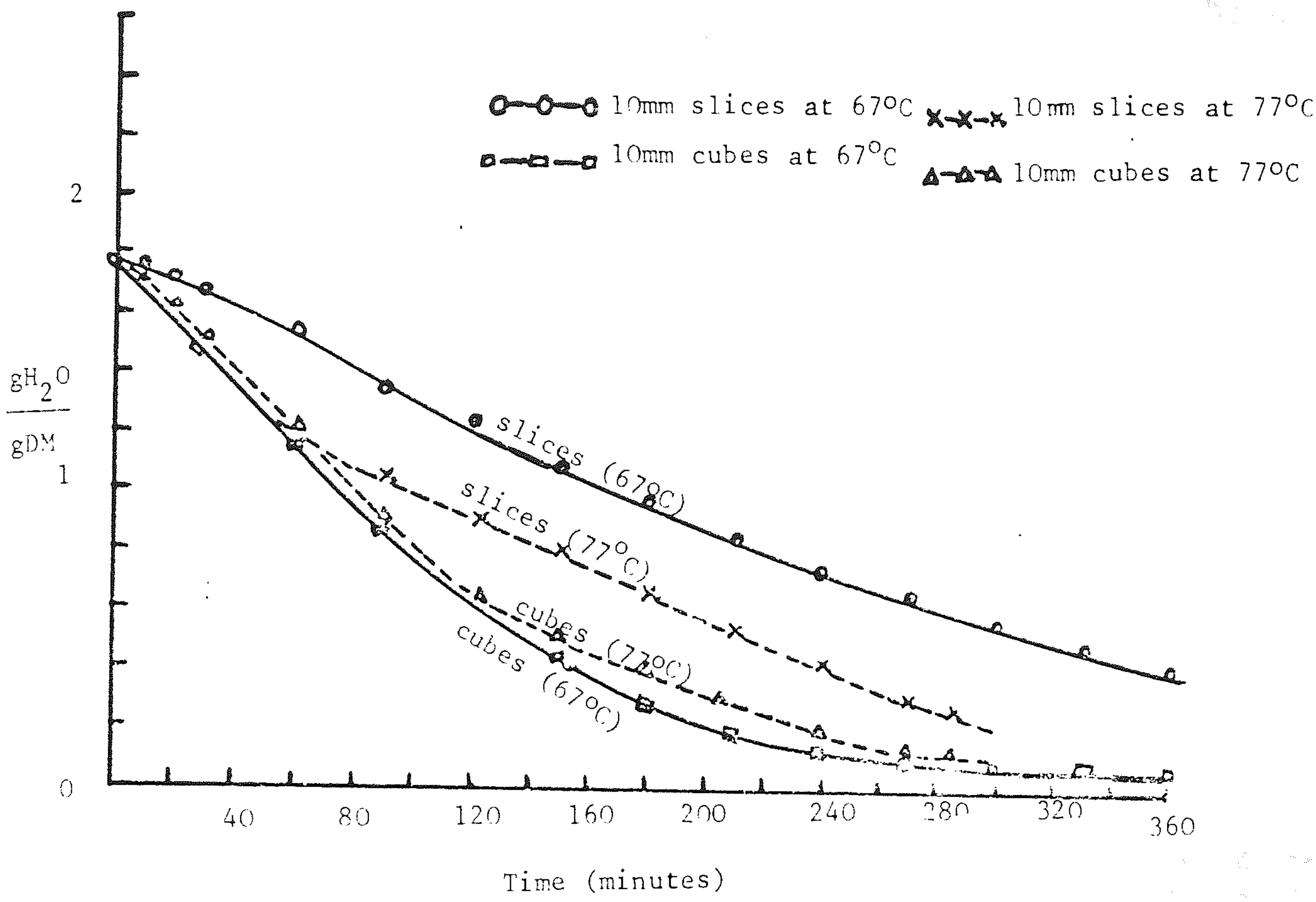
4.3.3.1. Geometrical Effect on the Rate of Drying of Plantain Pulp

The data for the analysis of the effect of sample geometry on the rate of drying is given in table APP-4.3 for 10mm cubes and slices. The moisture content of the plantain was 64% and the water content (dry basis) was plotted against drying time as shown in figure 4.2. The rate of drying was faster for cubes than the slices of the same thickness at both temperatures of drying. The 10mm slices were not uniformly sliced and there was evidence of wetness on the side of the slice facing the tray. In addition, slices tend to stick together when more than one layer is required to be dried, thereby resulting in slower rate of drying because of reduction in vapour diffusion.

4.3.3.2. Effect of Temperature on the Rate of Drying:

The data showing the effects of temperature is shown in table APP-4.4/4.5. Figure 4.3.shows that the rate of drying of a single layer tray 30cm x 20cm x 2cm was faster at 67°C than at 77°C. When the tray was filled to a double layer, the rate was faster at 67°C than at 77°C for the first 150 minutes before the trend changed and the rate became faster at 7°C that at 7°C. However, when the tray was filled to three layers, the rate of drying was faster at 77°C than at 67°C throughout the period of drying. In the single layer tray, the cubes probably suffered from case hardening effect at 77°C because the rate of evaporation

Figure 4.2 Geometrical effect on the rate of drying of plantain pulp



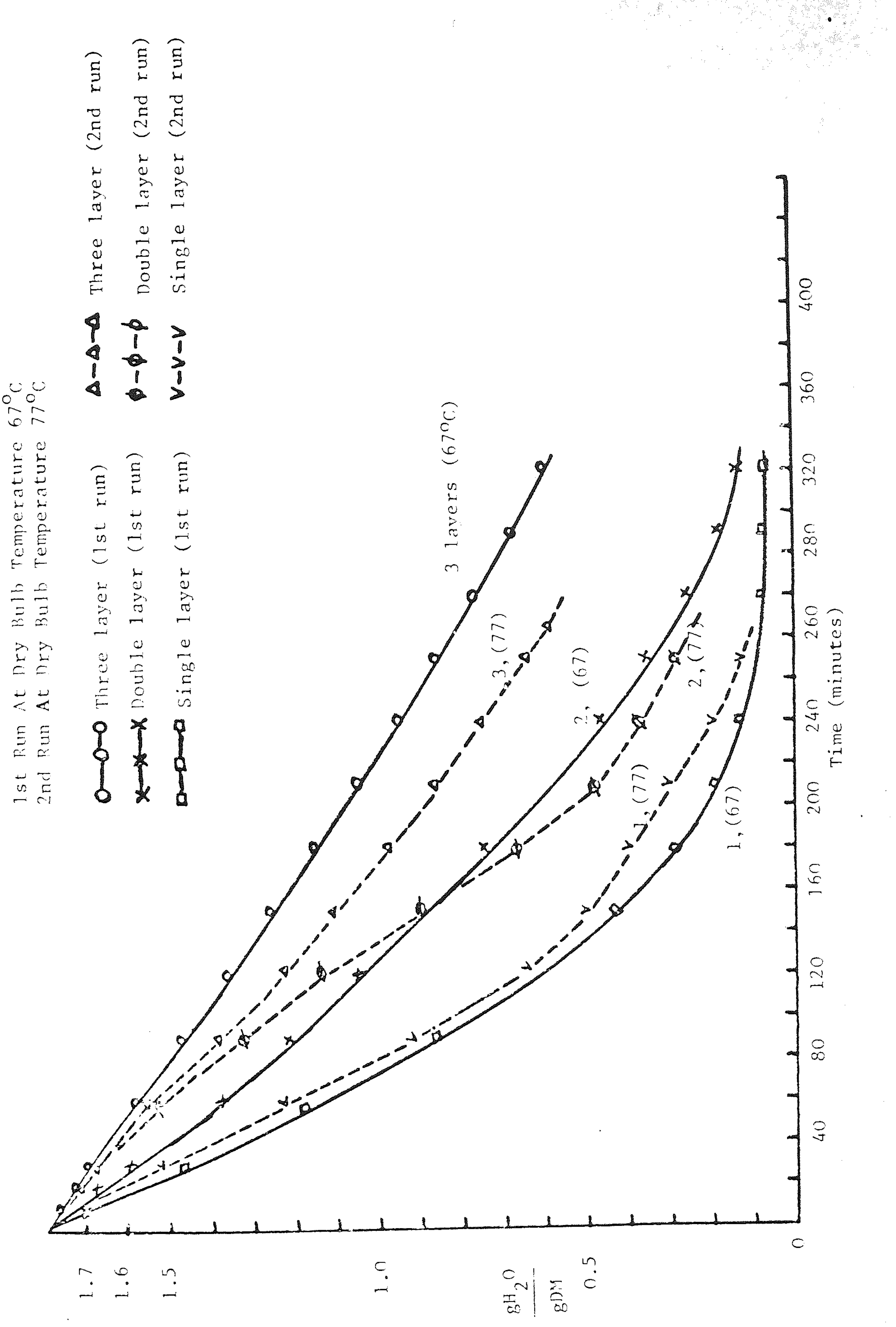


Figure 4.3 Effect of tray loading and temperature on the rate of drying of 10mm plantain cube

was not matched by the rate of water diffusion from inside the cube. The resultant effect was that the drying rate was less than at 67°C from the start of drying. That the rate of drying of single layer cubes was faster at 67°C than at 77°C could also be due to some faulty temperature recording . In the double layer tray, there was also the effect of case hardening at 77°C for the first 150 minutes of drying when some cubes shrank to create void space for water vapour to escape from the lower layer. This resulted in faster drying rate for the rest of the drying period. In the three layer tray, the top cubes suffered from case hardening effect and some of the cubes at the top appeared very dry at the end of the drying operation. However, the rate of drying was faster at 77°C than at 67°C eventhough some of the innermost cubes were still very wet at the end of the drying test. Drying plantain cubes in a tray at an air temperature below 70°C would give good drying rate with the resultant good end product which will also depend on the tray loading.

4.3.3.3. <u>Effect of Tray Loading on the Rate of Drying:</u>

The data showing the effects of tray loading is shown in APP-4.4,4.5. The rate of drying was fastest in a single layer tray and faster in a double layer tray than in three layer tray at any temperature of drying as shown in figure 4.3. It is usual to aim at a final moisture content about 10% for a good keeping quality of the dried product. In the drying of plantain cubes it took about 176 minutes for a single layer and 284 minutes for a double layer,(a ratio of 1:1.6) to reduce the moisture content to about 10% when dried at 67°C. At a higher temperature of 77°C it took about 220 minutes for single layer and 280 minutes for double layer(a ratio of 1:1.27). It would require a very long time to attain the set final moisture content for a three layer tray, eventhough it was not possible to establish this because of the limited time available for the drying test,(figure 4.3).

It follows that output for a given quantity of plantain in a given cabinet dryer can be doubled in 284 minutes by drying in double layer tray than in a single layer tray for 352 minutes.
There was evidence of wetness in the three layer tray due to some condensations taking place because the escape of the very humid vapours from the cubes heated by conduction was apparently obstructed by the dried cubes at the top layer. There was also evidence of uneven drying due to wetness of some innermost cubes resulting in poor quality end product. The trays containing two layers of cubes experienced less wetness because after a few minutes of drying, voids were created between the cubes due to shrinkage through which the vapours escaped. The highest throughput of dried plantain cubes was obtained by drying double layer trays in the cabinet dryer.

4.3.3.4. Determination of the Drying Constant for a Single layer of Cubes

The slope of the straight line of the plot $ln(W_\theta - We)/(W_o - We)$ versus time in the first falling rate period is known as the drying constant, (Saravacos and Charm 1962). For 5 sides of cube being dried, slope= $9\pi^2 D/16L^2$ (equation APP-3.2) For a thin slab of thickness 2mm drying from one face, slope = $-D\pi^2/16L^2$ (equation APP-3.1). Theoretically the ratio of the slope of a slab to a cube is 1:9.

The data for the plot of $\ln(W_\theta - We)/(W_o - We)$ are given in APP-4.6. The slope of the graph for 10mm single layer tray dried at 67°C was found to be 0.625 hr^{-1} and 0.58 hr^{-1} at 77°C (figure 4.4). The slope for 10mm single cube at 65°C was found to be 1.29 hr^{-1} (figure 4.4). The ratio of the slope of a single layer tray of cubes and that of the single cube is 1:2 from experiment. The rate of diffusion of cubes in a single layer tray lies between that of a thin slab and a single cube drying from 5 faces in the first falling rate period, However, when the ratios above are compared, the single layer tray of cubes behave more like single cubes than a slab. The result agrees with the findings of Van Arsdel and Copley (1964) who studied the drying rates in a well-designed cross-flow tray dryer and found that when a single layer of pieces is spread on a tray, the materials shrink as drying proceeds, and the structure of the layer on the tray becomes more and more open and relatively thinner so that drying takes place throughout the whole layer. The drying constant of 0.63 hr^{-1} for 10 mm single layer cubes in a tray at 67°C and 1.29 hr^{-1} for 10mm single cube at 65°C fall within the range of 0.34 hr^{-1} to 2.12 hr^{-1} given by Saravacos and Charm (1962).

It would, however, be inaccurate to determine the diffusion coefficient based on the formula for either the single cube or a thin slab. Hence it is more appropriate to carry out a plant trial and determine the slope from the experimental plot for use in the calculation of diffusion coefficient for the cubes.

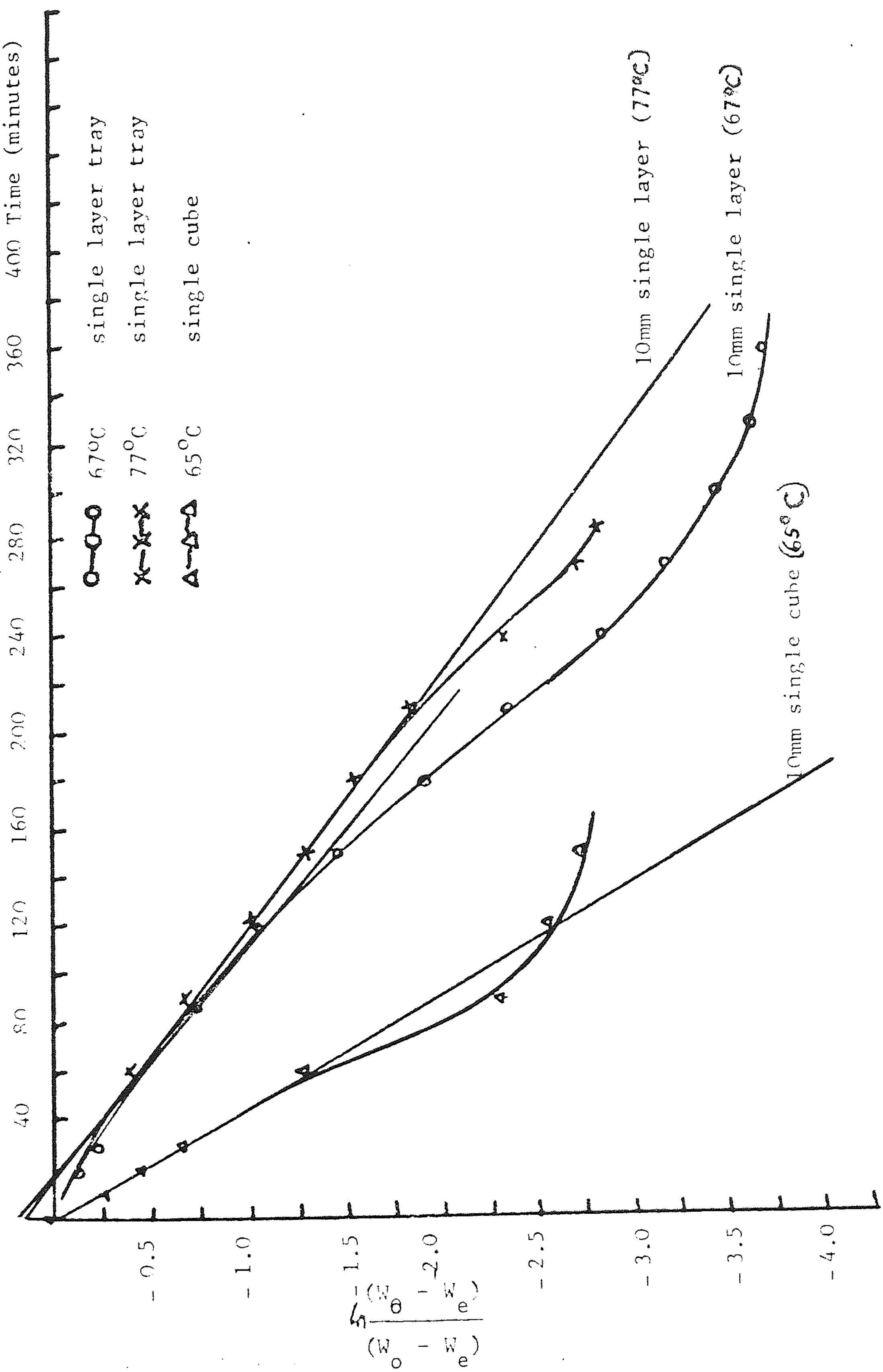


Figure 4.4 Fraction of evaporable water remaining in a plantain cube as a function of time for different temperatures 65°C, 67°C, and 77°C.

4.3.3.5. Summary of Conclusions:

1. Thin plantain slices could be dried in a double cylinder dryer to produce dried bands which could be milled to flour of desired particle size. The high feed-rate of 512 kg/hr of plantain pulp and its specific use for the production of pregelatinised flour places it as an alternative choice to a cabinet dryer.

2. Dicing of plantain pulp produces more uniform cubes than slicing.

3. The rate of drying was faster for cubes than slices at the two temperatures of drying.

4. The use of perforated trays greatly reduced the tray wetness and improved the rate of drying.

5. Drying plantain cubes at a temperature above 70°C would not significantly increase the rate of drying due to the effect of case hardening on the surface of the cubes. This effect would initially or throughout the drying operation, depending on the tray loading, reduce the rate of drying.

6. The highest throughput of dried plantain cubes is obtained by drying double layer trays in a cabinet dryer.

7. In single layers on a tray, cubes behave more like single cubes than like a slab.

8. The drying constant of 0.63 hr^{-1} for 10mm single layer cubes in a tray at 67°C falls within the range published in the literature for fruits and vegetables.

9. Plant trials should be carried out to determine the slope from the experimental plot rather than carrying out the calculation of the diffusion coefficient of the cubes on the formula for either the single cube or a thin slab.

4.4 Appropriate Process Flow Diagram for the Processing of Green Plantain into Flour

4.4.1. Choice of Technique

There are many routes to follow in the production of flour from green plantain (figure 4.1). In order to choose the appropriate technology for the production of plantain flour consideration should be given to the economic and social impact as well as to the environment in which the process will be carried out. Some of the routes shown in figure 4.1 are very expensive and would make the end product (plantain flour) very expensive. An appropriate process flow diagram is shown in figure 4.5. The route depicted in dotted lines is an alternative technique which can be considered as poorer choice by comparison with the cabinet dryer route for the following reasons:

1. The drying rate of drum dryer is higher and its use of energy very efficient(evaporation rate = 1kg H_2O/1.4 steam). However, the raw material imput required to operate economically for at least 14 hours batch is 56,000 kg of plantain pulp. This requires long shift and high energy input(section 4.3.3.5.)

2. Much time and experience are required for start-up operation each day in order to produce standard end product. Therefore it cannot be classified as a village technology.

3. Product waste is very high and if recycled results in poor quality end-product.

4. The range of products which can be handled in the dryer is limited to thin slices and slurries.

The selected route 1-9 can be described as appropriate for the following reasons:-

1. The size of plant can be selected to match the available raw material input and still operate economically. The capital cost may not have to be high.
2. Larger output can be obtained by using low capacity equipment and operating at two or three shifts at peak season.
3. The range of materials to be handled is wide and can be used to dry almost all fruits and vegetables including grains.
4. Its operation is simple and it can be manufactured locally.
5. It offers flexibility in use of energy(e.g. wood, gas, electricity or steam).

4.4.2. Operational Steps:

The drying operation will be carried out on 8-hour shift basis. The actual drying will be carried out in 6 hours while the remaining two hours will be for start-up, loading and unloading of dried products. The processes involved in route 1-9 are described briefly as follows:

Hot Water Blanching

The green plantain fruits are soaked in a hot water for about 10-15 minutes to soften the peel for easy peeling. The hot water can be provided by collecting the condensed exhaust steam in a tank. One should guard against the danger of over-blanching with the resultant effect of pulp softness. The optimum blanching time should be determined for equal sizes of fruit.

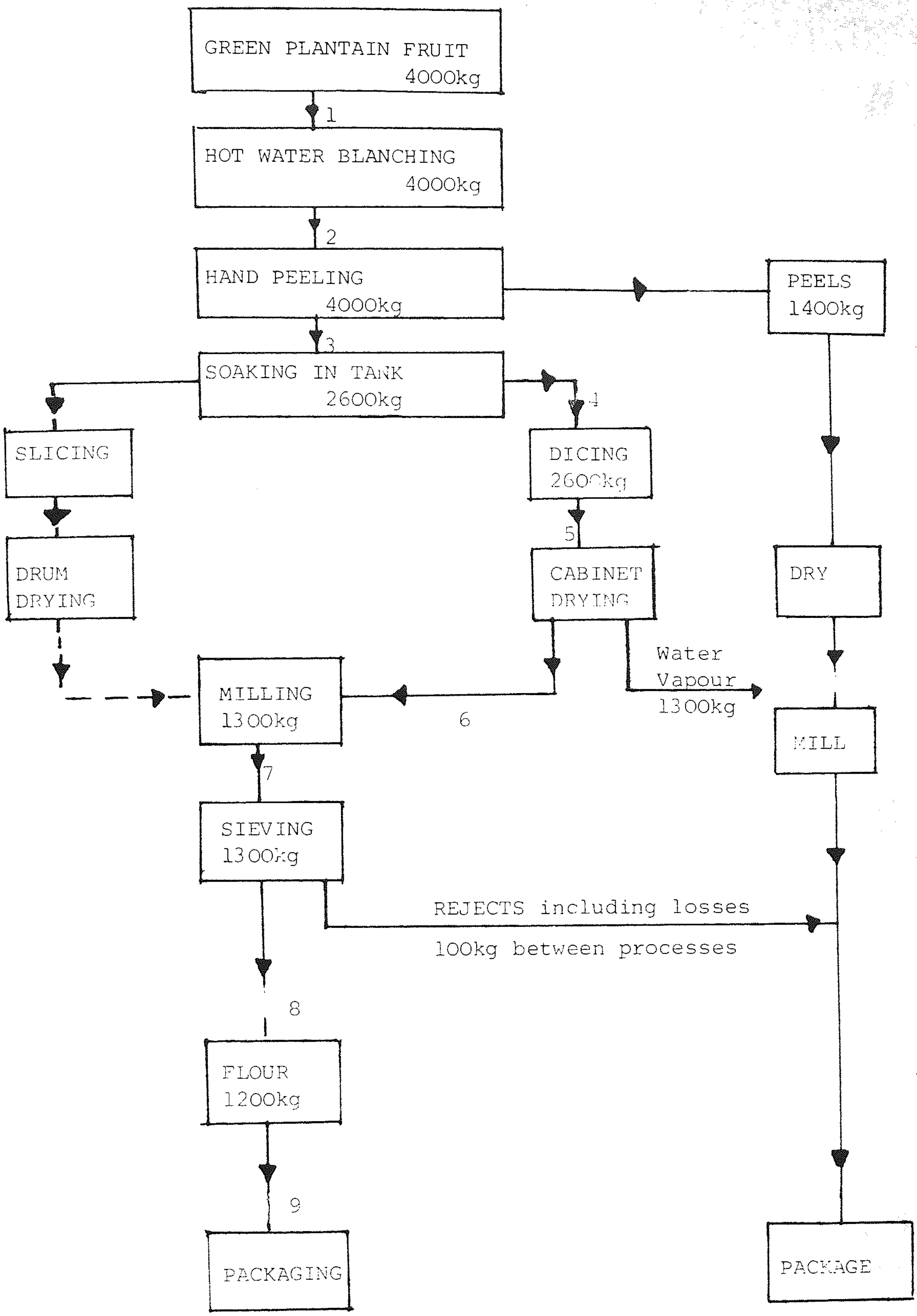


Figure 4.5 PROCESS FLOW DIAGRAM AND MASS BALANCE FOR THE PROCESSING OF PLANTAIN INTO FLOUR.

Hand Peeling

The blanched fruits were hand peeled by the author at the rate of 24 Man-Hour per 1000 kg of fruits. Without blanching, it takes about 72 Man-Hour to peel the same quantity. The peels could be dried and milled to produce animal feed.

Storage of the Pulp in a Water Tank:

The plantain pulp is put in a tank containing clean water to be held temporarily before slicing or dicing. In this way, enzymic browning action is temporarily prevented. This action is caused by the enzyme catalysed reaction of oxygen with certain phenolic compounds producing quinone structures and their polymerisation products which are responsible for the brown colour.

Dicing/Slicing

The pulp is diced or sliced using an automatic dicing machine like Kenwood Peerless or a Swedish "Halde" automatic slicer with different blades. Hand slicing can also be carried out where no machine is available or breaks down. In this case, it takes about 22 Man-Hour to slice 1000kg of pulp to a thickness of about 15mm. However, uniformity in size cannot be guaranteed in hand slicing operation.

Dehydration of Plantain Slices in a Cabinet Dryer

Standard trays will be filled to two layers and loaded in a cabinet dryer. The drying will be completed in about 6 hours at a temperature of not higher than $70^{o}C$.

Milling Process:

The dried slices can be milled using an end-runner mill or a hammer mill. The milling is continued until the desired particle size is obtained.

Sieving:

Sieves of aperture size 150-850 μm are used to produce flour of different particle size as required. The rejects are collected and used as animal feed.

Plantain Flour

The flour produced is graded according to particle size and packaged for the corresponding uses.

4.4.3. Material Balance

The initial target is to produce 20 bags of plantain flour of 50kg each a day. The material balance is shown in figure 4.2. The output can be improved by adjusting some of the figures. For example, it was observed that milling in a hammer mill produces a very fine flour that does not require any sieving for plantain biscuit production. Without any sieving, a total of 1300 kg of flour will be produced. The minimum quantity of flour obtainable from a given quantity of plantain fruit is 25% of the original fruit. This minimum value was used in the evaluation even though it is possible to obtain up to 28% as flour.

The peel is assumed to be 35% by weight of the plantain fruit. If dried and milled, it could be sold as animal feed. The less attractive option is to use the peel asmulch in the plantain plantation. Mulching has been proved to increase the output on long term basis.

The percentage moisture content of the pulp is taken to be 60% by weight of the pulp. It is expected that after drying, the moisture content will be reduced to 10%. This means that the amount of water to be evaporated is 50% of the pulp weight wet-basis.

The cabinet dryer has the capacity of holding 720 standard trays of dimension 810 x 410 x 32 mm. The manufacturers estimated that each tray could contain 5kg of wet material. It was, however, found during plant trial that this would result in very long drying time and poor quality product due to uneven drying.

It was also established previously that filling the tray to two layers deep gave the best result in terms of drying rate and end product (section 4.3.3.3.). Therefore the 720 trays of the 12 trucks will be filled with 3615g of plantain cubes each. This would give a filling of about two layers and the total pulp weight dried in a batch will be 2600kg.

4.4.4. Energy Requirement :

The demand for energy is for dehydration, milling, dicing/slicing and hot water blanching. The energy required for hot water blanching can be regarded as zero input cost since it is planned to use the exhaust steam condensate as the heating medium. It can be reasonably assumed that about 80% of the total energy employed will be used for dehydration. Water vapour to be evaporated is 217 kg/hr (i.e. 1300kg/6hr), while the dryer capacity is 720kg water vapour per hour.

If it is assumed that the drying will be carried out at air temperature of say 65°C, the total energy required will be given by the equation,

$$Q = M \times Cp\ (T_A - T_M) + m\lambda$$

where Q = Total energy required kJ

M = Weight of the plantain pulp kg

m = Weight of water to be evaporated kg

Cp = Specific heat of pulp and water J/kg °C

T_A = Air temperature °C

T_M = Initial Temperature of pulp and water which is taken as average room temperature(25°) obtainable in Nigeria.

λ = Latent heat of evaporation at 65°C

$$\therefore\ Q = 2600 \times 4.18\ (65 - 25) + 1300 \times 2345.7$$

$$= 348140 \text{ kJ} \approx 350 \text{ MJ}$$

If the 350 MJ required for drying represents about 80% of the total energy required for the whole process, then the total energy required will be about 440 MJ. This can be cheaply supplied by steam than by electricity. The power requirement of the fan motors is 33 H.P. which is equivalent to about 25 kW energy. The energy can be supplied electrically.

A summary of the process equipment and labour requirement for the 8- hour shift operation is given in table 4.2. Such items as tables for sorting and possibly for slicing, buckets etc will be included in the cost estimation as contingencies.

4.4.5. Manpower Requirement for the Factory Operation:

The manpower requirement for a food processing factory is the managerial, scientific, technical, skilled and other allied personnel employed in managing and carrying out the factory processes. There are essential features of an organisational chart for a factory operation. Figure 4.6. illustrates the organisation chart anticipated for the plantain processing factory. The actual number of staff in each section depends on the volume of operation. The qualification and salary scale for each post will be decided by the factory manager who should be a process engineer with some years of experience. Casual labourers needed for such operations like peeling and slicing will be recruited according to daily demand.

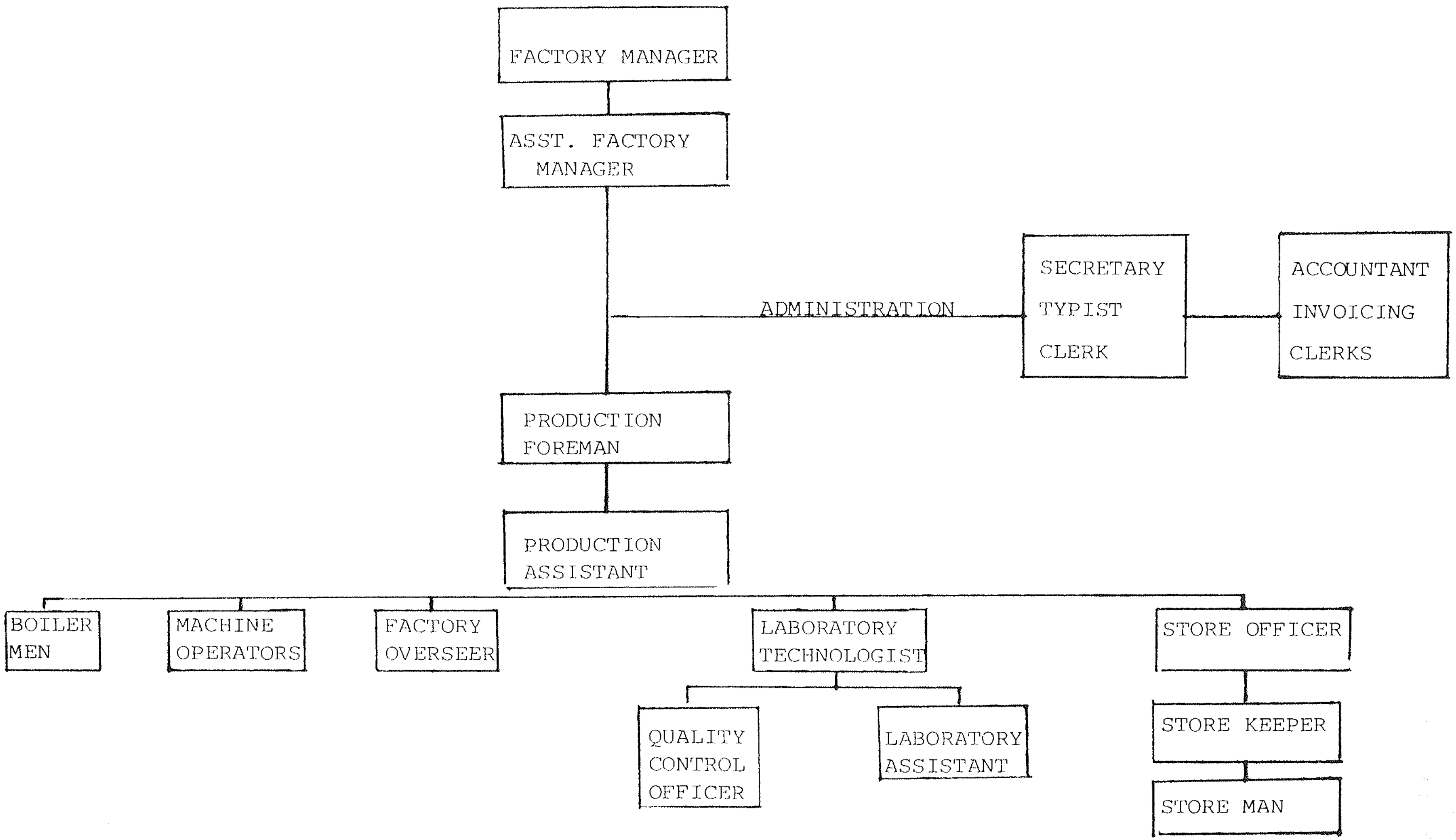
Table 4.2

Summary of the process equipment and labour requirement for the 8 - hour Shift Operation

	Process Equipment and Labour Requirement	Quantity
1.	Plantain Fruit Supply	4000 kg
2.	Hot Water Tank (1.5 x 1.5 x 1.2 m) (Stainless Steel)	5
3.	Hand Peeling of 4000kg plantain at 335 kg/8-hour (12 Stainless Steel knives)	12 knives (12 persons)
4.	Soaking Tank (1.5 x 1.5 x 1.2 m) - Stainless Steel	5
5.	Dicing of 2600kg of pulp (If sliced by hand, it would require about 7 persons to slice at the rate of 364g/ 8-hour/person)	1 unit (1 operator)
6.	Cabinet Dryer 1 unit of 12 Trucks	1 unit (4 operators)
7.	Bins for temporary storage of the dried pulp	10
8.	Milling of 1300g of dried pulp	1 unit (1 operator)
9.	Sieving Unit	1 unit (1 operator)
10.	Packaging (one heat sealing machine and bags)	1 unit (1 operator)
11.	Compressor	1 unit

Total unskilled labour required = 20 persons.

Figure 4.6. The Organisation Chart for the Factory Production of Plantain Flour:



4.4.6 Factory layout for plantain flour production

The factory layout for the daily processing of 4000kg of green plantain into flour is illustrated in figure 4.7. The factory will occupy an area of about 0.13 hectare of land. A boiler plant and an electrical plant will be required for power supply. A water treatment plant will also be required to provide clean water for the factory. The room for the storage of raw plantain will be air conditioned to provide a very low temperature for longer storage life of the plantain in the green state.

There is provision for future new process plant as plantations are expected to grow in size which will result in an increase in the volume of fruit production. The plantain flour produced will be stored and sold wholesale.

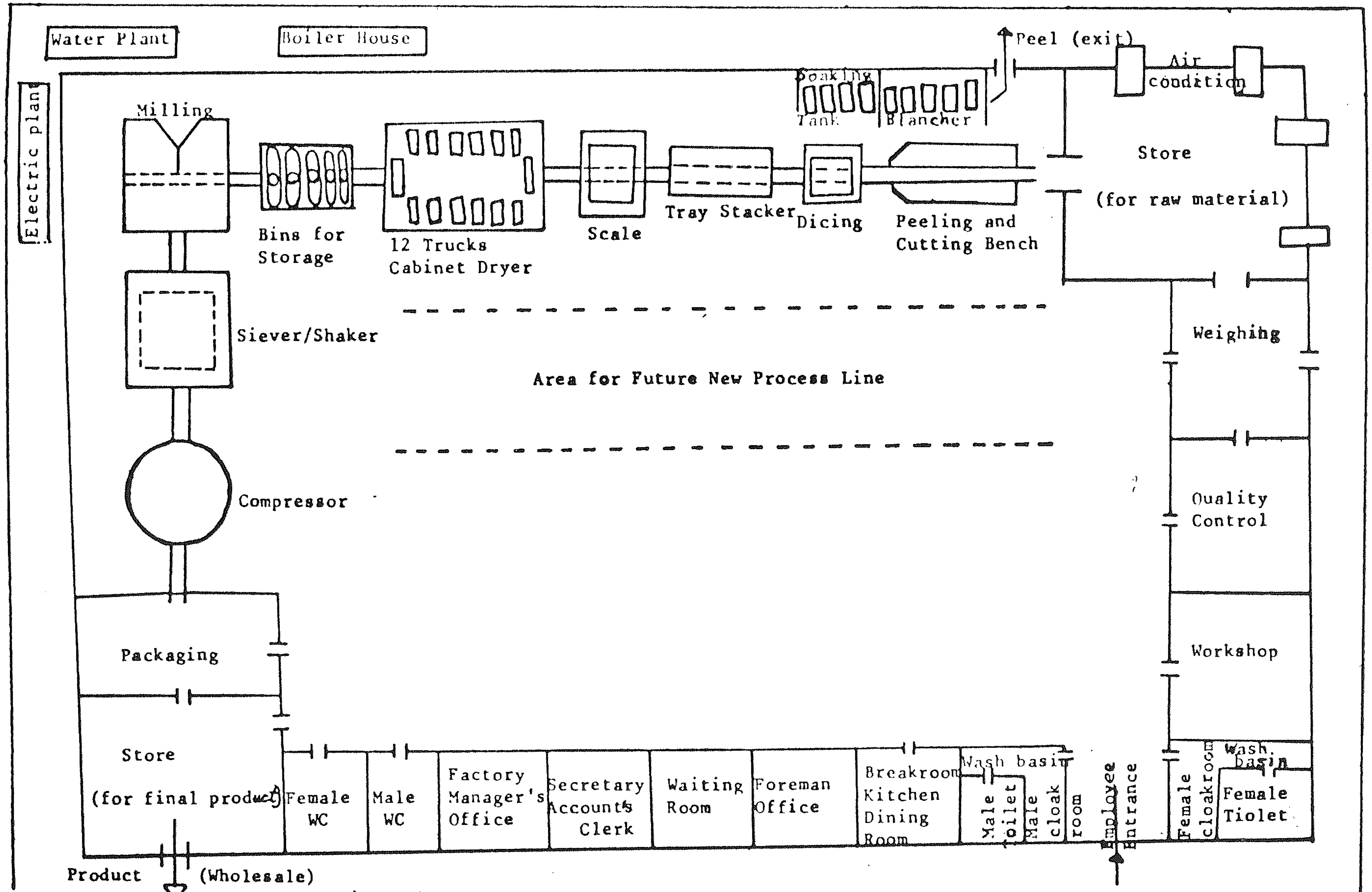


Figure 4.7 Factory layout for plantain flour production (Not to Scale)

CHAPTER 5

The Baking Properties of Plantain Flour and Consumer Reaction to Plantain Biscuit

5. The Baking Properties of Plantain Flour and Consumer Reaction to Plantain Biscuit

5.1 Introduction

The interest of research scientists in the production of composite flour from local raw materials is growing to include all possible cereals and tubers obtainable in the developing countries where adequate supplies of suitable home grown wheat are not available. The demand for bakery products as convenience food has been found to increase with urbanization.

In 1960 an FAO expert studied the possibility of producing biscuits from a mixture of wheat flour with corn flour and cassava starch in Uganda. Products of reasonable good quality were made. In 1964, FAO promoted and sponsored a "Composite Flour Programme" to overcome the technical restraints on the utilization of local grain and starchy flours in the production of bakery products (Faure, 1971).

A meeting was held at the Tropical Products Institute, London in 1970 by experts in baking technology to discuss the composite flour programme and it was decided that the use of composite flour should not be in direct competition to that of wheat flour. Bakery products made from composite flours should be assessed and priced on their own merits. It was agreed that biscuits might offer a better use of composite flour than bread, (Asselbergs, 1970).

5. 2 Review of literature on the use of plantain and banana in bakery products

Dupaigne and Richard (1965) carried out an investigation of the use of banana in biscuit making. They incorporated ripe banana flour into wheat flour at a level of 24% in the manufacture of army biscuits. In this experiment, the ripe banana flour was substituted for the ordinary sugar because of the high sucrose, fructrose and glucose content. They found that it is possible to produce an acceptable biscuit but maintained that the quality and nutritional value could be improved.

Leclerc and Wessling (1918) carried out experiments using 25% banana flour and 75% standard wheat flour in the baking of bread. They claimed that the texture and colour of the bread obtained were inferior to bread made from wheat flour alone as shown in table 5. 1.

Table 5. 1 Analysis of bread made with banana flour and standard wheat flour

Bread Composition	Total Ash %	Salt-free Ash %	Fat %	Fibre %	Protein (Nx6.25) %	Carbo-hydrate %	Colour	Texture %
Banana flour (25%) (Unripe fruit)	1.78	0.71	1.40	0.28	7.33	54.21	Grey-brown	96
Banana flour (25%) (Ripe fruit)	1.65	0.76	1.20	0.29	7.49	54.37	Light-grey	88
Wheat flour (Spring wheat)	1.28	0.31	7.08	0.13	8.74	52.77	Cream	99

Breads with banana flour contained 75% standard wheat flour.

Winckel (1924) recommended the use of 25% wheat flour and 75% banana flour in bread making. It was doubted whether the product would be acceptable to the American public. Rasper, et al (1974) studied the effect of non-wheat starches in composite doughs using yam, cassava, sorghum and millet. A substitution of 15% of typical Canadian wheat flour was made using flour from the above products for bread baking trials. Yam flour and cassava starch were considered the most satisfactory substitutes for wheat flour in the above trials. Using equal amounts of green banana flour and wheat flour, Edelmuro, et al (1977) prepared cup cakes which they claimed were acceptable to consumers.

The limited literature on the use of plantain and banana flour in composite flour for the manufacture of bakery products is evidence of lack of appreciation of the plantain crop when compared with the extensive literature on the use of other starchy staples and grains in composite flour.

The main objectives to be achieved in this study are:

1. To study the physical properties of plantain flour alone and in composition with wheat flour.
2. To determine the effect of dilution of strong wheat flour with plantain flour on the baking properties of the wheat flour for bread and cake.
3. To develop a new plantain shortcake biscuit using 100% plantain flour.
4. To carry out consumer acceptability tests of the plantain biscuit.
5. To carry out a preliminary test marketing of the plantain

biscuit.

5.3 Physical Properties of a Flour

5.3.1 Flour strength - Gluten in Flour

Flour is essentially a mixture of starch, damaged or un-damaged, electrolytes, moisture and a dried-up hydrogel (the gluten). The strength of a flour depends on the quantity and and quality of the gluten content. The gluten is the in-soluble flour proteins after they have become hydrated. It consists of two main proteins - gliadin (soluble in 70% alcohol) and glutenin (soluble in dilute alkali). The colloidal condition of the gluten (i.e. protein) in flour or dough is undoubtedly closely connected with the suitability of the flour for the baker. Gluten is elastic and tough to varying degrees and on baking becomes coagulated and sets to form a strong network within the starch gel. A weak and flowy gluten, however, is not as coagulated as a tougher one such as that found in the flour from good Manitoba wheat. But too much coagulation may occur in some wheats grown in tropical countries, such as India, with the result that the gluten loses extensibility and other desirable characteristics. The power of swelling in the presence of water possessed by proteins is related to the quality of gluten. A weak flour with poor protein content has a poor swelling power and the doughs are therefore weak. A strong flour contains a large amount of protein particles which have great swelling and hydration capacity, hence the pleasing elastic dough. The swelling power of gluten particles will be affected by the hydrogen ion concentration (pH) of the dough as well as the proteolytic enzymic activity, (Kent-Jones and Amos, 1967).

There are four distinct grades of flour; strong, medium strong, soft and special cake.

Strong Flours: They have high protein (11-15%) and take up much water when making doughs of the correct consistency and elasticity for the production of bread of satisfactory volume and good texture.

Medium Strong Flours: Have 9-11% protein and take up sufficient water to make doughs resilient enough to withstand the rapid early generation of gas during the initial period of baking.

Soft Flours: Contain proteins (7-9%) of low gluten strength and have poor water absorption. These flours give "lifeless" doughs which tend to run out as fermentation proceeds and in consequence produce heavy loaves of unsatisfactory texture. However they are mainly used for biscuits and confectionery products which rely on other ingredients like sugar for their texture and stability.

Special Cake Flours: These are known as high-ratio flours and are milled from the centre of high grade wheats containing 7-8.5% of good quality gluten. After milling the flour is heavily chlorinated which destroys the coherency of the gluten. The chlorine treatment increases the acidity of the flour and renders the starch more soluble, increasing absorption and retention of moisture. The water adsorption is greatly influenced by the particle size of the flour.

5.3.2 Physical Methods for the Measurement of Flour Quality

Flour quality can be assessed by physical and chemical analysis and by baking tests. The physical properties of the dough made from a flour and the changes taking place when the dough is fermenting are normally measured through rheological measurements related to the protein, starch, and water absorption power of the flour. These tests involve the use of the Extensograph, Amylograph and Farinograph.

5.3.2.1. Brabender Farinograph: Kent-Jones and Amos (1967) described the principle of the instrument (figure 5.1) as follows : The force taken to turn paddle mixer blades at constant speed through a dough of fixed initial consistency is graphically recorded in the form of a wide band and as the tests proceeds, this force varies according to the nature of the flour and hence different shaped bands or graphs, known as farinograms, are produced. The changes in the nature of the dough are thus recorded over a period and the evaluation is not restricted to any one time.

The reading from this instrument enables the following characteristics to be assessed.

(a) the water absorption power of the flour as volume of water used per 100g of flour (Since 300g of flour is used for the test, the actual volume recorded will be divided by 3) or as a percentage for a curve centred

on the 600 line at peak development.

(b) the dough development time in minutes: This indicates the mixing time required, from the moment "doughing up" starts to optimum development of the dough. It also yields the time for maximum band width (i.e. maximum elasticity of the dough).

(c) the dough stability: This is measured in minutes on the curve from its highest peak to the point where the middle of the curve drops 40BU (Brabender Unit) below the 600 line.

(d) the dough resistance: This is the sum of dough development time plus stability time.

(e) the dough weakening which is measured by how many BU the middle of the curve falls below the 600 line after 12 minutes.

This equipment does not measure individual physical properties nor the composite picture of the dough behaviour during fermentation and processing.

5.3.2.2. Brabender Extensograph: The equipment (figure 5.2) is particularly adapted to fermented doughs and for examining the influence on dough character of improvers. The test consists of stretching a dough of cylindrical form by means of a moving arm. The stresses set up in the dough by its resistence to extension are recorded as a graph. It measures the following characteristics of a flour dough prepared as for the Farinograph.

(a) Resistance to stretching i.e. toughness: This is

obtained from the height of the Extensogram measured 50mm after the curve has started.

(b) Extensibility i.e. the ability to stretch without breaking. It is measured in millimetres and is taken as the length of the curve.

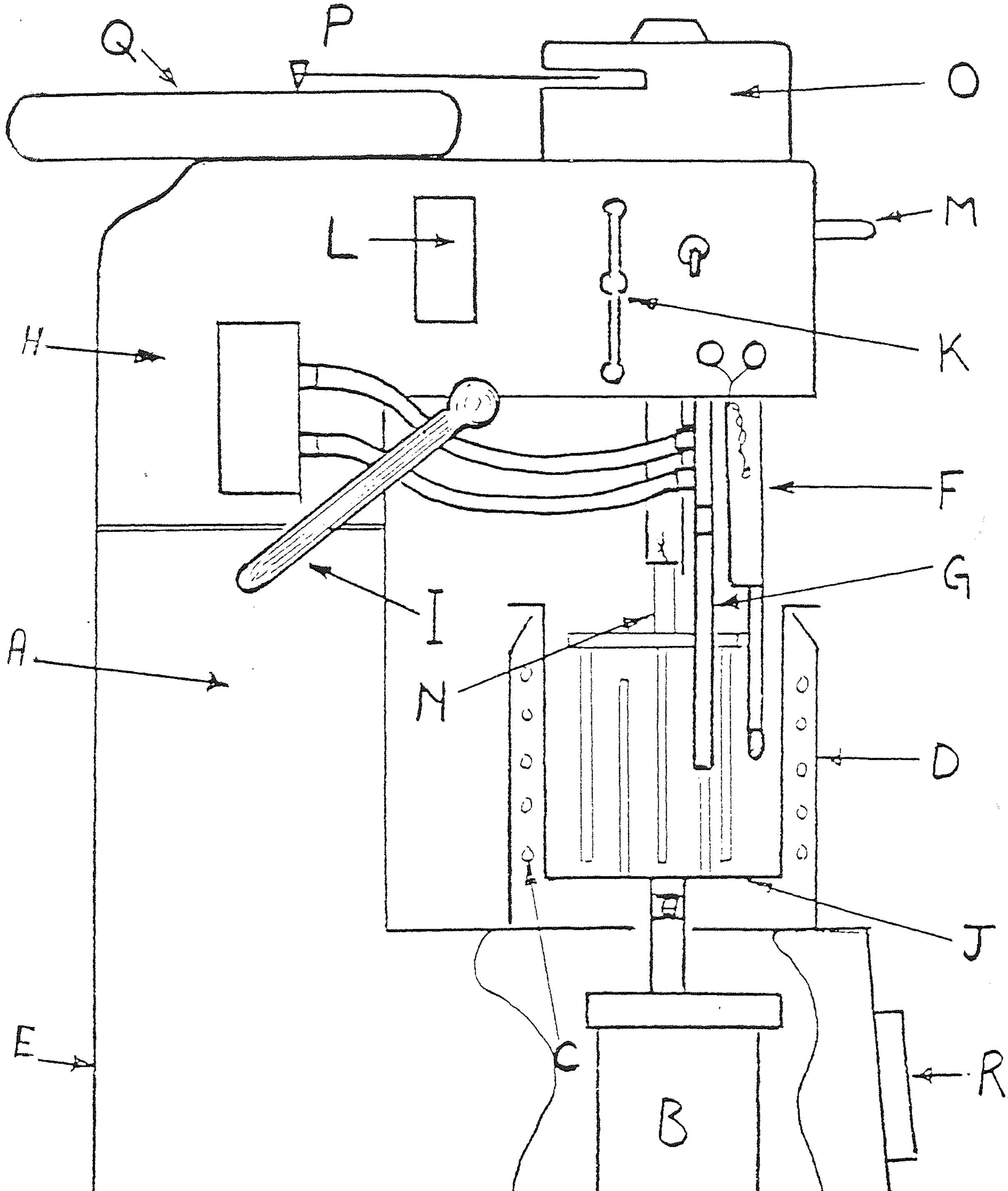
(c) The Ratio Number, which is obtained by dividing the resistance to stretching by the extensibility. The greater the ratio number, the "shorter" will be the dough.

(d) Dough Strength i.e. the measure of the gluten quality: This is obtained from the area of the curve.

5.3.2.3. <u>Brabender Amylograph</u>: The readings from this instrument (figure 5.3) are related to the viscosity of the gels formed when flours are heated uniformly in the presence of water. The increase in viscosity is due to the gelatinisation of the starch, the viscosity being influenced by the action of any amylase enzymes present. The gelatinisation of starch within the loaf during baking has an influence on the condition of the crumb of the baked loaf i.e. whether it is dry, sticky or normal. It simulates the effect of the baking on starch by raising the temperature of a flour/water suspension at the constant rate of approximately 1.5^{o}C per minute, during which the starch gelatinises.

The increase in viscosity due to gelatinisation is plotted automatically on a graph. A high curve reveals a starch with good water binding capacity resulting in bread with dry eating crumb. A low curve shows a starch with low water binding capacity. When this curve is lower than normal it

Figure 5.3 Brabender Viscograph - Diagrammatic Form.



KEY TO DIAGRAM - Brabender Viscograph

A	Main Frame
B	Stirrer Motor (Pot Drive)
C	Radiant Heating Element
D	Reflective heater housing
E	Control mechanism in rear of main frame
F	Glass Thermoregulator
G	Cooling element (may be raised and lowered)
H	Instrument head (may be raised and lowered)
I	Head lifting handle
J	Rotatable slurry pot
K	Transport lever (Thermoregulator drive control)
L	Cooling control switch (may be on front of instrument on certain models)
M	Thermoregulator manual drive (zero setting knob)
N	Measuring probe
O	Sensing element (May be 250, 350 or 750 cm/gram)
P	Recording pen
Q	Graph Paper (with electric drive and manual control)
R	Main controls (vary with model type)

is usually due to excessive proportion of damaged starch which is more subject to breakdown by the enzyme Diatase and which produces a bread usually with a sticky and crumby texture. The low curve could also be an indication of excessive α-amylase activity.

5.4 Determination of Physical Properties of Plantain Flour as Composite with Wheat Flour

5.4.1 Materials and Equipment

Materials:
(a) Strong Canadian Wheat flour (Leviathan) obtained from the store belonging to the National Bakery School, the Polytechnic of South Bank, London.
(b) Plantain flour (ungelatinised) obtained by peeling green plantain fruit, drying the pulp, milling and sieving to the required particle size.
(c) Water

Equipment:
(a) Brabender Farinograph
(b) Brabender Amylograph
(c) Brabender Extensograph
(d) Stirring Device
(e) Thermometer
(f) Beakers
(g) Spatula
(h) Covering glass
(i) Stop Clock

5.4.2 Operational Procedure

5.4.2.1 Water Absorption Power (W.A.P.) using Farinograph. The working of the instrument has been described in detail in "Modern Cereal Chemistry " pp 340-349 (Kent-Jones and Amos, 1967), and is illustrated in figure 5.1 (section 5.3.2.1)

The samples for test are as follows:

Test Sample Number	Leviathan (%)	Plantain Flour (%)
0 (Control)	100	-
1	90	10
2	85	15
3	80	20
4	75	25
5	70	30

300g of the composite flour mixed in accordance with the percentages given above for each flour was put in the mixing bowl of the farinograph and dry mixed for one minute to ensure homogeneity. Warm tap water was cooled to 30°C and poured into the burette until it was filled to the graduated mark. The pen was placed on the paper and the motor started. Water was run gradually into the mixing bowl from the burette. As the mixing started, initially the pen rose over the 600 line mark but dropped again below the mark. This continued momentarily but as the water worked into the dough, the pen rose above the 600 line and the curve ran level for a few moments, neither rising nor falling, on the 600 line. That was taken as the peak of the curve and the motor was stopped, the burette reading taken as the water absorption. Having determined the water absorption another 300g of the composite sample was put in the mixing bowl which had been cleaned and the test repeated. But this time all the water as determined in the first preliminary test was poured into the bowl at once. Any flour clinging to the sides of the mixing bowl was scraped down into the dough with a spatula and the mixer covered with a sheet of glass to prevent evaporation. The mixing was run for twelve minutes and the motor stopped. The mixer was thoroughly cleaned after use, and between tests and each percentage of plantain was similarly tested. Different Farinograms (curves) as shown in figure 5.4 were obtained.

5.4.2.2. Protein quality of the test samples using Extensograph

The working of the instrument has been described in detail in "Modern Cereal Chemistry" pp 337-339 (Kent-Jones and Amos, 1967) and briefly in section 5.3.2.2. with diagramatic illustration.

The dough prepared in the Farinograph is mechanically moulded into baton shapes of fixed weight and allowed to stand for 45 minutes. At the end of this period, the roll is clamped at each end in the Extensograph. The middle of the dough piece is then stretched downwards by means of an arm which descends at a constant rate and the deformation continues until the dough breaks. The moving arm is connected to a pen which continuously records the tension in the dough and the extent to which the dough has been stretched. When the dough has been stretched, it is reformed into a baton shape stood for a further 45 minutes and again stretched. This is repeated for the third time, thus obtaining three Extensograms after 45, 90 and 135 minutes.

5.4.2.3. Viscosities of the test samples and plantain flour using Amylograph

The working of the instrument has been described in detail in

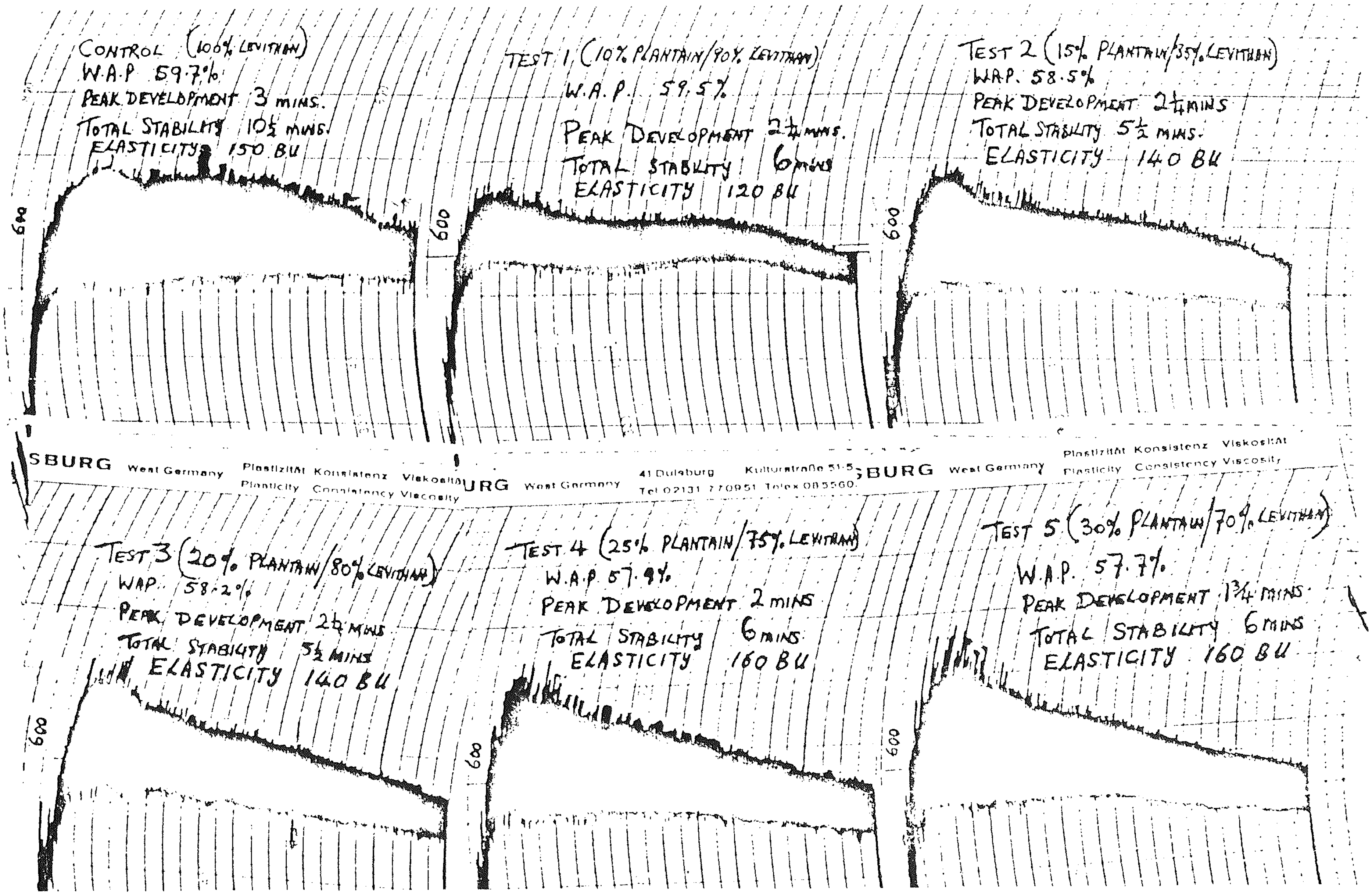


Figure 5.4 Interpretation of Farinograms of blends wheat flour and plantain flour.

"Modern Cereal Chemistry" pp 351-354, (Kent-Jones and Amos, 1967) and illustrated in figure 5.3 (Section 5.3.2.3): The method adopted was as follows :-

80g of flour mixture under test was weighed in scale.
The instrument burette was filled with water, so that the water level was actually 450 ml.
The overflow device on the burette drained off any surplus water, so that the water was always level at exactly 450 ml.

Approximately one fifth of the water contained in the burette was drained into the vessel of the stirring device and the flour added. Both were stirred into a stiff paste with a spatula. After this, approximately one quarter at a time of the water remaining in the burette were successively added to the paste under continuous stirring. Then the cover of the stirring device was put on the vessel. With 20 turns of the crank the content of the vessel was stirred into a homogenous slurry, which was free from lumps in approximately 8 seconds.

The slurry thus obtained was poured into the amylograph "pot". The water remaining in the burette was used to rinse out the stirring device. After the remainder of the water containing the residue of the slurry has been poured into the pot the probe was put in place and the starting temperature was set at 25°C. The recording pen was adjusted to the zero line of the chart paper.

The head of the Amylograph was then swung into position and the control switch turned on. The temperature of the suspension was allowed to increase to 93^{o}C in 45 minutes. During this period, changes in viscosity are constantly measured and recorded on chart paper.

In order to determine the viscosity of 100% plantain flour, a series of tests were carried out to determine the quantity of plantain to be used. In each case, the total volume of the solution was 530ml. This was achieved by assuming that 1cc of water is equivalent to 1g and when 45g of plantain flour was used instead of 80g, 35cc of distilled water was added extra to the solution after adding the usual 450cc from the burette.

5.5. Observations and Results

5.5.1 Farinograph: A marked reduction in peak development time and length of time of stability were observed as soon as the first dilution sample was tested. This reduction in peak development time was not directly portional to the amount of plantain flour incorporated into the mix but continued at a much reduced rate (see graphs figure 5.4). However, the total stability time did not continue to decrease and the higher dilutions displayed a slight increase in stability time. The actual doughs became much more plastic as the level of dilution increased. Some reduction in W.A.P. was noticed as the dilutions increased. The results of different tests are shown in table 5.2. below.

Proportion of plantain flour %	0 (Control)	10	15	20	25	30
Water Absorption (%)	59.7	59.5	58.5	58.2	57.9	57.7
Peak Development Time (mins)	3.0	2.25	2.25	2.25	2.0	1.75
Elasticity (BU)	140	120	140	140	160	160
Stability Time (min)	7.5	3.75	3.25	3.25	4.0	4.25
Total Stability Time (min)	10.5	6.0	5.5	5.5	6.0	6.0
Dough Weakening (BU)	45	65	84	94	100	105
(CM)	0.8	1.1	1.5	1.7	1.8	2.0

Table 5.2 Farinograph properties of blends of wheat flour and plantain flour

Figure 5.4 shows the farinograph curve characteristics for different levels of dilution of Leviathan wheat flour with plantain flour.

5.5.2 Amylograph: As the proportion of plantain flour in the mixture increased the viscosity of the slurry at peak gel increased dramatically. The gelling point temperature was higher for the mixtures than the control. The time and temperature at peak gelatinisation decreased with dilutions.

The viscosity of 80g plantain flour in 450ml of distilled water was too high to be measured by the instrument. 45g plantain flour in 485ml of distilled water gave viscosity value below 1000 BU except for the freeze dried sample which gave 1060 BU. Figure 5.5 shows the viscosity graph obtained from 45g plantain flour in 485ml of distilled water. The graph was recorded as a line which at first ran parallel to

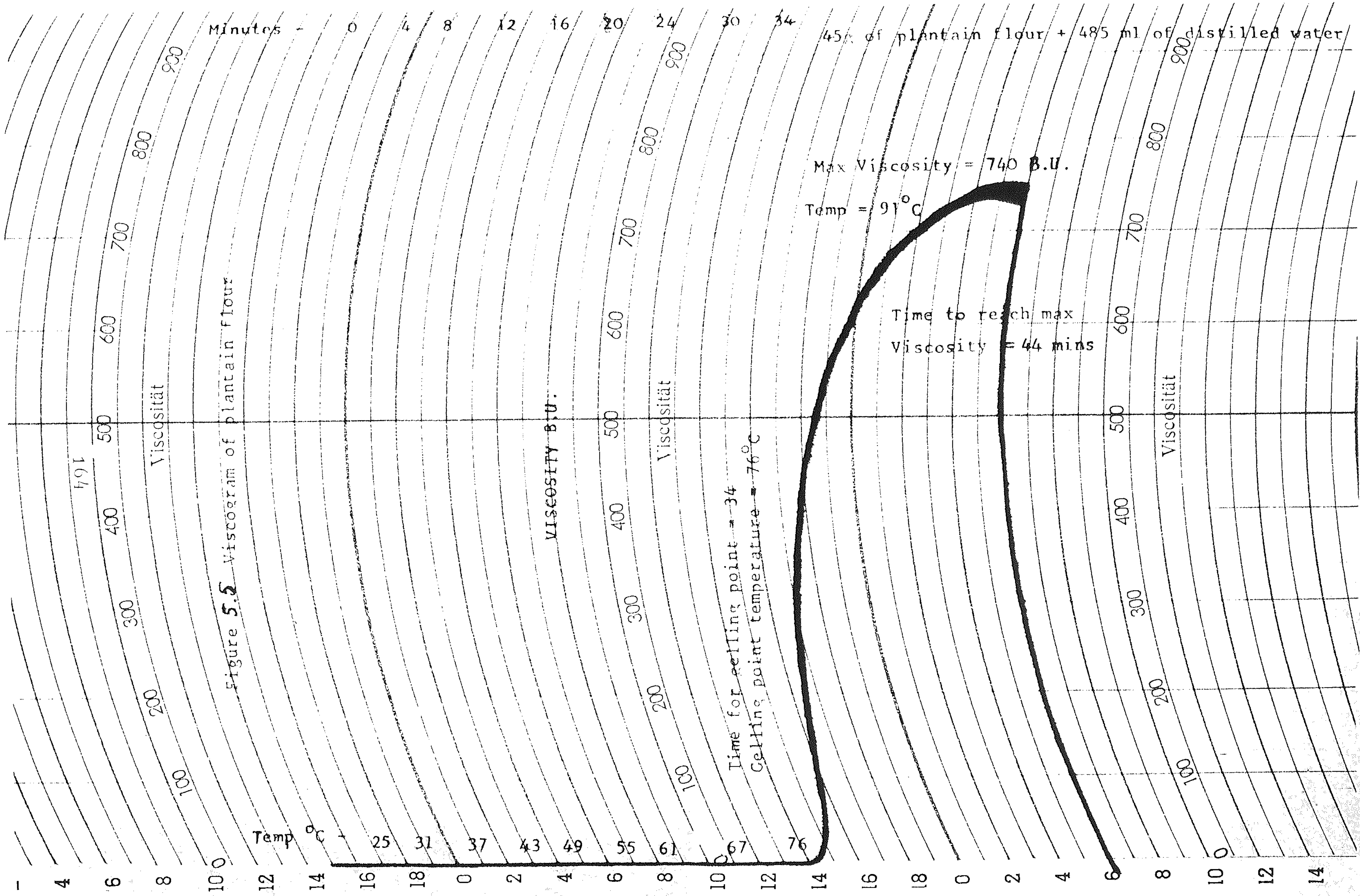


Figure 5.5 Viscogram of plantain flour

TABLE 5.3. VISCOSITY OF PLANTAIN FLOUR AND THE EFFECT OF SUGAR CONTENT

Type of plantain	Wt of flour (g)	Temperature of drying (°C)	Gelling point temperture (°C)	Time (mins)	Max. viscosity (BU)	Temperature for max. viscosity (°C)	Reducing sugar(%)	Non-reducing sugar(%)	Total sugar (%)
Ungelatinised	80	55	75.25	33.5	Beyond maximum viscosity recorded by the instrument				
"	50	55	76	34	1120	89			
"	45	55	76	34	740	91			
"	40	55	76.75	34.5	520	94			
"	45	65	75.4	33.6	760	88			
"	45	75	74.5	33	960	86.5			
"	45	-24	73	33.6	1060	88			
"	45	50	73.75	32.2	855	88	4.42	0.32	4.74
Gelatinised	45	93	79.75	36.5	200 (after 45 mins)	93	4.42	0.32	4.74
Ungel. (turning yellow)	45	50	71.5	31.0	565	89.5	18.60	2.35	20.95
Gel. " "	45	93	82	38	12 (after 45 mins)	93	18.60	2.35	20.95
Ungel. (ripe)	45	50	73	32	330	93	27.99	2.09	30.08
Gel. "	45	93	85	40	10 (after 45 mins)	93	27.99	2.09	30.08
Ungel. (ripe)	45	50	73.75	32	90	93	38.15	1.04	39.19
Gel. "	45	93	88	42	4 (after 45 mins)	93	38.15	1.04	39.19
Ungel. (overripe)	45	50	76	34	237	93	37.46	0.73	38.19
Ungel. (ripe)	80	50	71.5		1820	86.5	27.99	2.09	30.08

to the horizontal axis but at 76°C started to rise reaching a peak at 91°C after 44 minutes.

The results are tabulated in tables 5.3 and 5.4 below

Proportion of plantain flour %	0 Control	10	15	20	25	30
Temperature at the start of gelation (°C)	57	60	60	60	60	61.5
Time at the start of gelation (mins)	20	23	22.5	22	22	24
Temperature at the peak gelation (°C)	85	83.5	83	82	82	81.25
Time at the peak gelation (min)	40	39	38.5	38	38	37.5
Maximum Viscosity (BU)	665	118	1130	1230	1480	1680

Table 5.4. Viscosity of mixtures of plantain flour and Leviathan flour

5.5.3. Extensograph: The resistance & extensibility shows good correlation with one another. In general as a dough matured it became shorter and displayed greater visco-elastic properties. A visco-elastic material shows no yield stress and incomplete recovery when the stress is removed. This was shown on the graph by an increase in resistance (R) but without a dramatic decrease in extensibility (E). As a result, the Raio Figure (R/E) remained within certain tolerances that gave a guide to the visco-elastic properties of the dough. A good ratio is from 2 to 4. If the ratio figure increased dramatically, which would normally be as a result of increase in resistance, then the dough would be excessively stable withou sufficient extensibility to allow the dough to increase in volume properly. On the other hand if the ratio figure was low it would show that the extensibility of the dough was excessive signifying too much flow without sufficient resistance to retain sufficient volume of gas to allow proper aeration. The results obtained from the tests are given in table 5.5 below.

Proportion of Plantain flour (%)	Time (mins)	Resistance (R) (BU)	Extensibility (E) mm	Ratio (R)/(E)	Area mm^2
0 (Control)	45	285	137.5	2.07	70
	90	330	130	2.53	74
	135	380	130	2.92	75
10	45	300	130	2.30	62.6
	90	460	115	4.00	87.4
	135	530	103	4.17	85.3
15	45	410	112.5	3.60	78.0
	90	590	87.5	6.74	75.1
	135	630	72.5	8.68	64.4
25	45	450	90	5.00	54.5
	90	670	72	9.30	69.0
	135	660	65	10.15	50.0
30	45	580	62.5	9.28	50.2
	90	665	55	12.09	50.0
	135	580	60	9.60	57.5

Table 5.5 Results from Extensograph

5.6 Discussion

The decrease in total stability of the dough with the increase in proportion of plantain as measured by the Farinograph indicates a decrease in the gluten content (table 5.2, section 5.5.1). The protein content of plantain flour is about 3% and it contains no gluten forming protein as confirmed by gluten wash (Chilambwe and Afam, 1980). They showed the effect on the gluten content of the dilution of strong Canadian Patent flour with plantain flour as follows:

Composition (%)	WF (100)	WF/PF (80/20)	WF/PF (60/40)	WF/PF (40/60)	WF/PF (20/80)
Gluten (Protein) %	12.1	8.1	6.6	4.6	1.6

Note: WF = Wheat flour PF = Plantain flour

This means that any dilution with plantain flour beyond 20% will reduce the gluten content of the composite below the acceptable level for breadmaking (9-15% Protein). They also established that the coherence, stability, extensibility and colour of the gluten progressively deteriorated with increase of plantain content.

The addition of 10% plantain flour brought about a significant decrease in total stability. However the decrease remained at a constant level between 10% and 30% dilution showing that other factors like resistance to mixing due to the presence of plantain flour may well be influencing the test. Taking the results at face value it can be argued that at lower dilution rates of up to 20%, the short process method for breadmaking, which allows the dividing of the dough straight after mixing, can be employed, (section 5.8.1).

The viscosity of the plantain flour and its composite with wheat flour can be affected by the following factors :

1. the state of the starch : (a) when damaged mechanically during milling, the viscosity is different from that of the undamaged starch. (b) Whether the starch has been partially pregelatinised during heat treatment. The viscosity of pregelatinised starch differs from that of ungelatinised starch.

2. The amount and nature of protein present.

3. The amount of enzyme present for diastatic activity.

4. The amount of fermentable sugar present.

The viscosity of the composite flour increased with increase in the quantity of the diluent - plantain flour, showing that the starch of the composite has a better water binding capacity. The high viscosity would normally indicate that the flour would have a low starch damage figure with little enzymic activity. The control displayed a relatively good acceptance figure when compared against other similar bread flours that may well be used in a long fermentation process. The viscosity range for good baking property is 350-800 BU for rye flour, (Kidman 1977 - Literature Handout, RMT 18), and a stronghold flour had a peak of 790 BU. The Leviathan flour has a viscosity of 665 BU. It may be assumed that the Leviathan flour by itself will have functioned fairly well in supplying sugars to a fermenting dough. However, as the dilutions increased the peak gel increased so dramatically that at first glance it may be thought that insufficient sugars will be hydrolised from the starch in the gel. A more realistic explanation might be that the increase in viscosity was brought about solely by the plantain starch whilst the wheat flour provided sufficient hydrolysed starch.

Careful study of Tables 5.6 and 5.7, which show gelling times of wheat flour and of plantain flour will yield an estimate of total baking time for composite plantain flour.

	Time for start of gel	Temperature at the start of gel	Time for maximum gel	Temperature at maximum gel	Maximum gel
100% Canadian Patent Flour (80g)	20 min	57°C	40 min	85°C	665
100% Plantain Flour (80g)	33.5 min	75°C	Beyond the recording of the instrument		
Wheat Flour (85%) + Plantain Flour (15%)	22.5 min	60°C	38.5 min	83°C	1130

Table 5.6 Comparison of the gelling point temperature of wheat strong flour and plantain flour and a composite of both flours.

Table 5.6 shows that the starch of plantain flour takes longer time to start gelling but from the fast rate of gelling as observed during the viscograph test on 80g plantain flour, one can reasonably assume that the time and maximum viscosity at peak gelling would be significantly less than the 40 minutes and 85°C for the 80g wheat flour. This means that when bread dough is prepared from a composite of wheat strong flour and plantain flour, there is the possibility of either producing an under-baked or over-baked bread. This might happen because at a given baking time, the starch of wheat flour might not be fully gelatinised. But if enough time is allowed for the full gelatinisation of the wheat starch, this might result in a very dark crust of the bread, an evidence of over-baking. The dark crust is as a result of caramelisation reaction of the excess sugar contained in the plantain flour with the amino-acid content of the flour at a high temperature.

The production of plantain flour involves heat treatment. This might result in the inactivation of the α-amylase naturally present in the flour, thereby leaving a flour with very low amylase figure.

This hypothesis is confirmed by the fact that the viscosity of corresponding dilution with plantain pulp gave low viscosity (Leather and Wegrzyn 1982). Their results are compared with the results from plantain flour as follows:

	Gelling Point Temp.	Time for start of gelling	Temp. at maximum viscosity	Time at maximum viscosity	Maximum Viscosity
WF(90%) + PF(10%)	60°C	23 min.	83.5°C	39 min.	1118 BU
WF(90%) + PP(10%) solids	61°C	24 min.	86°C	40.5 min	800 BU
WF(85%) + PF(15%)	60°C	22.5 min.	83°C	38.5 min	1130 BU
WF(85%) + PP(15%) solids	61°C	24.0 min.	85°C	40 min	980 BU

WF = Wheat flour; PF = Plantain flour; PP = Plantain pulp.

Table 5.7 Comparison of the gelling properties of plantain pulp and flour.

If the α- amylase content is low, the diastatic activity of the enzyme on the starch will be low. Therefore the starch will gelatinise fully and fast to give the high viscosities shown in table 5.7 above. If a flour, having high protein content of good quality gluten has viscosity above the level of good bread-making, an addition of artifical α- amylase like malt will help to lower the viscosity point. However, care must be taken to add the corect quantity. This does not necessarily apply to the composite flour made from wheat and plantain flour.

In order to investigate the effect of the state of plantain starch and the sugar content of the flour on its viscosity, the viscosities of 45g gelatinised and non-gelatinised plantain flour respectively were determined under the same condition. The results as tabulated in table 5.3 show that the viscosity of the ungelatinised flour is far greater than that of the gelatinised flour. There is also marked decrease in the viscosity with increase in the total sugar content for both gelatinised and non-gelatinised flour. Ayernor (1973) studied the effect of pregelatinisation on the viscosity of yam starch (flour) and found that pregelatinised flour with an initial viscosity 380 BU at 20°C showed a decline in viscosity with rise in temperature. At 95°C, the viscosity fell to 120 BU. He, however, found that the non-pregelatinised flour remained at the initial viscosity of 20 BU up to 74°C and that prolonged heating to 95°C brought the viscosity stable at 730 BU. He attributed the large difference in the maximum viscosities of the two flours to the high physical modification of starch in the pregelatinised flour as viscosity is affected by the size of particles of the dispersed phase of the colloidal system. The obvious conclusion would be that to produce dough of good gelling property for breadmaking a non-gelatinised plantain flour should be used in composition with strong wheat flour.

Gelatinised plantain flour is usually dark brown in colour because of high temperature drying (section 2.4.2, plates 2.5 - 2.7). When used in baking a dark coloured crust was produced which would be unacceptable to consumers. Although a golden-brown colour is desirable in the baking of bread, biscuit and cake, a controlled browning is necessary. Green plantain pulp has been shown to contain about 5% total sugar of which 4.5% is reducing sugar, (section 2.4.2, table 2.6). It contains amino-acids like glycine, (section 2.2.1.2, table 2.4), which could react with the reducing sugar present when heated at high temperatures (180-200^{o}C) to produce brown substance called Melanoidins. The process is called maillard reaction. A pregelatinised plantain flour has undergone this process partially and during further baking the browning reaction might not be effectively controlled.

The main determining factor in deciding if a composite flour will make a dough suitable for breadmaking is the result from the extensograph test. Examining the ratio figures obtained above it can be assumed that suitable dough with acceptable visco-elastic properties would be produced from the 10% dilution for a short to medium length fermentation dough and for a straight"no time"dough, the 15% dilution. All other dough tests gave figures which showed that they were much too stable and lacked suitable viscosity.

5.7 Conclusions

The decrease in dough stability with increase in rate of dilution shows decrease in gluten content of the composite flour. At 10% dilution of strong wheat flour with plantain flour an acceptable dough can be produced even for a process involving a long fermentation period. At 15% dilution an acceptable dough will still be produced if the short process method for breadmaking is used e.g. Chorleywood Bread Process (CBP) and Activated Dough Development (ADD) Process (see section 5.8.1)

The starch of plantain flour has great affinity for water and good water-binding capacity which would result in bread with dry eating crumb (section 5.3.2.3.).

From the point of view of available fermentable sugar, the viscograms indicate that the composite flour would not be suitable to sustain any periods of fermentation over 1½ to 2 hours. However, from the viscosity figures it can be established that plantain flour is mainly responsible for the increase in viscosity. Therefore it is possible to assume that the wheat starch will still provide sugars to the yeast while fermentation is in progress.

A composite flour of equal amounts of strong wheat flour and plantain flour could be used in the manufacture of confectionery products like Madeira Cake. The egg albumen present in the egg used for the cake making will combine with the gluten of the composite flour to form a non collapsable girderwork in the cake provided a balanced recipe is used. Plantain flour which has no gluten forming protein could be called a very soft flour. It can be used in the production of rotary moulded biscuits of the shortcake type, which are not dependent upon a protein structure.

5.8 The Breadmaking Potential of Plantain Flour

5.8.1. Breadmaking processes

The three main methods in breadmaking are Conventional or Traditional (Bulk Fermentation), Activated (Chemical) Dough Development (ADD) and Chorleywood (Mechanical) Bread Process (CBP).

Traditional or Conventional (Bulk Fermentation) Method

This is a straight dough process where all the ingredients are mixed together in one operation and the fermentation carried out in bulk from 30 minutes to about 15 hours, depending on the amount of yeast, water and salt used, the type of flour, the temperature of the finished dough and the room where it is stored (Fance, 1966).

William (1975) described the function of yeast in a fermenting dough as threefold (a) the stretching of the gluten strands by the gas produced with the physical and chemical changes taking place, and the retention of the gas produced giving well-risen loaves, (b) the aeration of the dough by the gas produced during proving and baking to give a palatable texture, and (c) the production of a characteristic flavour of well-made bread.

In using dried yeast or low quality compressed yeast it is usual to prepare a flying ferment to improve rehydration and subsequent fermentation. The ferment is a mixture containing a proportion of water, the yeast, any yeast food and sufficient water to make a thin batter. The yeast immediately begins to ferment and multiply, and soon is active and vigorous, so that it is ready to complete the fermentation of the rest of the flour.

A ferment is generally allowed to stand until it shows signs of collapse. However, the fermentation time can be determined by the quantity of yeast used. In the traditional process, the quantity of yeast is determined to firstly slowly produce gas, to distend and modify the dough structure and then finally to maintain optimum rate of gas production in the final proof stage - commonly up to 4 hours fermentation takes place until the yeast is killed in the oven.

When the rest of dry ingredients are ready, the ferment is added and the dough made up. The dough is then allowed a period for the second stage of fermentation and development. After the bulk fermentation, the dough is divided, allowed to recover, moulded to its final shape and then given the final proof period before baking.

Activated (Chemical) Dough Development (ADD)

This is a no-time method of bread production. By adding reducing agent for example L-cysteine hydrochloride to destabilise the gluten structure and allow rapid modification of the dough, the dough stability is then achieved by the use of oxidising agent. The "no-time" process requires more enzyme activity to feed the greater yeast quantities used and thus produce gas at a faster rate and temperature of 29-32^{o}C are commonly used. Care is needed to adjust water temperature to supply the heat required. This process eliminates "bulk fermentation" time but the final proof period still exists to develop volume and structure in the loaf. The yeast is about double the quantity used in traditional bulk fermentation process for good aeration. The high yeast levels and temperature use food-supplies at much increased rate, so that the original sugars are rapidly exhausted and adequate final proof thus still depends on enzyme activity.

Chemical dough development processes in general use medium strong flours since the prolonged strains imposed by bulk fermentation do not exist while the high levels of oxidants help to stabilise the structure. However, to obtain high water absorption values, flours used for this process invariably have high levels of "damaged starch" and this limits strength reduction. The dough is divided straight from the mixer for final proving and eventual baking.

Chorleywood (Mechanical) Bread Process (CBP)

This is essentially a "no-time" dough process where the modification of the gluten structure of the dough is brought about by prolonged and heavy high speed mixing. The dough materials are subjected to an intensive mechanical mixing within a short period in a suitable mixer capable of introducing a higher work level within a short period. Correct work input is important and temperature needs to be carefully controlled.

This process eliminates the bulk fermentation period, altogether. This is achieved by the intense mechanical mixing which, in the space of only a few minutes, develops the dough in a manner which takes several hours in conventional processes. It is, however, stressed that an oxidant must be used and that fat is necessary as well as extra water in the dough making. As with the ADD process, the correct level of oxidant is required to stabilise the dough structure while the fat lubricates the gluten strain during the high speed mixing.

Williams, (1975) summarised the three principles vital to the production of good quality bread using the mechanical dough development process as follows:

1. A critical minimum level of a specified type of fat.
2. A high and specified level of a particular oxidising agent or combination of oxidising agents.
3. A specific amount of mechanical work: 11 watt hours per kilogram dough must be introduced into the dough during a total mixing time of three to five minutes.

The main difference in the three processes of breadmaking is in the mixing method. Dividing, intermediate proof, moulding, final proof and baking stages often utilise the same machinery and follow the same flow pattern for both mechanical and chemical processes, with relatively small changes from the bulk fermentation process.

William (1975) summarised the differences in the mixing methods for the three processes as follows:

Bulk fermentation:

Conventional slow-speed mixer - 20 minutes approximately. Rest in mixing bowl for three hours in a controlled atmosphere, temperature 27°C, relative humidity 70-75% with a knock back after two hours. Divide.

Chemical dough development (ADD) - No-time process

Conventional slow-speed mixer - 25 to 30 minutes. No bulk fermentation. Temperature 29 - 32^{o}C. Divide immediately.

Mechanical dough development (CBP) - No-time process

Higher - energy input mixer - To a work level of 11 watt hours per kilogram of dough in a time period of 3 - 5 minutes. Need for cold water about 10^{o}C. No bulk fermentation. Divide immediately.

He maintained that in each case improvements in the loaf quality would be affected by alterations to the recipe. With bulk fermented doughs in commercial practice yeast foods such as calcium and ammonium salts, sophisticated fat blends and enzyme-active soya flour are usually added to produce a commercially acceptable loaf. In the case of the dough produced through "no-time" process, the basic formula will give a poor loaf no matter how skilful the baker is though fat and yeast foods will give some degree of improvement.

5.8.2 Selection of a suitable method and level of plantain flour substitution

In a joint investigation with Chilambwe (1980), experiments were carried out to ascertain the extent to which wheat flour could be replaced by plantain flour in the production of high quality bread loaves. The potentials of the conventional (bulk) fermentation, ADD and CBP were assessed in order to select the most technically and economically suitable process. The recipes used were as follows:

Bulk Fermentation		ADD		CBP	
Flour	1000g	Flour	1000g	Flour	1000g
Yeast	20g	Yeast	20g	Yeast	20g
Salt	18g	Salt	18g	Salt	18g
Ambirex	10g	F A D	10g	Dynarex	10g
Fat (Compound)	10g	Fat (Compound)	10g	Fat	10g
Water	600g	Water	600g	Water	600g

Note: 1 The flour represents the total amount of plantain and Canadian (Leviathan) flour or Wheatmeal (Cerovin) used.

2 The composition of the flour was either plantain flour 15% and wheat flour 85% or plantain flour 20% and wheatmeal flour 80%.

The conclusions from this joint work were as follows:-

1 A fully acceptable white bread can be made using 85% wheat white flour (Leviathan) and 15% plantain flour. The crumb and sheen of the bread made from the composite flour were darker in colour when compared with the control bread (100% Leviathan flour). At 20% plantain flour substitution , the crumb and sheen were too dark to be acceptable.

2 A fully acceptable brown bread can be made using 80% wheatmeal flour (Cerovim) and 20% plantain flour. At levels of plantain flour substitution above 20% the loaf volume, crust colour and bloom pile were inferior to the control bread (100% wheatmeal flour). However the crumb colour and sheen were not affected.

3 The bulk fermentation process produced an inferior white bread even at 15% plantain flour substitution when compared with the control bread (100% wheat flour). This was attributed to the low level of gluten present in the composite flour.

4 Although the CBP method gave the loaf of best volume, the process

was considered most unsuitable for African countries because it requires cold water of approximate 10°C, in an area where the average ambient temperature is about 28°C, and the high speed mixer needed is expensive to purchase, to operate and to maintain.

5 The ADD process was considered the most suitable for production of plantain composite bread. It gave a consistent dough comparable with the control. There is no special equipment required unlike the CBP method. Conventional bread mixers are used, the only modification being the extension of the mixing time.

The photographs of the final products produced using conventional (fermentation) and ADD methods are shown in appendix APP5-1. Full details of the test bakes carried out and test data are given in Chilambwe (1980). The details of plantain bread production using ADD method are given below (section 5.8.3).

5.8.3 Pilot-scale production of plantain bread using the ADD method

This work was carried out in Nigeria at the Department of Food Science and Technology, the University of Ife, Ile-Ife.

Equipment

Mixer: Morton (medium size) - Supplied by Morton Machine Co Ltd., Wisham, Scotland

Moulder: Mono-universal - Supplied by D Ayres Jones & Co Ltd., Swansea, Great Britain

Prover, Oven and Baking trays - Supplied by Henry Simon Ltd., Stockport, England

Breadmaking formula

Plantain flour	5.25kg	Salt	525g
Strong Wheat flour	29.75kg	L-cysteine	1.8g
Yeast (Dried)	364g	Ascorbic acid	2.4g
Fat (Compound)	700g	Water	25 litres
Sugar	1750g		

Note: The wheat flour was supplied by The Flour Mills (Nigeria) Ltd.

Dough preparation and baking

The flours were dry mixed to ensure even consistency as shown in plate 5.1. The temperature of water for yeast growth was $31^{o}C$ and after brewing and mixing thoroughly, was poured along with other ingredients into the mixing bowl and blended for 4 minutes at speed one of the instrument. Then the dough was divided into 500g lots and moulded in the automatic moulder. After placing in baking tins, the dough was placed inside the prover (plate 5.2) for about 45 minutes. Water vapour was provided by plain hot water in trays at the bottom of the prover. This water was replaced from time to time in order to maintain a constant supply of moisture for proofing as well as for a humidity of between 75 and 95%. The proofed dough was baked in a gas oven at a temperature of $210^{o}C$. The final baked bread is shown in plate 5.3.

The bread was found to be acceptable to a small group of consumers who bought it at the standard price of 40 kobo (Nigerian) per loaf. There was no change in volume and taste. This recipe contained additional sugar in order to make the bread sweet to Nigerian taste. The bread main-tained its quality for about 5 days when stored in ambient condition of about $28^{o}C$ and 85% relative humidity. Further more detailed tests are required to determine the market demand, price and consumer acceptability of the plantain bread.

5.9 The Cake-Making Potential of Plantain Flour

Different types of cakes are made using different types of flour. Plantain flour is a very weak flour with no gluten-forming protein. The use of strong flour with a high gluten content is not encouraged in cake-making because it produces a stiff batter which reduces the rate of heat penetration to the centre of the cake thus causing the cake to dry out too quickly. (Kent-Jones and Amos, 1967). However, the use of

Plate 5.1 Dry mixing of plantain and wheat flour.

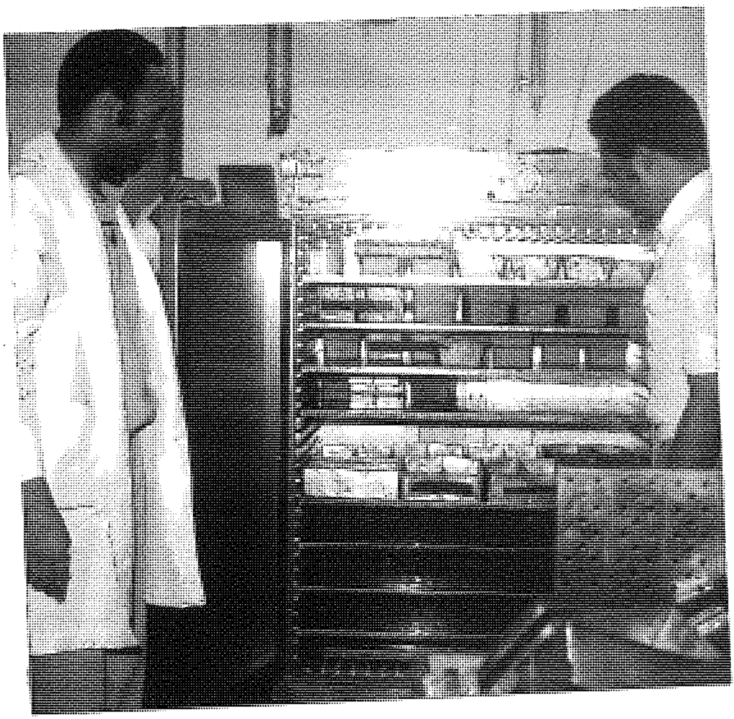


Plate 5.2 Bread prover

Plate 5.3 Plantain baked bread

a composite flour made from a very strong flour and a very weak flour could serve as a suitable medium-strong flour for cake production.

5.9.1 Processes in cake making

Several different methods are used in the preparation of cake batters. The two principal ones are the "sugar-batter" and "flour-batter" methods. Fance (1966) discussed the principles underlying these methods as follows:

Sugar-Batter Method: All the fats and sugar are beaten to a light cream either by hand or machine. In the creaming process, the rapidly moving hand or beater disrupts the surface and enters the mix, drawing air in with it which is retained,provided that the mixture is sufficiently stable. When the fat/sugar mixture is light and fluffy, the eggs are added in suitable proportions and beating continues until the mixture is a smooth, complex emulsion of fat, sugar, eggs and air. A successful mixing requires the right temperature of the raw materials which is between 18 and 21°C. When the last eggs have been beaten in, the flavouring is added and colour adjustment made with a suitable dye. The sieved flour and baking powder are then carefully dispersed through the mix. If milk is used, it is added after the flour has been mixed in so that there is no direct contact with the flour which would result in the formation of gluten and cause toughening of the cake. An adaption of the sugar-batter method is used by some manufacturers who add a proportion of the flour during the fat/sugar creaming stage. This prevents the risk of curdling and the possibility of toughening.

Flour-Batter Method: An equal weight of flour is beaten with the fat until a light and well aerated nature is obtained. The sugar and eggs are whipped together in approximately equal portions, but the whipping should not be prolonged. The sugar/egg ratio should never exceed 1:1.25, and the temperature of the materials should be between 18 and 21°C.

After the addition of egg colour and flavouring to either of the mixtures, the whisked egg/sugar is added to the fat/flour in stages and carefully blended in. Any balance of flour is then added, together with baking powder, and finally milk and fruit are mixed in. A good blending of the two mixtures is necessary because it is important that the air whisked into the mixture is conserved for good aeration. Good cakes can be made by dissolving the sugar into the eggs and adding the solution to the well-beaten fat/flour in portions, beating well after each addition until the mixture is smooth.

Some bakers consider it an advantage to add the acid constituent of the baking powder to the fat/flour mix and the bicarbonate of soda to the sugar/milk solution. In this way little or no reaction will take place between the chemicals until the cake is in the oven.

5.9.2 Plantain Madeira Cake

A joint project was carried out on the use of plantain flour for Madeira cake production. The objective was to determine the extent to which plantain flour could replace strong Canadian flour (Leviathan) for the manufacture of Madeira cake. Both the sugar - and flour - batter methods were used in order to recommend a suitable process. An attempt was also made to produce a Madeira cake using 100% plantain flour. The recipes used were as follows:

Sugar Batter (Conventional)	
Flour	1000g
Sugar	800g
Fat (Cake Margarine)	800g
Egg	800g
Baking Powder	6g
Milk	180g

Flour Batter Method	
Flour	800g
Sugar	800g
Fat (Cake Margarine)	800g
Egg	800g
Flour	200g
Baking Powder	6g
Milk	180g

Note: The flour represnts the total amount of plantain and wheat flour (Leviathan).

The conclusions from this joint work were as follows:

1 An acceptable Madeira cake can be manufactured using 50% plantain flour and 50% strong wheat flour (Leviathan),

2 The use of flour batter method produced a better cake.

3 It is not feasible to produce Madeira cake using 100% plantain flour because it does not contain gluten forming protein (plates 5.4 and 5.5).

Full details of the project are given in Afam (1980).

The production of plantain Madeira cake has been repeated in Nigeria in the Department of Food Science and Technology, the University of Ife. The cakes produced were well received by a small group of selected housewives. Further detailed consumer acceptability and marketing tests need to be undertaken in order to determine the size of possible demand.

5.10 The Biscuit-making Potential of Plantain Flour

Smith (1972) gave specifications that could be used to describe a biscuit product. It should -

1 be based on a cereal content - wheat, oat, maize, barley, soya, rye etc

2 contain less than 5% moisture. If decorated with a non-cereal product (cream, marshmallow, icing, jelly, jam etc) the moisture present in the decoration shall not be considered in the 5%

3 not be considered a biscuit when more than 60% of its total weight is not cereal based

4 be considered a biscuit if so-called by custom, habit or tradition.

The terms biscuit and cookie should be deemed synonymous.

Plate 5.4 Madeira cake made from plantain flour, wheat flour, and equal amount of wheat and plantain flour using flour batter method.

Plate 5.5 Madeira cake made from plantain flour, wheat flour, and equal amount of wheat and plantain flour using sugar batter method.

5.10.1. Classification of biscuits

Wheal (1971 and 1974) described the two methods by which biscuits can be classified - degree of enrichment and processing or by the method of shaping.

5.10.1.1. Classification by enrichment and processing

Biscuits are roughly divided into two main groups, namely "Hard dough biscuits" and "Soft dough biscuits".

Hard dough biscuits

Hard dough biscuits are usually low in combined fat and sugar content and high in water addition at the dough stage. In some cases fat is layered into the dough during processing and if this is taken into account such biscuits have a very high apparent fat content. During processing all traditional 'hard dough' biscuits pass through some intermediary process between the mixing machine and the shaping machine. This intermediary process may take the form of fermentation and surfacing or layering.

Modern trend with some types of hard dough biscuits is to use a chemical action to assist in the conditioning of the protein in the dough and in some cases to reduce or even dispense with the intermediary process. If, however, the intermediary process is dispensed with then the character of the biscuit is altered completely.

Hard dough biscuits can also be subdivided into three groups, lean (water and cream crackers), medium (rich tea, osborne, marie, garibaldi) and puff (butter puffs, waffles, fruit puffs).

Soft dough biscuits

These biscuits are normally high in combined fat and sugar content with a low moisture addition. In processing the dough passes direct from the mixing machine to the shaping machine. They are subdivided into three further classes - short, medium and flow types.

Short biscuits: These are very rich biscuits containing a high percentage of combined fat and sugar but with the fat far in excess of the sugar (e.g. shortbread and shortcake).

Medium biscuits: The medium contain a lower percentage of combined fat and sugar, the balance of which is not quite so critical (e.g. digestive abnernethy).

Flow biscuits: These are also high in their combined fat and sugar content but in contrast to the 'short' types, the sugar greatly exceeds the fat content (e.g. ginger nuts, rice, perkin etc.).

5.10.1.2. Classification by method of shaping

Although the character of the dough in many cases determines or limits the shaping method employed, some doughs may be shaped by a variety of methods each of which may confer not only a different appearance, but also a different texture to the biscuit. The many shaping methods employed include stamp cutting, embossed cutting, rotary moudling, rotary cutting, wire cut, and rout press. The principle of rotary moulding only will be described as it is used for this project.

Rotary moulding: This method of shaping entails smaller machinery requiring less floor space and is relatively simple to operate. Whereas the stamp cutting and emboss cutting methods of shaping require the use of a sheeter, gauge rollers, and a cutting head for shaping, the rotary mould dispenses with the sheeter and the gauge rollers and shapes the biscuit from the raw dough.

The principle of shaping is based upon that used for the hand production of shortbread from wooden blocks or dies. The dies are engraved round a phosphor bronze roller which is known as a "die roller" or a "moulding roller".

In the machine,the moulding roller is placed in front of a steel fluted roller. Above these is the hopper into which the dough is fed . On starting,the two rollers revolve in opposite directions forcing the dough down between them. This action forces the dough into the dies and fills them. Then as the rollers move away from each other,underneath,the dough meets a knife blade which may be either fixed or oscillating. This blade which is flush with the surface of the die roller scrapesoff the excess dough from the die roller, and this surplus forms a sheet on the back roller and revolves with it. Thus there is no waste.

We now have each die filled with dough and the next problem is the extraction of the biscuit from the die without distortion. This is achieved by means of suction. Directly beneath the die roller is a rubber covered roller, around which the extraction web runs. To remove the biscuits from the die roller the rubber roller is raised forcing the extraction web, which is very coarse weave onto the bottom of the biscuit to which it adheres. Then as the extraction web moves away from the die roller the biscuit sticks to the web and is withdrawn from the die. All that remains is for the biscuit to be removed from the extraction web and conveyed to the oven. This is achieved by running the extraction web round a knife edge thus peeling the web away from the biscuit.

The character of the dough used for this method is very important. Obviously,the dough must be strong enough to bind together and withdraw the dough piece complete from the intricate engraving associated with such biscuits as custard cream. On the other hand,should the dough be high in water or syrup and present a sticky surface to the die then again the dough will tend to stick in the engraving when the dough piece is extracted.

The average composition of a rotary dough is

Flour	Sugar	Fat
3	1	1

However it is possible to handle a variety of ginger snaps which possess a low syrup and water content, using a plain round die for this method of shaping.

5.10.2 Factors affecting biscuit flow

The amount of flow or spread developed in a biscuit during baking depends on many factors.

Flour type	Aerating agents	Dough mixing
Fats	Starch	Processing
Sugar	pH	Scrap utilization
		Baking

Smith (1972) maintained that every ingredient used in making a dough, every process and every environmental condition influences the quality of the product. Paramount is the influence of the actual mixing process. The best of ingredients, incorrectly mixed, will yield an inferior product.

Dough mixing

Dough mixing can be considered either by method or degree.

Method: With soft doughs mixing can be carried out by the "All in" method or the "Creaming" method.

The "all in" method is precisely what the name implies, a one stage mixing process whereas the "creaming" method entails the pre-creaming of the fat and sugar, or the fat and part of the flour, before the other ingredients are added and is essentially a two stage process.

The "creamy" method will improve the fat dispersion and will produce a greater shortening effect than that obtained by the "all in" method.

Degree of mixing: Insufficient mixing of a soft dough can lead to irregular flow due to the uneven distributions of the raw materials through the dough mass. It could manifest itself as variations in biscuit sizes over the whole dough run or if really serious as irregularities in the parameters of individual biscuits.

Excessive mixing of soft doughs will result in the development of gluten in the dough and a reduction in shortness. The development of gluten strands within the dough will make it more resistant to flow and in extreme cases may even cause shrinkage.

5.10.3. Development of recipe for plantain biscuit manufacture

"Is it not possible that starch plays as an important a role as the protein ? Yet who has published any work from the starch angle in respect of biscuit making ? Here is a wide field crying out for investigation. Anyone willing to become a pioneer ?" (Smith, 1972).

Since plantain flour has only non-gluten forming proteins, its use as raw material in biscuit production is limited to those biscuits that do not rely on gluten for their structure. Soft dough biscuits like shortcake and flow type biscuits fall into this category (section 5.10.1). The standard recipes for shortcake and flow type biscuits are given in (Wheal, 1971) and are as follows :-

Shortcake Biscuits		Flow-type Biscuit (e.g. Rice Biscuit)	
Biscuit (wheat) flour	1000g	Biscuit (wheat) flour	1000g
Lard/Oleo	180g	Fat (Compound)	170g
Fat (Compound)	235g	Margarine	150g
Icing Sugar	320g	Caster Sugar	650g
Salt	10g	Sodium Bicarbonate	4.5g
Buttablle 570	1g	Cream Powder (Acid Calcium Phosphate)	8g
Egg Colour (Yellow) (Vegetable dye)	0.125g	Ammonium Bicarbonate	5.5g
Water	120g	Egg Colour (Yellow)	2cc
		Water	220g

Initially experiments involved the replacements of biscuit wheat flour in the above standard recipes and the assessment of test bakes.

5.10.3.1 Test Bake 1 - Batch production of shortcake biscuits

Method

Shortcake biscuits were manufactured using the appropriate standard recipe (section 5.10.3) and plantain flours produced after drying plantain pulp at 93°C (ie gelatinised flour) and 50°C (ie ungelatinised). The flours were produced from the same batch of plantain fruit (section 2.3.4.3).

250g of plantain flour were mixed with all the fat in the Hobart Mixer (plate 5.6) for a minute. A creamy dough was obtained. The remaining 250g of flour and the ingredients were then added and the mixing continued for another one minute. The resulting dough was sheeted to a thin layer in the Automatic Pastry (plate 5.7), and the sheeted dough shaped into biscuits using manually operated Machine Cutter (plate 5.8). The biscuits were baked at 232°C in the baking oven (plate 5.9). Two batches of biscuits were produced from the gelatinised and non-gelatinised plantain flours respectively.

Result

The biscuits produced were organoleptically assessed by 12 people. All commented on the bitter or lemon-like taste of the biscuits produced from the flour dried at 93°C. The biscuits produced from the flour dried at 50°C tasted sweet and the colour was brighter.

5.10.3.2 Test Bake 2 - Batch production of flow type biscuits

Method

Flow type biscuits were manufactured using the appropriate standard recipe (section 5.10.3) and ungelatinised plantain flour. The dough produced as in section 5.10.3. 1 was consistent and the sheeting was carried out until a thin sheet of dough was obtained. The baking was carried out at 232°C for 15 minutes. It was noticed that the plantain

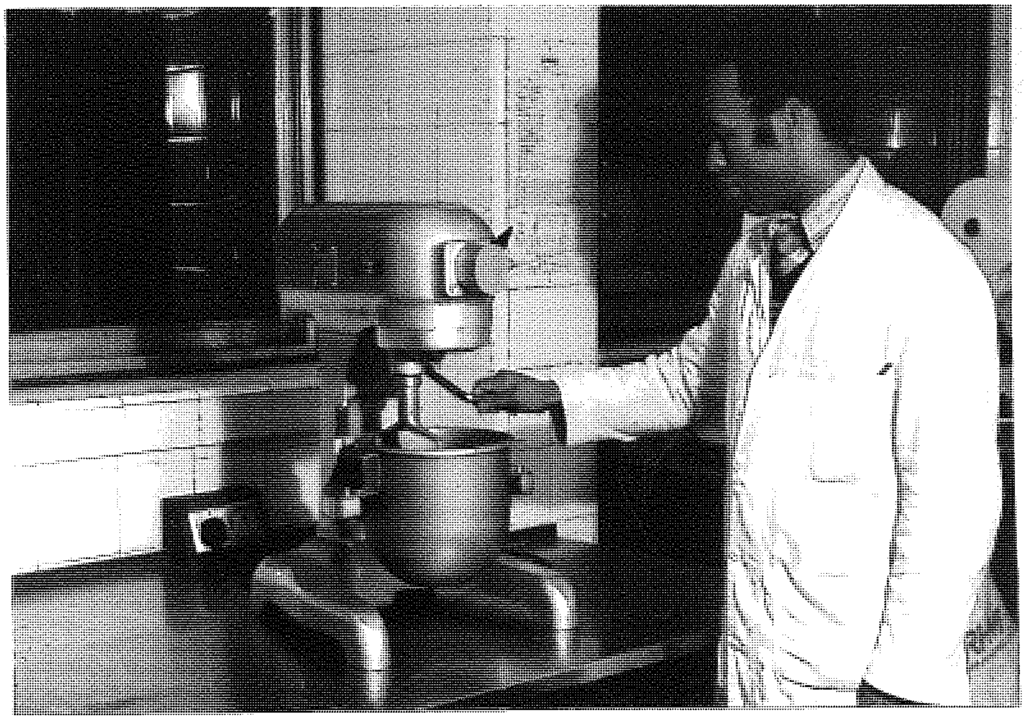


Plate 5.6 Hobart mixer.

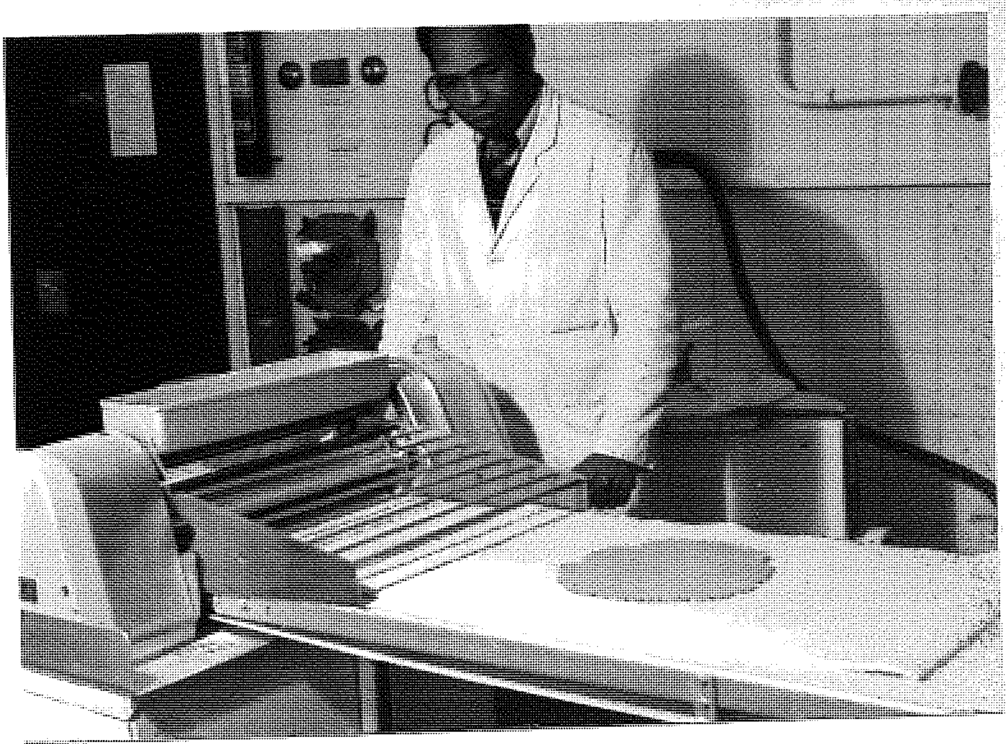


Plate 5.7 Automatic pastry

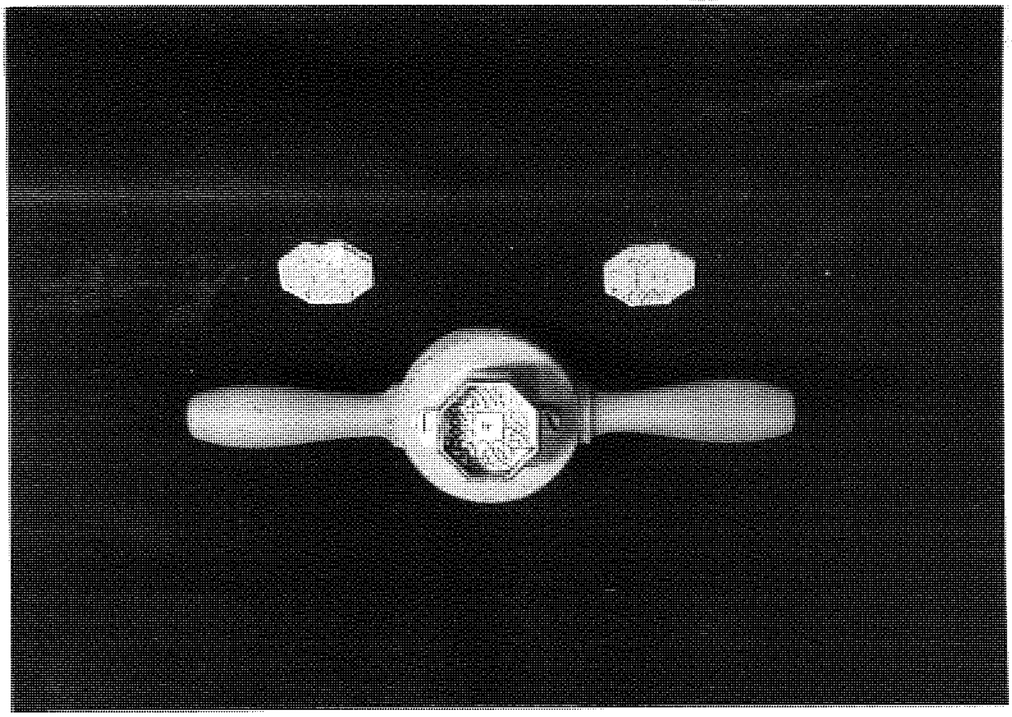


Plate 5.8 Machine cutter.

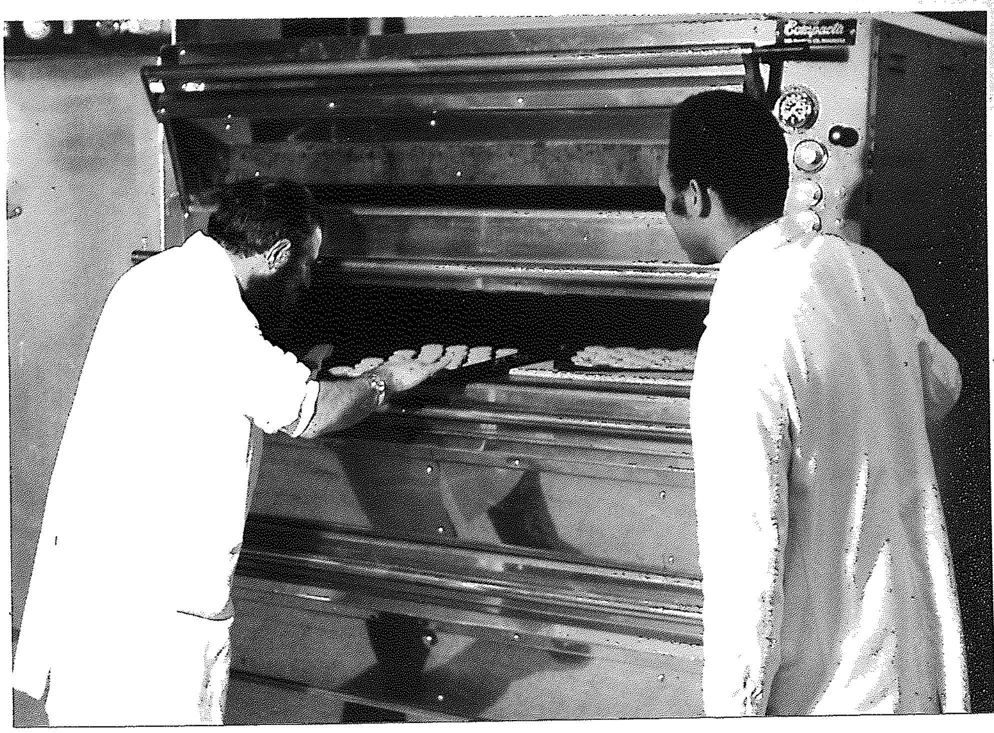


plate 5.9 Baking oven

dough was dry and needed more water for flow.

Result

The biscuits produced were organoleptically assessed by 20 people and the overall reaction was that the plantain biscuits were chewy, soft, undercooked, marginally too sweet and not crumbly. The flavour of the biscuit was claimed to be very acceptable indicating that acceptable biscuit could be baked when the right proportion of ingredients, temperatures and time were employed.

5.10.3.3 Test Bake 3 - Production of flow type biscuits with reduced sugar (section 5.10.3)

Method

The flow type biscuit formula was adopted but 7% less sugar (ie 23g) and 4% more water (ie 4.4g) were used. The baking was carried out at different temperatures and time periods (ie 205°C for 10 mins, 177°C for 14 mins). The dough was easy to handle for both mixing and sheeting. The thickness of the sheeted dough was 3mm.

Result

The biscuits baked for 10 minutes at 205°C were of better brown colour than the ones baked at 177°C for longer time, which looked lighter in colour and seemingly underbaked. The centre core of the biscuits was slightly wet which reduced the crispness at the centre. The periphery was more dry and crisp. The biscuits were still a little over sweet.

5.10.3.4 Test Bake 4 - Production of flow type biscuits with reduced sugar (section 5.10.3)

Method

Flow type biscuits were also manufactured according to a formula in which 10% less sugar (ie 33g) and 4% more water (ie 4.4g) were used.

Also the quantity of the ammonium bicarbonate was increased by 27.3% to increase flow and ensure better aeration. Both hexagonal and circular shaped biscuits were produced. The baking was done at 187°C for 10 minutes. Trays were placed under the baking trays to avoid burning of the under face.

Result

The circular shaped biscuits produced showed some dampness at the centre core which disappeared after 48 hours. The biscuits were moderately crisp and brittle. The hexagonal shaped biscuits baked evenly. The flow was directed perpendicularly outwardly from the periphery. The biscuits produced were crisp, brittle and of good quality.

5.10.3.5 Test Bake 5 - Production of flow type biscuits with final modification of the standard recipe (section 5.10.3)

Method

Flow type biscuits were manufactured according to a formula in which 41% weight of sugar was used instead of the 65% based on the weight of flour stipulated in the formula. Also 23.53% of fat and margarine was used instead of 32%. The baking was carried out at 187°C for 10 minutes.

Result

The hexagonal shaped biscuits were evenly baked and there was no dampness at the centre core. Although that the aeration was not high, the texture of the biscuits was crisp and moderately sweet. There was definite plantain flavour taste and the biscuits absorbed moisture from the atmosphere easily to go soft. There is need for strong moisture proof packaging material.

5.10.3.6 Conclusions from the test bakes

1. It was found possible to produce plantain shortcake and flow type biscuits from 100% plantain flour.
2. Biscuits made from 100% ungelatinised plantain flour were more acceptable in taste and colour than those from pregelatinised plantain flour.
3. Plantain biscuits produced using a modified flow type recipe were better and more acceptable than those produced using the modified shortcake recipe.
4. Choice of temperature and time was crucial for the production of good quality plantain biscuits.
5. The shape and thickness of the biscuit was found to affect the baking time and the quality of the final product.
6. It was most important to check the quality of the raw plantain flour for moisture and sugar contents in order that the correct quantity of flour should be used in the recipe.
7. Two recipes for the production of plantain biscuit are as follows:

Recipe (1)		Recipe (2)	
Plantain flour	1000g	Plantain flour	1000g
Castor Sugar	400g	Pulverised Sugar	400g
Fat (Compound)	170g	Fat (Compound)	322g
Margarine	150g	Sodium Bicarbonate	3.6g
Sodium Bicarbonate	5g	Ammonium Bicarbonate	1.8g
Ammonium Bicarbonate	7g	Water	164g
Cream powder (Acid Calcium Phosphate)	8g		
Egg Colour (Vegetable dye)	2cc		
Water	250 ± 50g		

5.10.4 Pilot-scale production of plantain biscuit using rotary moulder

5.10.4.1 Equipment

High Speed Mixer:	Type Simon Vicars Mark II, Model A Manufacturer: Simon-Vicars Ltd, Newton-le-Willows, Merseyside, England
Rotary Moulder:	Manufacturer: John Pelkman Engineering Co Ltd, 50 Combe Road, New Malden, Surrey, England
Reel Oven with Trays:	Circulation type with 8 swings. Manufacturer: Gilbert-Fyna, G & R Gilbert Ltd, Hackbridge Road, Hackbridge, Surrey, England

5.10.4.2 Procedure

Quantities of ingredients in proportion to receipe (1) (section 5.10.3.3) and the creaming method of blending were adopted.

2kg of plantain flour were mixed with all the fat and margarine in the high speed mixer for about two minutes. A very creamy dough was obtained. The remaining 2kg of flour and the ingredients were then added. The cream powder was dissolved in water and added to the mixture. The egg colour was dispersed in a little quantity of water and rinsed into the mixture.

Altogether about three quarters of the estimated water was added and the mixing carried out for another one minute. Further water was added gradually and mixed until the dough was soft and greasy when touched (plate 5.10).The mixing took altogether four minutes.

The dough was fed into the rotary moulder (plate 5.11) as described in section 5.10.1.2 which when started produced unbaked biscuits in rolls, which were collected in trays.

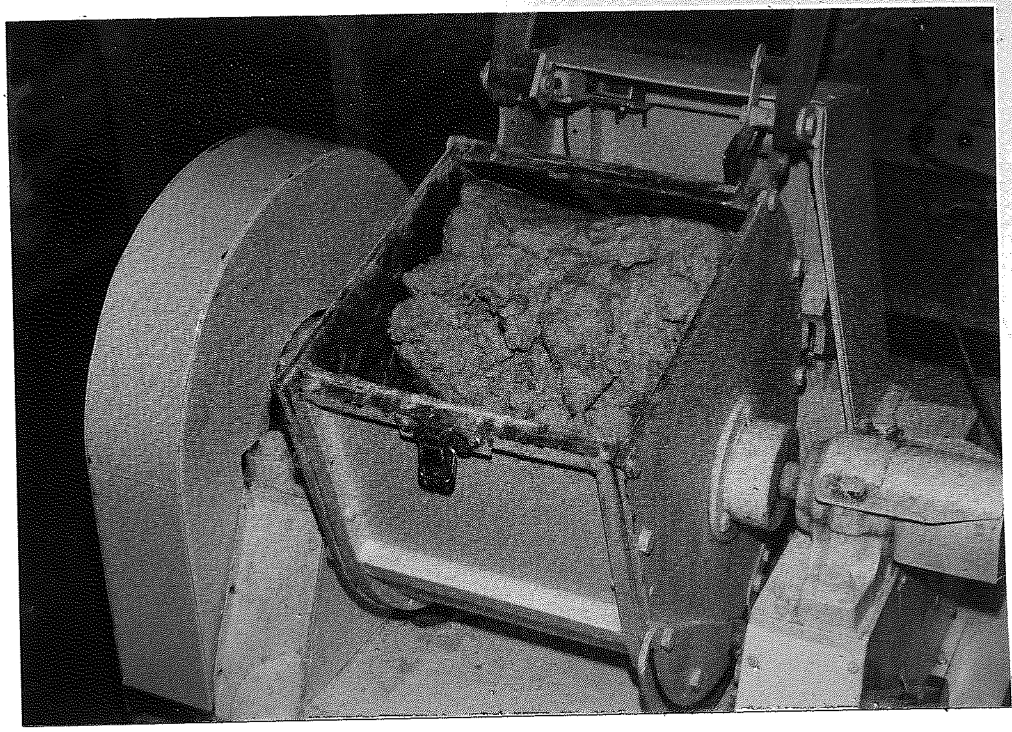


Plate 5.10 Dough mixing in high speed mixer.

Plate 5.11 Rotary moulding of plantain biscuit at South Bank Polytechnic

The trays of raw biscuits were then baked in the reel oven which moved in a circular motion. The temperature of baking was 199°C (380°F) and: the baking was completed in 9 minutes.

5.10.4.3 Comment and Discussion

Since plantain flour contains no gluten-forming protein, the use of fat and margarine is not primarily to act as shortening agents but to enrich and impart flavour to the biscuits. It interferes with the continuous aqueous phase, thus lessening the hardness of the biscuit.

The sugar was used to sweeten the biscuit and contributes to structure. It confers hardness to the biscuit by going into supersaturated solution which sets on cooling to provide the biscuit with a hard structure.

The production of rotary moulded biscuit cannot be varied easily because of the inherent nature of the dough which requires stiffness, crumbleness, low moisture content and relatively high shortening content. This limits the inclusion of ingredients into the dough that would contribute moisture and softening properties.

The biscuits were crisp and sweet and had noticeable pleasant plantain flavour. The distinct plantain flavour made it more acceptable to Africans and Asians who normally eat plantains as their preferred staple. The sweetness of the biscuit could be lessened by reducing the amount of sugar added.

However plantain biscuit has a particular tendency to absorb moisture from the atmosphere and soften. Hence strong moisture-proof packaging material would be required to maintain the quality of these biscuits.

5.10.5 Pilot-scale production of rotary moulded plantain biscuits prepared at the "Flour Milling and Baking Research Association" (F.M.B.R.A)

In order to obtain an independent opinion on the use of plantain flour in biscuit manufacture, the F.M.B.R.A, Chorleywood, England was commissioned to produce plantain biscuit from recipe (2) section 5.10.3 using their rotary moulder. A brief report on the production and modification of recipe (2) by the Association is attached in the appendix APP-5.2 . The production of the moulded biscuits and the final baked product are illustrated in plates 5-12 and 5-13. The baking was carried out in a travelling oven which was electrically heated with forced convection. The trays moved horizontally at a predetermined speed which ensured that all the trays received identical heating.

The main differences between the two recipes involved the water content and the amount of the raising agent used. Less water and no acid powder was used in the Chorleywood process. This resulted in a biscuit that was too friable and powdery in taste. Not all the sugar could go into solution to give a continuous aqueous phase which, when set, will give a hard structure. The lack of water could however be offset by the use of more fat to provide a creamy effect. This was not done at Chorleywood and the biscuit was more like a shortcake. Having used only small amount of raising agents at Chorleywood, the use of acid powder to reduce the alkaline residue and buffer the pH was not considered necessary.

Thus the production of two different biscuits using the same plantain flour has illustrated how a minute change in the recipe could appreciably influence the end product. However it must be reported that consumer reaction towards both type of biscuits was favourable (section 5.10.7.4).

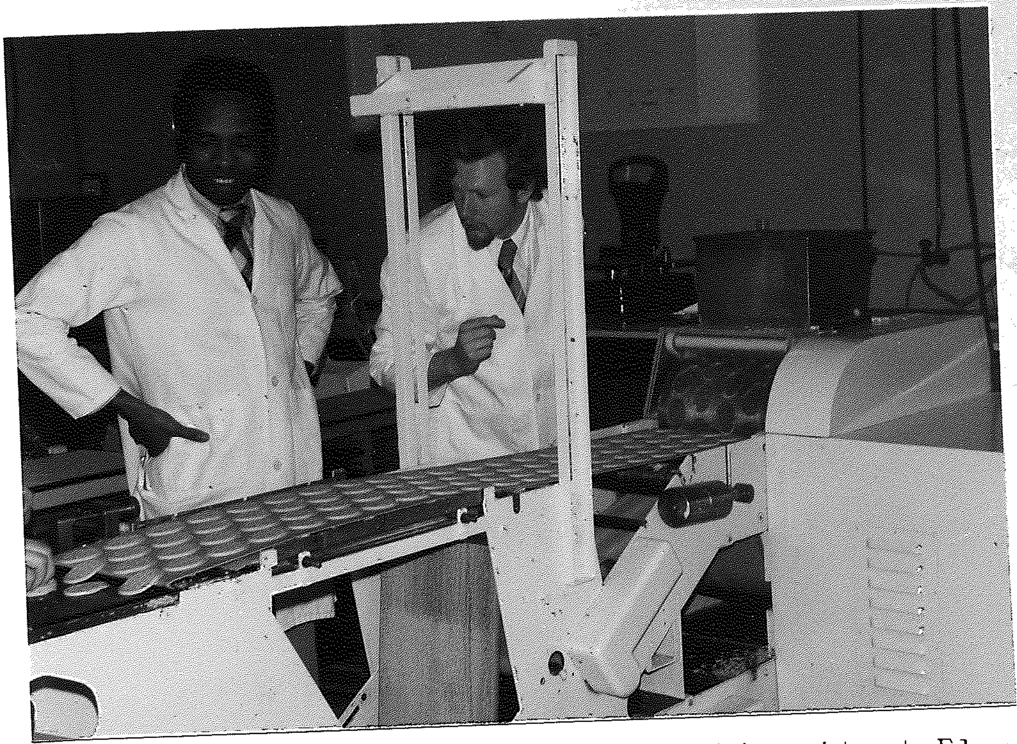


Plate 5.12 Rotary moulding of plantain biscuit at Flour Milling and Baking Research Association (FMBRA), Chorleywood.

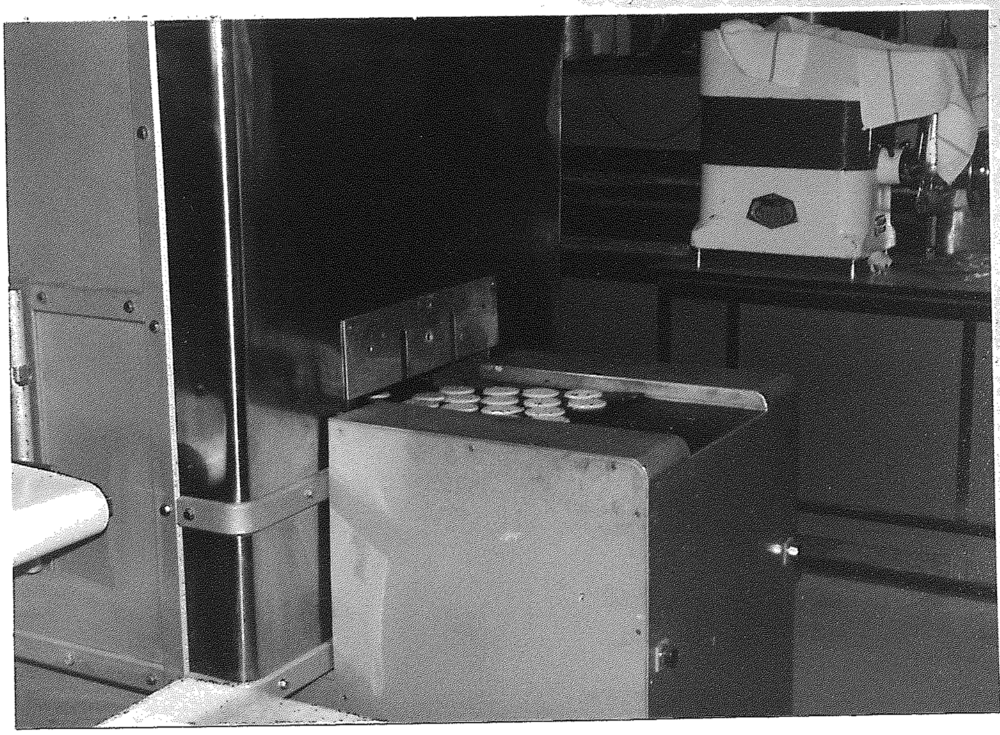


Plate 5.13 Baked plantain biscuits from a travelling oven at FMBRA, Chorleywood.

5.10.6 Production of plantain biscuit using plantain flour and plantain pulp

5.10.6.1 Equipment

As described in section 5.10.4; Kenwood Chef Liquidiser.

5.10.6.2 Development of recipe

A batch process based on recipe (1) (section 5.10.3.6) was used. Green plantain pulp contains about 60% w/w water and plantain flour contains 10% w/w water. Therefore to obtain an equivalent solid plantain pulp containing about 10% moisture, the actual weight of green plantain pulp used was halved (ie for every 100g of pulp, there was 50g of solid with 10% moisture and 50% assumed free water.) It was found from preliminary tests that plantain flour could be substituted with up to 30% plantain pulp (solids) in the making of good consistency dough. Thus the recipe adopted was as follows:

Plantain flour	700g	Sodium Bicarbonate	5g
Plantain pulp	600g	Ammomium Bicarbonate	7g
Castor sugar	400g	Cream powder	8g
Fat (Compound)	170g	Egg colour	2cc
Margarine	150g	Water	30 ± 5g

In the actual trials two assumptions were made that the moisture content of the green plantain pulp was not above 60% (ie 52 - 60% section 2.2.1.3) and that the moisture content of the plantain flour was not above 10%.

5.10.6.3 Procedure

Green plantains were peeled and the pulp sliced into small cubes. The cubes were then liquidised in an electrically-operated Kenwood Chef liquidiser. The liquidised pulp was then mixed with half the quantity of the plantain flour, and all the fat and margarine, in the high speed mixer for about one minute. The remaining plantain flour and ingredients other than the water were then added. The cream powder was dissolved in a small quantity of water before being added to the mixture. This mixture was then blended for about two minutes. The rest of the water was added slowly and the mixing continued until a consistency dough was obtained. Altogether mixing laster for three and a half minutes.

The raw plantain biscuit production using the rotary moulder and baking using the reel oven were carried out as described in section 5.10.4

5.10.6.4 Observation and Discussion

The amount of plantain pulp to be mixed with plantain flour was dependent on the initial moisture content of the plantain flour. The plantain biscuits produced using 30% plantain pulp (solids) and 70% plantain flour were of better quality than those produced using 100% plantain flour. This modified procedure produced biscuits which were hard, crunchy, and less friable than those produced using 100% plantain flour, (Plates 5.14 and 5.15).

Plantain flour takes up water to form a dough for biscuit manufacture. The water added was in the form of free water which can be given up easily during the biscuit baking. In the case of the dough made from a mixture of plantain flour and pulp, some of the water was in bond form. When the biscuit made from it was baked, the water was not given up easily, which resulted in a slow baking of plantain biscuit.

The economic impact of the use of plantain pulp in biscuit making is yet to be assessed. However, the elimination of the drying process for 30% plantain solid required for biscuit manufacture will surely result in saving the total energy imput required to process plantain to biscuit.

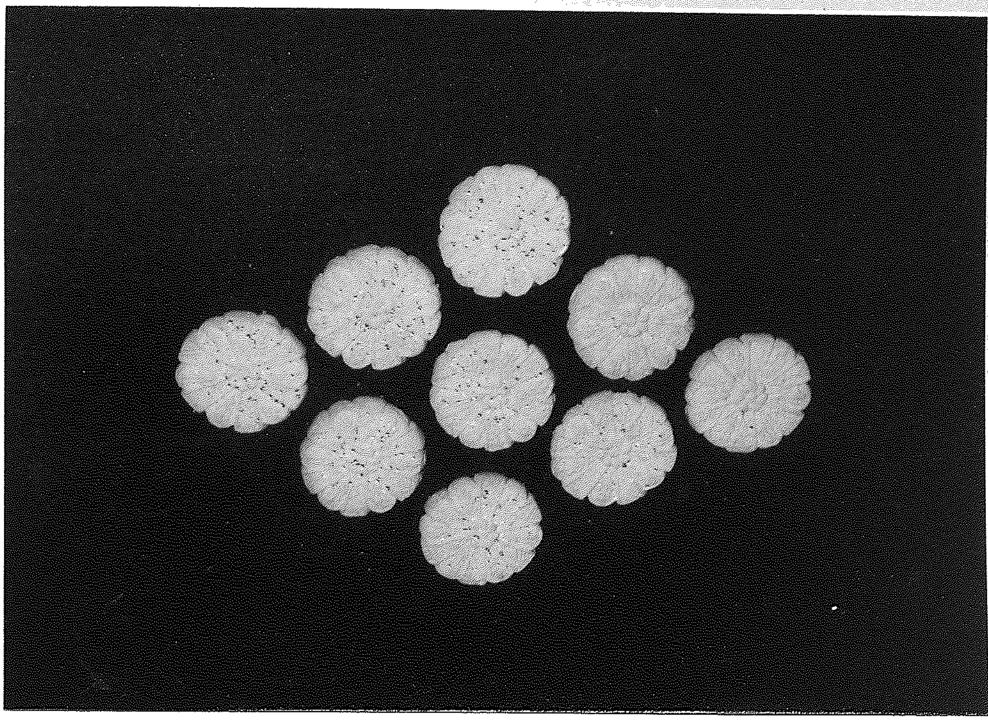


Plate 5.14 Baked plantain biscuits from reel oven at South Bank Polytechnic.

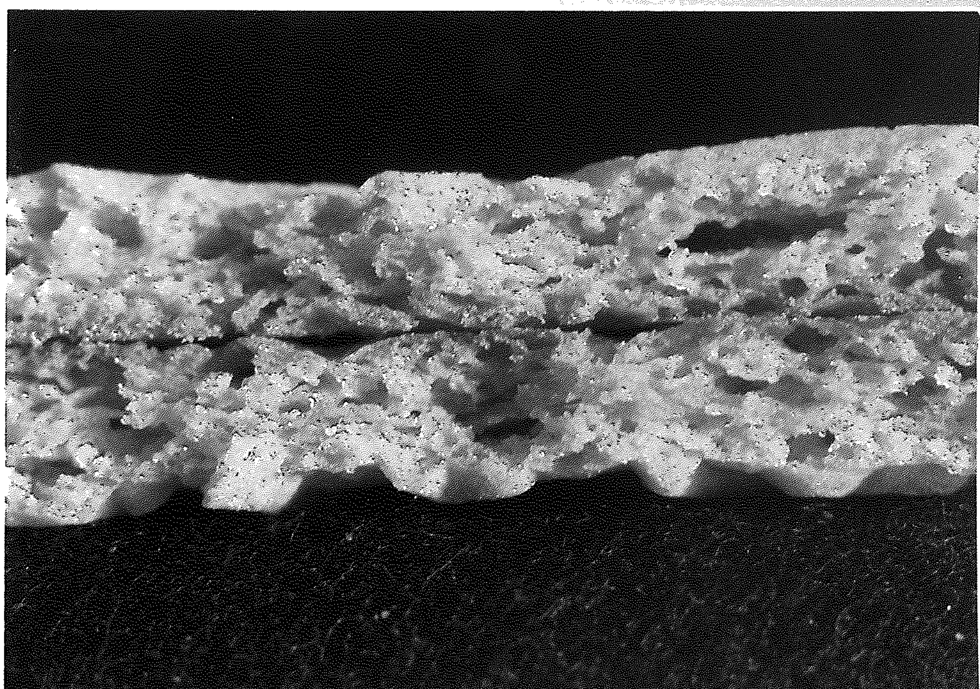


Plate 5.15 The internal structure of the plantain biscuit baked at South Bank Polytechnic.

5.10.7 Consumer Acceptability Test of Plantain Biscuits

Sensory methods of textural measurement involve the use of panels of human judges or assessors. There are two main categories of panel, the trained panel which consists of a comparatively small number (3 to 20) of carefully selected and trained assessors and the so-called consumer panel which consists of a relatively large number (50 or more) of assessors, untrained and randomly selected. The former is used to detect differences between samples, to quantify differences by ranking or scoring and for texture profile work, while the latter is used mainly for preference and acceptance testing.

Consumer test is normally carried out in a representative area where the product would be sold. Simple random sampling techniques offer the most accurate portrayal of the population to be tested.

5.10.7.1 Purpose and Scope

Both the trained and consumer panels were used for the assessment. The main objective was to gain information on the effect of changes in the recipe for the manufacture of plantain biscuit on the quality and acceptability to all social classes. Respondents were divided into three groups, (1) a collection of people of all walks of life at a press conference, (2) school children aged 14 - 18 years from six secondary schools and a small group of research personnels at the Federal Institute of Industrial Research (FIIRO), Lagos.

The press conference was organised at the conference centre of the National Horticultural Research Institute, Ibadan. The people who attended consisted of journalists, prominent farmers, local industrialists, lecturers, civil servants, housewives, directors of other research institutes and some government agricultural policy makers. A total of 41 people filled the questionnaire after testing. The first group represented the type of people who would invest or influence other people to invest in the project. Their opinion could be regarded as independent and objective.

A group of school children was selected from six secondary schools and the questionnaires were distributed to 252 scholars in forms five and six. Although the opinion of children could be influenced easily by things like size, package design and taste, their verdict was still very crucial since most biscuits are eaten by them.

The independent tasting at FIIRO involved 17 trained staff (not necessarily for biscuit testing). The results which have been statistically analysed by FIIRO are continued in the appendix APP-5.3

5.10.7.2 Design of the Questionnaire

The questionnaire was designed so that both triangular test and hedonic scale rating could be carried out at the same time. The tasters were presented with two different biscuits produced using recipes (1) and (2) (section 5.10.3.3) and asked to assess each of the two biscuits after tasting. The ratings for each sample were given numerical values ranging from like very much (7) to dislike very much (1). A sample of the questionnaire is included in the appendix APP-5-4.

5.10.7.3 Results and Discussion

In group (1), (section 5.10.7.1), 26 respondents filled the questionnaire correctly. 8 out of the 15 respondents who filled it wrongly failed to identify the odd sample.

Total and Mean Hedonic Scale Scores for plantain biscuits

	Flow Type (odd)	Shortcake Type (pair)
Total	15.4	14.3
Mean	5.9	5.4
Expression	Like Moderately	Like Moderately

Since only two samples were being evaluated, the mean scores received by each were compared using the t-test and statistical chart. It was found that there was no significant difference at 5% level.

In group (2),(section 5.10.7.1), 163 respondents filled the questionnaire correctly, 69 out of 89 respondents who filled it wrongly, failed to identify the odd sample.

Total and Mean Hedonic Scale Scores

	Flow Type (odd)	Shortcake Type (pair)
Total	738	1007
Mean	4.5	6.1
Expression	Like slightly	Like very much

Using t-test and statistical chart, it was found that there was a significant difference at 0.1% level. The detailed calculation for both trials is shown in the appendix APP-5.5

The reasons given by respondents for preferring one or other were based on the flavour and texture. The biscuits produced using recipe (1) (ie flow type) were judged to have a bitter taste and to crumble too easily. The biscuits produced using recipe (2) (ie shortcake type) were considered softer and sweeter in taste.

In group (1) where the respondents were adults, the flow type had a higher score than the shortcake type indicating a better acceptability.

However, the percentage scores based on the total scores of the two samples (51.85% and 48.15%) were very close, indicating that either of the biscuits could sell equally well.

In group (2) where the respondents were mainly school children, the shortcake type had a higher score indicating a better acceptability. The gap between the percentage scores (57.7 and 42.3) was significant. This can be explained by the fact that children like sweet biscuits, a property that was attributed to the shortcake type.

All the respondents, with the exception of 5, expressed their willingness to buy either of the biscuits if sold in the market.

5.10.7.4 Conclusion

The texture of the plantain biscuits appeared acceptable to the Nigerian consumers. The flow type and shortcake plantain biscuits could be manufactured simultaneously and sold to cater for the different age groups. Plantain biscuits is a new product and has its own characteristic flavour. This might be an advantage for those who love to eat plantain. However, the flavour could be completely suppressed by using other strong flavouring agents if so desired.

5.10.8 Preliminary test marketing of plantain biscuit

5.10.8.1 Introduction

In carrying out consumer acceptability testing, the objective was to ascertain if the consumer liked the product and whether he would be prepared to buy it if sold in the market. However, no information was obtained as to likely market demand which would depend on the price of other competitive products, the advertising and promotional activity.

The concept of test marketing fits in with the desirability of a realistic setting for the determination of the actual degree of acceptance. It enables one to obtain an estimate that translates directly into sales. In this process, the respondents are presented with the opportunity of buying the product.

It has been noted that it is all too easy for a person, even in doubt, to say that he likes a product and might well buy it. However, test buying assures us of a judgement affecting a respondents pocketbook. Actually offering a product for sale using concept exhibits with photographs or finished art work stimulates the first purchase opportunity of consumers who receive price-off coupons for new products which they have not tried before.

The principal danger in using this method is the confounding of price with product acceptance. If a product has few persons interested in buying it, one will have to make sure that high price was not the reason before rejecting the concept. This is very relevant in the case of plantain biscuit which might be compared invariably with wheat biscuit which might be cheaper. On the other hand, some products may have greater purchase appeal if they seem to offer more benefits for less money. Test marketing is a validation study and appraisal of product performance. It helps to ensure that the standards of acceptance are reasonable and in keeping with the overall objective for new product introductions (Sherak, 1966).

5.10.8.2. Cost of production of plantain biscuit

Green plantain was bought at a special rate of 21 pence per 0.45kg. from Brixton Market, London (section 2.3.1). 6kg of plantain flour was used for batch production of the plantain biscuit. To produce this amount of flour, 21.5kg of green plantain was required since 28% by weight of the raw green plantain is produced as flour.

Therefore the cost of green plantain = $\frac{21.5}{0.45}$ x £0.21 = £10.03.
The processing cost was taken roughly as 20% of the cost of green plantain. Processing cost is 20% of £10.03 = £2.
The total cost of 6kg plantain flour = £10 + £2 = £12.
Cost of plantain flour = £12 ÷ 6kg = £2 per kilogram.

Cost Headings	Quantity	Unit Cost (kg) (£)	Total Cost (£)
Plantain flour	6000	2	12.00
Castor sugar	2370	0.38	0.99
Fat (Compound)	1020	0.50	0.51
Margarine (Cake)	900	0.44	0.39
Celophane (bags)	95	0.01(1 bag)	0.95
Raising agents	34	-	0.19
Total Cost		=	£15.03

The cost of biscuit production was taken roughly as 30% of the cost of plantain flour. Processing cost for biscuit production is 30% of £12 = £3.6.

The total cost of biscuit production from green plantain is £15.03 + £3.6 = £18.63.

Quantity of packets of biscuits weighing 100g produced = 93.

Cost per pack to recover production cost = £18.63/93 = 20 pence.

From the above cost headings it is obvious that the cost of plantain flour is about 80% of the total cost. The green plantain fruit was bought as a retail price of 21 pence per 0.45 kg. The wholesale price, which ranges from 15-18 pence per 0.45 kg, could reduce the total cost so that the biscuit could be sold at 20 pence per pack with a little profit. At 20 pence per pack the cost of the plantain biscuit was about double the price of the similar wheat shortcake biscuit. This is understandable when one considers the price of wheat flour (biscuit flour) which was 24 pence per 0.45 kg and compares it with 90 pence per 0.45 kg for plantain flour in London in 1981.

Normally, plantain biscuit would be manufactured for the market of those countries like Nigeria where plantain is grown and is regarded as traditional staple food. In those countries it could be assumed that the cost of green plantain fruit would be cheaper. For example, in Nigeria the unit cost of plantain fruit production ranges from ₦0.05 to ₦0.13 (i.e. 4-10.4 pence per kg; where ₦1 = 80 pence) per kilogram, (section 6.3.3.).

5.10.8.3. Design of the questionnaire for test marketing

The wording of the questionnaire was simple and straightforward so that the consumers could make up their mind easily and waste less time in filling the forms. The questionnaire took for granted that the consumer has already bought the product at a given price and wanted to know if he liked the flavour and if he would buy it again. It also wanted to know if he would buy it at a price 33% higher than the present price. Finally, the consumer was given the opportunity to comment on the product. A sample of the questionnaire is attached in the appendix APP5

5.10.8.4. Scope for the test marketing

The product was sold in the bakery shop of the Polytechnic of South Bank, London to students and staff for one weeek, and to the staff of the Nigerian High Commission in London. 100 packages were also sold at the International Conference on the Resources of Plantain and Cooking Bananas at Ibadan Nigeria.

It is important to carry out the test in a mixed community that is representative of the target market. At the same time, it is important to produce a product that can compete well with other similar products in international market.

5.10.8.5. Results and Discussion

The results are judged from the number of people who completed their questionnaires. This number was not, however, representative of the number of people who bought the biscuits. Altogether 40 people returned their questionnaires in London. Those who bought some in Nigeria paid with naira money and were not included in the analysis.

Analysis of the questionnaire yielded the following results :- 95% of the people who bought the biscuits liked the flavour, 75% indicated that they would buy it again at 15 pence per pack, and only 10% would buy it again at 20 pence per pack. That 75% of the people who bought the biscuits indicated that they would be willing to buy it again at 15 pence even though the price was 50% more than the ordinary wheat shortcake biscuit is noteworthy.

It was observed that some of the consumers of Asian, Indian and African origins bought the biscuits more than once during the week allocated for the sale. However, a much more detailed test marketing should be carried out in the countries where commercial production is likely to be carried out so that the size of demand and the possible market share can be determined.

The objective to assess the behaviour of consumers when they are presented with the opportunity to buy the product has on the whole been favourable and encouraging.

5.11 Summary of Conclusions

1 Rheological studies showed that up to 10% dilution of strong wheat flour with plantain flour can produce an acceptable bread dough even for a process involving a long fermentation period. At 15% dilution an acceptable bread dough could still be produced if the short process method for breadmaking is used (ie Chorleywood Bread Process (CBP) or Activated Dough Development (ADD) Process).

2 Test baking trials showed that acceptable white bread can be produced using 85% wheat white flour (Leviathan) and 15% plantain flour; and acceptable brown bread with 80% wheatmeal flour (Cerovim) and 20% plantain flour. The ADD process was considered the most suitable for the production of plantain composite bread because no special equipment was required and conventional bread mixers could be used.

3 A composite flour of equal proportions of strong wheat flour and plantain flour could be used in the manufacture of an acceptable madeira cake preferably using the flour-batter method.

4 Plantain biscuits of the shortcake and flow types were manufactured using 100% plantain flour. The texture of the biscuits were acceptable to Nigerian consumers and there was distinct plantain flavour which might be an advantage for those who grow and eat plantain. However, the flavour could be completely surpressed by using strong flavouring agents.

5 Preliminary test marketing showed that about 75% of the people who bought the biscuits indicated that they would be willing to buy them again, even though the price was 50% more than the ordinary wheat shortcake biscuit.

However, a much more detailed test marketing should be carried out in the countries where commercial production is planned so that the size of demand and the possible market share can be determined.

CHAPTER 6

Financial and Economic Evaluation

6. FINANCIAL AND ECONOMIC EVALUATION

6.1. INTRODUCTION

6.1.1. The need for an economic feasibility study

It has been established that it is technically feasible to produce plantain food products - flour, biscuit, bread and cake. Whether the commercial production of these products can be recommended will depend on the economic feasibility of the project. It is proposed that the project would be set up as a limited company in which the government may have a share. The company would produce plantain flour and sell it to wholesalers. In this study an economic evaluation of the production of the raw material plantain as well as the plantain flour production process in an agro-industrial venture is carried out.

The factors affecting the economics of plantain processing are reliable supply of raw material, cost of the technology which will depend partly on whether the process is labour or capital intensive, economies of scale, plant location and value to the national economy.

The availability of raw material of adequate quality at a reasonable price is a major concern of all agriculture - based industries. Lack of supplies in sufficient quantities and when required has been one of the major problems of a great number of fruits and vegetable processing plant in Nigeria and other developing countries. McLean (1978), assessing these problems maintained that only two factories of any size operate exclusively as fruit and vegetable processors in Nigeria. These are the Lafia Canning Factory in Oyo State and the Vegetable and Fruit Processing Co Ltd in Borno State. The Lafia Canning Factory produces fruit juices and obtains half the raw material from its own estate and the remainder from local farmers. But the total raw material available is only sufficient to enable the plant to operate at about 30 per cent of its full capacity. The Vegetable and Fruit Processing Co. Ltd has its own tomato plantation and produces a substantial quantity of tomato paste, its sole product. Two other producers of tomato paste, Cadbury Nigeria Ltd in Zaria, Kaduna State and Akesan Food Industry Ltd in Oyo State have closed their factories because of supply difficulties.

In view of the above it is necessary to give careful consideration to the problem of adequate supply of plantain fruit.

6.1.2. Problems of traditional cultivation of plantain

Plantain is grown traditionally on smallholdings by rural households, although some small scale plantations have recently been set up. The major problems confronting traditional farmers are pests, climate, and damage by wind.

Many local farmers claimed that when insects attack plantain leaves, the latter change from green to yellow colour resulting in poor yield during harvest. The problem of insect attack on plantain leaves is not restricted to small plantain farmers. During a group discussion on plantain protection, it was estimated that the losses of plantain in Africa due to the attack of black sigatoka insect could be up to 50 per cent unless adequate control is applied (2nd International Conference on Plantain and Cooking Bananas, 28 July- 1 August 1981, held at International Institute for Tropical Agriculture, Ibadan, Nigeria). The attack of black sigatoka on plantain has reduced its yield in Central America and it is claimed that the spores of the insects are usually found on the lower side of the leaves and would be better killed by fungicide applied using knapsack spraying.

In Nigeria the year falls neatly into two seasons, the rainy season between April and September and the dry season between October and March. Planting is carried out traditionally at the beginning of the rainy season resulting in a marked seasonal pattern of production of plantain fruits. Over 70% of the harvest is obtained between July and December. During the rainy season, there is the problem of draining water logged land which could be solved by providing ditches. In the dry season plantain stems dry out resulting in the loss of some stands. This could be prevented through irrigation.

The problem of wind damage is the greatest cause for concern to all the farmers. About 10% of the plantain stands on average are damaged by wind annually. The effect of wind could be lessened by providing wind-breaks.

6.1.3. Scale of farming and processing plant:

In practice the farm will have to grow gradually. It is important that the scale of farming should match the projected scale of processing. Fenn (1971) stressed the difficultly in organising raw material supplies for larger plants in addition to the problems of capital and management. The small processing unit is better able to cope with irregular supplies because its overhead costs are low. The larger the processing plant the further afield it has to go to find its total supply requirements. Also the risk capital increases as the plant capacity increases. Therefore the plant capacity is dependent on the amount of raw material to be processed but should be large enough to justify the expenditure in capital and overhead costs.

Mante (Personal Communication - 1979) suggested that a horticultural farm should develop gradually from a small to a medium size and that operators can be classified as full time small scale farmers when they maintain between 10 and 30 hectares of plantation. Mante found that at size below 10 hectares the farmers tend to work part-time on their farms. The experience acquired from the small plantation (i.e. between 10 and 30 hectares) is utilised in the establishment of medium scale plantations where additional short-time farm management training is desirable. Contract farming involving local farmers, as an alternative to own estate for a processing plant offers more security to small and medium size farmers not only in terms of price guarantee but also as an assured market for their produce. This could be considered as a supplementary source of supply.

There is need for a plot to lie fallow for some years before planting on it so that a better yield could be obtained. Brandt (Personal Communication - 1979) studied the farming system for banana production in Uganda and recommended that a plantation plot should be left fallow for about 3-4 years with elephant grass growing on it if possible before planting bananas on it.

In view of the above considerations, the plantation and processing plant will be planned to produce 1000 kg of plantain flour a day through one shift operation. It is estimated that an area of 100 hectares of plantain plantation will produce enough plantain fruit to enable the plant to operate for 240 days in a year. However in practice, the plantation will be started on a medium scale of 30 hectares per year and will build up gradually to the required size over a number of years. This development will have to also allow for a part of the plantation area to lie fallow for a minimum of two years after the previous stands have been removed from the land. The overall plantation size will therefore be considerably larger than 100 hectares. During the early stages of plantation development, it is proposed that contract farming will be tried out. If contract farming proves to be successful, it may also be continued on a limited scale.

The economic assessment of plantain flour production will be carried out in two stages, namely the cost of production of plantain fruits and the processing cost for plantain flour production, section 6.3. This will be carried out on the basis of financial cost analysis and then in terms of the benefits and costs to the national economy.

6.2. Production of Plantain Fruit and Flour

6.2.1. Agronomic data on plantain fruit production

Fruit production will be based on a 100 hectare plantation size. A difficulty in making an economic assessment of plantain production is that large scale production of a wholesale trade in plantain are limited. Therefore the production costs and wholesale market price of plantain for a potential flour producer are not easy to establish. The cost of plantain cultivation is estimated from agronomic data as shown below. For the purpose of our calculations it will be assumed that all fruits for the processing plants are obtained from the 100 hectare plantation.

Plantain fruit can now be obtained all year round by scheduling planting over a period of 12 months (Sanchez Nieva et al 1971). There will be need for irrigation during the dry season. But in an area like River State of Nigeria, where rainfall is adequate for about 9 months of the year, the cost of irrigation will be minimal (Swennen - Personal Communication 1981). Estimates made by Devos and Wilson (1978), Ndubizu and Obiefuna (1979) and Obiefuna (1980) suggest that between 1600 and 2000 plantain stands can be established in a hectare of land. For the proposed plantation, it is assumed that 1800 stands per hectare will be maintained. On the average, a bunch contains 35 to 38 fingers with an average finger weight of 250g in the first three years and 175g in the remaining period of production. A plantain stand produces a single bunch every year. However, Obiefuna(1980) established that by planting early and late sword suckers, one can maintain two suckers for the ratoon crops. A ratoon crop is a sucker produced by the parent plant which is allowed to flower along side the parent plant. This is also known as maintaining two suckers per mat. Thus, the total yield of plantain from the experimental hectare can be raised from 15,000kg in the first year of harvesting to 26,000kg in the second year, an increase of 73%. Therefore it is reasonable to carry out the calculation on the yield per hectare based on 15,000kg for the first year and 26,000kg for the second year of harvest and later years. The increase in total yield due to the ratoon crop makes it possible for the revenue from plantain sales to exceed the costs of plantation from the second year of fruit harvest, (Ndubizu and Obiefuna 1979). They also recommended that a stand should be replaced after eight years from the date of planting since the yield would fall sharply after that. For the planned plantation, a ratoon crop will be maintained while other suckers will be sold.

Obiefuna (1980) established that a plantain stand flowers in ten months from date of planting and produces an average of three suckers in the first six months of planting. He planted suckers in early April and obtained mature fruits between April and June the following year. The planting was at the beginning of the rainy season and flowering occurred after about seven months. On average, the total time between planting a sucker and harvesting the mature fruit is between twelve and eighteen months.

6.2.2 Labour Requirement of Plantain Fruit Production.

Ndubizu and Obiefuna (1979), Obiefuna (1980), estimated that the labour requirements for a hectare of plantain plantation is between 180 and 200 man-days in the first year but much lower in subsequent years. Swennen (Personal Communication - 1981) found that for a 5 hectare plantation in his experimental plot in Ohne, River State of Nigeria, 6 men were employed during the rainy season and 3 men during the dry season. This means that a total of 1200 man days was required for a 5 hectare plantation in a year as unskilled labour. Wachuku, (Personal Communication - 1981) employed 12 unskilled labourers to maintain his 12 hectare plantation and assigned one person to a hectare permanently all year round. He also employed an extra person as clerical officer. He claimed that he recovered his capital cost for the plantation in the second year of harvesting. The one person per hectare works out to be 1260 man-days for 5 hectares, working 5 days in a week. Therefore it will be assumed that a total of 100 unskilled labour will be required for a 100 hectare plantation. In addition, some skilled staff will be required as shown in the organisational chart (figure 6.1) for fruit production.

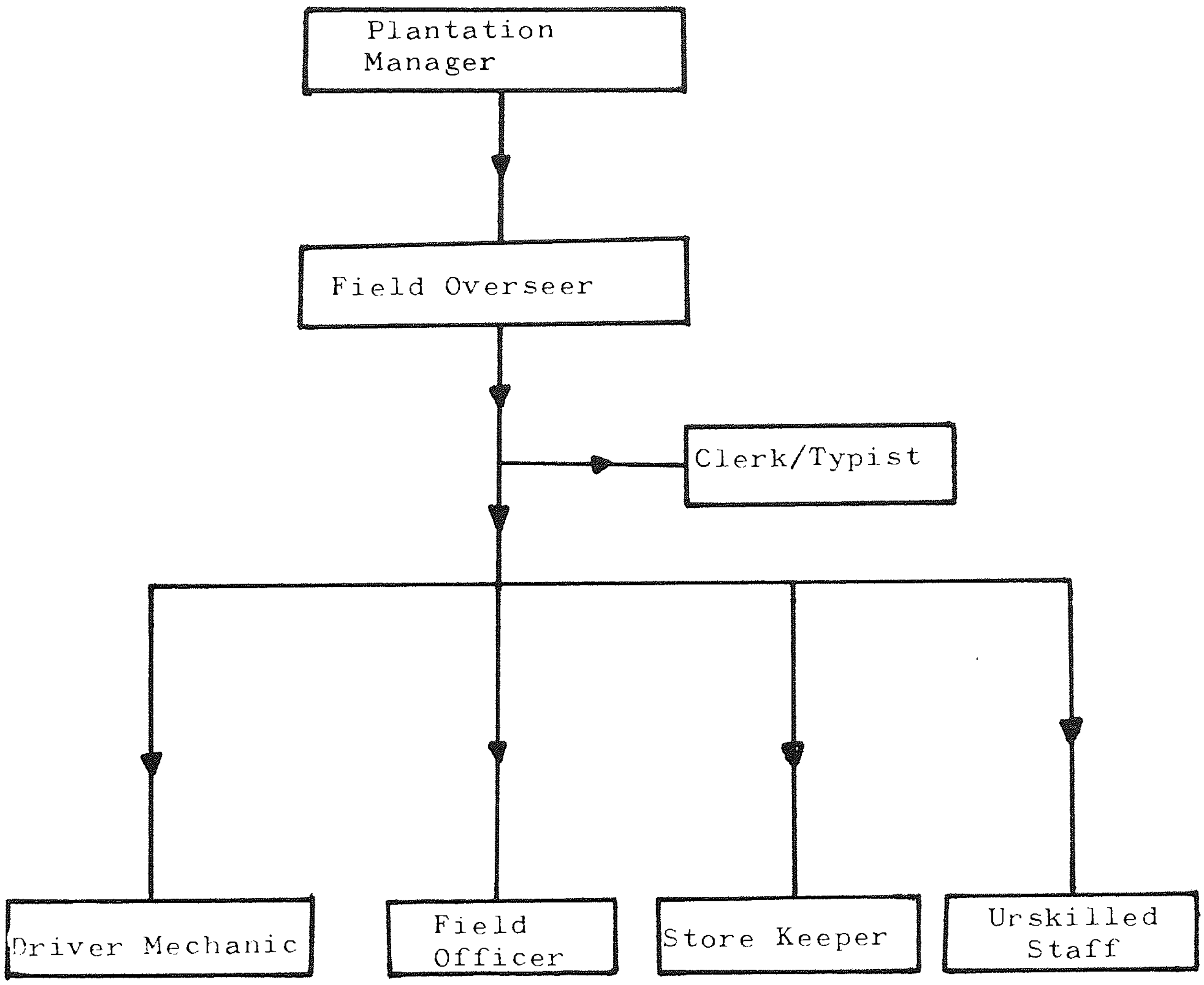


Figure 6.1 Organisational Chart for Plantain Plantation Management.

The above seems to be a reasonable organisational chart for the size of operation. As the plantation grows in size a larger number of employees may be required. Obviously an expanded plantation will require large scale plantation management expertise and further consideration will have to be given to large farm implements and infrastructure which are beyond the scope of this work.

The manager will be responsible for overseeing implementation and running of the plantation. He will select the other members of the staff who will be responsible to him. He will organise and direct the activities of other employees with view to ensuring the proper functioning of the whole plantation and a regular supply of raw material for the processing plant. Briefly his tasks would include:

1. procuring and ensuring the proper distribution and use of all inputs.
2. directing farming operations with special care so that they correspond with the rotation plan and the principles of good land and water management.
3. collecting and arranging the delivery of the produce to the processing plant.

6.3. Economic and Social Benefits and Financing

The main purpose of economic evaluation of a project is to ensure that adequate returns are obtainable from the capital employed. The value of return on investment may be assessed as a percentage rate of return. The return on investment (ROI) and two somewhat more sophisticated measures, the discounted cash flow (DCF) and the internal rate of return (IRR) are commonly used in carrying out project appraisal. Brief descriptions of these measures are given below with a view to choosing the appropriate approach for the evaluation of plantain flour production. A simple illustration (see table 6.1) is used.

Year	1	2	3	4	5	6	7
Net Income (after tax)	-1000	200	300	250	250	250	250

Table 6.1 Stream of Cash Flows over time.

In the illustration it is assumed that ₦1000 was invested in a project in the first year. The net income after all expenses have been met is given for each year for the period of the operation of the project as shown in the table 6.1. The pay back period (the period required to recover the investment capital) is 4 years.

6.3.1 The RO1, DCF, and IRR of the Streams of Cash Flows

The Return on Investment is the average annual net cash flow as a percentage of the total fixed investment. In the illustration (table 6.1) ROI will be 25 per cent. This approach, however, has a number of serious limitations. It ignores the fact that costs and benefits accruing at different times have different values. The values are different because of inflation and in any project evaluation the cash flow should be presented in real terms.

Even if the actual cash flows are in real terms, there is a difference between the values of costs and benefits at different time because of opportunity cost. For example, £100 which will be available in two years time is not identical to £100 that is available now, since the latter can be invested to produce more than £100 in two years. It does not allow comparison of the effects of rapid recovery of costs and delayed recovery, an important factor in situation of high risks. It does not give the duration of the project.

If we know the opportunity cost of capital(i.e. the return on the best alternative use of capital) the net present value (NPV) can be found by discounting the future net cash flows back to the present. For the above example, assuming that the opportunity cost of capital is 8 per cent, we have

$$NPV = -1000+\frac{200}{(1.08)}+\frac{300}{(1.08)^2}+\frac{250}{(1.08)^3}+\frac{250}{(1.08)^4}+\frac{250}{(1.08)^5}+\frac{250}{(1.08)^6}$$

$$= -1000+185.19+257.2 + 198.5 + 183.76 + 170.15 + 157.54$$

$$= 152.34$$

The NPV is positive showing that the project is worthwhile at 8 per cent opportunity cost. The limitations of this approach are the uncertainty about the opportunity cost of capital and lack of information on the closeness of the project to the margin of acceptability.

The IRR gives the maximum opportunity cost of capital at which the project is worthwhile. The IRR is normally defined as the rate of return that makes the NPV zero and is calculated on this basis. Let r be the rate of return. To find its value we solve the equation,

$$-1000 + \frac{200}{1+r} + \frac{300}{(1+r)^2} + \frac{250}{(1+r)^3} + \frac{250}{(1+r)^4} + \frac{250}{(1+r)^5} + \frac{250}{(1+r)^6} = 0$$

$$r = 0.128$$

Therefore the IRR for the project is 12.8 per cent which is higher than the 8 per cent interest charge on borrowed money (ie cost of capital). The limitation of the IRR is that by itself it does not give any indication of the size of capital investment.

Inevitably, there will be uncertainties, hence the need for the application of sensitivity analysis. This identifies the costs and other assumptions to which profitability of the project is most sensitive.

In view of the above considerations, in our evaluation the NPV and IRR measures of project profitability will be employed in parallel. For plantain fruit production and its processing into flour, the costs of fruit and flour production will be estimated. Cash flows for an integrated complex, comprising a plantation and a factory will be determined for each year, followed by the determination of the NPV and IRR. Sensitivity analysis will only be applied to examine the effect of different levels of sales of suckers on the profitability of the project (i.e. on the NPV and IRR). The economic benefits of the project to the Nigerian economy will be considered in section 6.6.

6.3.2. The Unit Cost of Fruits Production

In order to calculate the unit cost of plantain from a 100 hectare plantation, the capital, operating and administrative overhead costs were determined as shown in table 6.2(a). The annual cost of production was calculated after depreciating the capital cost of different items for a number of years using the straight line depreciation method (table 6.2(b)). The actual duration of farm implements will depend on individual use but from studies of labour intensive projects, the assumptions made in the note for tables 6.2(a), 6.2(b) and 6.2(c) seem to be reasonable.

ITEMS/YEARS (e)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CAPITAL COSTS (a)+(b)																
100 Spade at ₦ 4 each	400	400			400				400	400			400			
100 Machets at ₦ 4 each	400	400			400				400	400			400			
100 Handhoes at ₦ 2 each	200	200			200				200	200			200			
50 Wheel barrow at ₦ 28 each	1400				1400				1400				1400			
25 Meter tape steel at ₦ 24 each	600				600				600				600			
10 Weighing Balances at ₦ 1000 each	10000								10000							
1 Tractor with accessories	10000								10000							
1 Farm House	50000															
5% for Maintenance & Repairs	3650	50			150				1150	50			150			
5% for Contingencies	3650	50			150				1150	50			150			
Total Capital Cost	80300	1100			3300				25300	1100			3300			
OPERATING COSTS																
Plantain Seeds(Suckers) at ₦ 25 per sucker	45000								45000							
Fertilizer at ₦ 4.0 per 50kg bag	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000
Furadan 10g at ₦ 2.5 per kg	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625
Insecticide(Agrottion) at ₦8 per kg	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1439
Fuel (c)	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Driver/Mechanic (c)	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Wages (Unskilled labour) (g)	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000
Total Operating Cost	208063	163063	163063	163063	163063	163063	163063	163063	208063	163063	163063	163063	163063	163063	163063	163063
ADMINISTRATIVE OVERHEADS (g)																
1 Manager	4668	4818	4968	5118	5268	5418	5568	5718	5868	6018	6168	6318	6468	6618	6768	6918
1 Field Overseer	2532	2652	2772	2892	3012	3132	3252	3372	3492	3612	3732	3852	3972	4092	4212	4332
4 Semi Skilled labour	6000	6200	6400	6600	6800	7000	7200	7400	7600	7800	8000	8200	8400	8600	8800	9000
Stationery	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
5% for Fringe Benefits (e.g. Housing allowance)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Total Admin Cost	15450	15920	16390	16860	17330	17800	18270	18740	19210	19680	20150	20620	21090	21560	22030	22500
Overall Cost	303813	180083	179453	179923	183693	180863	181333	181803	252573	183843	183213	183683	187453	184623	185093	185563

see notes for a,b,c,d, & g.

Table 6.2(a) The Capital, Operating and Administrative Costs for Plantain Fruits Production

ITEMS/YEARS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CAPITAL COSTS																
100 spade at ₦4 each	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
100 Machets at ₦4 each	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
100 Handhoes at ₦ 2 each	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
50 Wheel barrow at ₦ 28 each	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
25 Meter tape steel at ₦ 24 each	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
10 Weighing Balances at ₦ 1000 each	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
1 Tractor with accessories	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
1 Farm House	6250	6250	6250	6250	6250	6250	6250	6250	6250	6250	6250	6250	6250	6250	6250	6250
5% for Maintenance & Repairs	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325
5% for Contingencies	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325
Total Capital Cost	10400															
OPERATING COSTS																
Plantain Seed (Suckers) at ₦ 0.25 per sucker	5625	5625	5625	5625	5625	5625	5625	5625	5625	5625	5625	5625	5625	5625	5625	5625
Fertilizer at ₦4.0 per 50kg bag	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000
Furadan 10G at ₦2.5 per kg	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625	15625
Insecticide(Agrattion) at ₦8 per kg	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438	1438
Fuel	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Driver/Mechanic	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Wages(Unskilled Labour)	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000	120000
Total Operating Cost	168688															
ADMINISTRATIVE OVERHEADS																
1 Manager	4668	4818	4968	5118	5268	5418	5568	5718	5868	6018	6168	6318	6468	6618	6768	6918
1 Field Overseer	2532	2652	2772	2892	3012	3132	3252	3372	3492	3612	3732	3852	3972	4092	4212	4332
4 Semi skilled labour	6000	6200	6400	6600	6800	7000	7200	7400	7600	7800	8000	8200	8400	8600	8800	9000
Stationery	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
5% for Fringe Benefits(e.g.Housing Allowance)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Total Annual Admin Cost	15450	15920	16390	16860	17330	17800	18270	18740	19210	19680	20150	206620	21090	21560	22030	22500
Overall Annual Costs	194538	195008	195478	195948	196418	196888	197358	197828	198298	198768	199238	199708	200178	200648	201118	201588

Table 6.2(b) Annual Cost of Fruit Production with Capital Cost Depreciated for the Appropriate Years

Table 6.2(c) The Unit Cost of Fruit Production

PLANTAIN ESTATE (100 Hectares) YEARS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
OVERALL COST N	194538	195008	195478	195948	196418	196888	197358	197828	198298	198768	199238	199708	200178	200648	201118	201588
INCOME																
Number of fingersat 38 fingers per bunch minus 10% less due to wind damage		6.156×10^6	12.312×10^6	12.312×10^6	12.312×10^6	12.312×10^6	12.312×10^6	12.312×10^6	12.312×10^6	6.156×10^6	12.312×10^6	12.312×10^6	12.312×10^6	12.312×10^6	12.312×10^6	12.312×10^6
Weight of Fruit at 0.25 kg per fingers 1,000,000kg(e)+(f)		1.5390	2.6675	1.7785	1.7785	1.6005	1.6005	1.6005	1.6005	1.5390	2.6675	1.7785	1.7785	1.6005	1.6005	1.6005
Saleable suckers minus 10% loss due to wind damage	324000	486000	486000	486000	486000	486000	486000	324000	324000	486000	486000	486000	486000	486000	486000	486000
Revenue from suckersale at N0.25 per sucker (A) 100% Sale of Suckers N	81000	121500	121500	121500	121500	121500	121500	81000	81000	121500	121500	121500	121500	121500	121500	121500
Unit Cost of Fruit Production N/kg		0.05	0.03	0.04	0.04	0.05	0.05	0.07	0.07	0.05	0.03	0.04	0.04	0.05	0.05	0.05
(B) 75% Sale of Suckers	60750	91125	91125	91125	91125	91125	91125	60750	60750	91125	91225	91125	91125	91125	91125	91125
Unit Cost of Fruit Production N/kg		0.07	0.04	0.06	0.06	0.07	0.07	0.09	0.09	0.07	0.04	0.06	0.06	0.07	0.07	0.07
(C) 50% Sale of Suckers N	40500	60750	60750	60750	60750	60750	60750	40500	40500	60750	60750	60750	60750	60750	60750	
Unit Cost of Fruit Production N/kg		0.09	0.05	0.08	0.08	0.09	0.09	0.10	0.10	0.09	0.05	0.08	0.08	0.09	0.09	0.09
(D) 25% Sale of Suckers N	20250	30375	30375	30375	30375	30375	30375	20250	20250	30375	30375	30375	30375	30375	30375	30375
Unit Cost of Fruit Production N/kg		0.11	0.06	0.09	0.09	0.11	0.11	0.11	0.11	0.11	0.06	0.10	0.10	0.11	0.11	0.11
(E) 10% Sale of Suckers N	8100	12150	12150	12150	12150	12150	12150	8100	8100	12150	12150	12150	12150	12150	12150	12150
Unit Cost of Fruit Production N/kg		0.12	0.07	0.10	0.10	0.11	0.11	0.12	0.12	0.12	0.07	0.10	0.10	0.12	0.12	0.12
(F) No Sale of Sucker Unit Cost of Fruit Production N/kg		0.13	0.07	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.07	0.11	0.11	0.13	0.13	0.13

See notes on (e), + (f)

Table 6.2(c) The Unit Cost of Fruit Production

Notes for tables 6.2(a) and 6.2(c)

(a) The price lists were obtained from U.T.C. ware Ibadan or CIBA- geigy Enugu for 1981 price.

(b) All spades, machets and handhoes will be replaced in the second year after land preparation and planting. Thereafter they will be replaced after every three years. The wheel barrow and meter tape will be replaced after eight years and the farm house written off after sixteen years.

(c) From the experience of project appraisals carried out in developing countries, it is estimated that the fuel cost of operating a tractor is the same as the salary of the driver operating it.

(d) Project life for 16 years is assumed on the assumptions that the most durable part of the capital equipment (ie buildings) will last for 16 years. Within this period, crops will be taken from two plantings, the first planting will take place in the first year and the second planting in the ninth year.

(e) The harvesting of fruits from a plantation will continue till the ninth year when a fresh plantation will be established.

(f) There is increase in fruit weight of 73 1/3 per cent in the third year due to yield from ratoon crop. During the fourth and fifth year, there is decrease in weight of 33 1/3 per cent based on the weight in the third year. The weight of the fruit remains at 60 per cent of the weight in the third year for about three more years in the plantation life.

(g) The salary structure adopted corresponds with those operating in other commercial or industrial enterprises with government controlling interest. A minimum daily pay of ₦5 for 1981 was assumed.

From table 6.2(a), it will be noticed that the initial cost of establishing and running the plantation for the first year is ₦303813. Thereafter, one would require about ₦ 182,000 yearly to run the plantation for the remaining life span of the plantation. It will be noticed also that almost all the capital equipment is replaced after every four years. The annual operating cost increases slightly yearly because of annual increase in salaries of the permanent staff. The overall annual cost when depreciation is taken into account is about ₦200,000 (table 6.2(b)) and the varying unit cost of fruit production ranges from ₦0.05 to ₦0.13 per kilogram depending on the number of suckers sold, (table 6.2(c)).

6.3.3. The Unit Cost of Plantain Flour:

The capital, operating and administrative overhead costs are shown in table 6.3(a). The initial total cost for the first and ninth years are ₦321843 and ₦194325 respectively. This is because all the capital equipment, except the buildings, are replaced in the ninth year. Thereafter one would require about ₦65,000 yearly to run the factory for the rest of the operating period. The annual cost, including depreciation of capital equipment on a straight line basis, is ₦30148 for the first year and ₦155944 for the ninth year. The overall annual cost for the rest of the years of operation is about ₦122.000(table 6.3(b)). The unit cost of plantain flour including depreciation varies from ₦0.46 to ₦0.74 per kilogram depending on the number of suckers sold as shown in table 6.3(c). See explanatory note on tables 6.3(a) and 6.3(c).

Table 6.3(a) The Capital, Operating and Administrative Costs for the Processing of plantain fruit into flour.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
IS/YEARS																	
ITAL COSTS (a)																	
ldings	Factory House)																
	Offices)	150000															
	Boiler House)																
inery & Equipment: (b)+(c)	Cabinet Dryer and Trays	58000								58000							
	Electric Plant	10000								10000							
	Steam Plant	16000								16000							
	Dicing Machine	1000								1000							
	Hammer Mill	5000								5000							
	Packaging Machine	10000								10000							
	Compressor	1500								1500							
	Tables, Bins & Knives	2000				2000				2000				2000			
	10 Tanks	4000								4000							
	3 Scales	2400								2400							
	Cutting Bench	1000								1000							
	Lorry	10000								10000							
	5% for Contingencies	13545				100				6045				100			
	Total Capital Cost	297990				2100				132990				2100			
ATING COSTS																	
	Power and Water Supply		1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
	Packaging Material		2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
	20 Unskilled Labour		24000	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000
	Driver/Mechanic		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
	Fuel Cost		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
	5% Maintenance + Repairs																
	General Charges		1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
	Total Operating Cost for 1 shift		31350	31350	31350	31350	31350	31350	31350	31350	31350	31350	31350	31350	31350	31350	31350
tal operating cost for the appropriate number of shifts (f)			62700(2)	94050(3)	62700(2)	62700(2)	62700(2)	62700(2)	62700(2)	62700(2)	62700(2)	94050(3)	62700(2)	62700(2)	62700(2)	62700(2)	62700(2)
NISTRATIVE OVERHEAD COSTS																	
	1 Factory Manager (d)	5760	5910	6060	6210	6360	6510	6660	6810	6960	7110	7260	7410	7560	7710	7860	8010
	1 Factory Foreman		3564	3714	3864	4014	4164	4314	4464	4614	4764	4914	5064	5214	5364	5514	5664
	1 Laboratory Technologist		2532	2652	2772	2892	3012	3132	3252	3372	3492	3612	3732	3852	3972	4092	4212
	10 Semi Skilled Labour		15000	15420	15840	16260	16680	17100	17520	17940	18360	18780	19200	19620	20040	20460	20880
	Stationery		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
	5% Benefits (e.g. Housing Allowance)	288	1350	1392	1434	1476	1518	1560	1602	1644	1686	1728	1770	1812	1854	1896	1938
		6048	30856	30738	31620	32502	33384	34256	35148	36030	36912	37794	38676	39558	40440	41322	42204
ALL COSTS (Annually)		321843	61206	62088	62970	65952	64734	65616	66498	194325	68262	69144	70026	72908	71790	72672	73554

Table 6.3(a) The Capital, Operating and Administrative Costs for the Processing of Plantain Fruit into Flour

ITEMS/YEARS		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CAPITAL COSTS																	
Buildings	Factory House																
	Offices	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
	Boiler House																
Machinery	Cabinet Dryer and Trays	7250	7250	7250	7250	7250	7250	7250	7250	7250	7250	7250	7250	7250	7250	7250	7250
& Equipment	Electric Plant	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
	Steam Plant	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
	Dicing Machine	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125
	Hammer Mill	625	625	625	625	625	625	625	625	625	625	625	625	625	625	625	625
	Packaging Machine	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
	Compressor	188	188	188	188	188	188	188	188	188	188	188	188	188	188	188	188
	Tables, Bins & Knives	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
	10 Tanks	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
	3 Scales	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
	Cutting Bench	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125
	Lorry	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
	5% for Contingencies	1237	1237	1237	1237	1237	1237	1237	1237	1237	1237	1237	1237	1237	1237	1237	1237
	Total annual capital cost	24100	24100	24100	24100	24100	24100	24100	24100	24100	24100	24100	24100	24100	24100	24100	24100
OPERATING COSTS																	
	Power and Water supply		1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
	Packaging Material		2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
	20 Unskilled Labour		24000	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000
	Driver/Mechanic		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
	Fuel Cost		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
	5% for Maintenance & Repairs & General Charges		1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1250	1350
			31350	31350	31350	31350	31350	31350	31350	31350	31350	31350	31350	31350	31350	31350	31350
Total operating cost for the appropriate number of shifts (see note on "f") (f)			62700(2)	94050(3)	62700(2)	62700(2)	62700(2)	62700(2)	62700(2)	62700(2)	62700(2)	94050 (3)	62700(2)	62700(2)	62700(2)	62700(2)	62700(2)
ADMINISTRATIVE OVERHEAD COSTS																	
	1 Factory Manager	5760	5910	6060	6210	6360	6510	6660	6810	6960	7110	7260	7410	7560	7710	7860	8010
	1 Factory foreman		3564	3714	3864	4014	4164	4314	4464	4614	4764	4914	5064	[illegible]	5364	5514	5664
	1 Laboratory Technologist		2532	2652	2772	2892	3012	3132	3252	3372	3492	3612	3732	3852	3972	4092	4212
	10 Semi skilled labour		15000	15420	15840	16260	16680	17100	17520	17940	18360	18780	19200	19620	20040	20460	20880
	Stationery		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
	5% Benefits (e.g. Housing Allowance)	288	1350	1392	1434	1476	1518	1560	1602	1644	1686	1728	1770	1812	1854	1896	1938
	Total annual admin.cost	6048	30856	30738	31620	32502	33384	34266	35148	36030	36912	37794	38676	39558	40440	41322	42204
	OVERALL Annual Costs	80148	117656	148000	118420	119302	120184	121066	121948	122830	123712	155944	125476	126358	127240	128122	129004

Table 6.3(b) The Depreciated Capital Cost, the Operating and Administrative Costs for Plantain Flour Production

Table 6.3(c) Unit Cost of Flour Production

ITEMS/YEARS	1	2	3	4	5	6	7	8
PROCESSING FACTORY OVERALL COST (Capital, Operating and Administrative) N	30148	117656	148888	118420	119302	120184	121066	121948
Weight of Fruit Kg		1.5390×10^6	2.6675×10^6	1.7785×10^6	1.7785×10^6	1.6005×10^6	1.6005×10^6	1.6005×10^6
Weight of Plantain Flour at 28% fruit weight (e) Kg		430920	746914	497967	497967	448148	448148	448148
Cost of Fruit(A) at Unit Cost of fruit of N0.13/Kg (ie No Sale of Suckers)		200070	213404 (N 0.08/Kg)	200070	200070	200070	200070	200070
Unit Cost of Flour N/kg		0.74	0.49	0.64	0.64	0.72	0.72	0.72
Cost of Fruit(B) at Unit Cost of Fruit of N0.05/Kg N (ie 100% Sale of Suckers)		80000	80026 (N0.03/Kg)	80000	80000	80000	80000	80000
Unit Cost of Flour		0.46	0.31	0.40	0.40	0.45	0.45	0.45
Cost of Fruit(C) at Unit Cost of fruit of N 0.07/Kg N (ie 75% Sale of Suckers)		112000	106702 (N0.04/Kg)	112000	112000	112000	112000	112000
Unit Cost of Flour		0.53	0.34	0.46	0.46	0.52	0.52	0.52
Cost of Fruit(D) at Unit Cost of fruit of N0.09/Kg N (ie 50% Sale of Suckers)		144000	160052 (N0.06/Kg)	144000	144000	144000	144000	144000
Unit Cost of Flour		0.61	0.41	0.53	0.53	0.59	0.59	0.59
Cost of Fruit(E) at Unit Cost of fruit of N0.11/Kg N (ie 25% Sale of Suckers)		176000	186728 (N0.07/Kg)	176000	176000	176000	176000	176000
Unit Cost of Flour		0.68	0.45	0.59	0.59	0.66	0.66	0.66
Cost of Fruit(F) at Unit Cost of fruit of N0.12/Kg N (ie 10% Sale of Suckers)		192000	213400 (N0.08/Kg)	192000	192000	192000	192000	192000
Unit Cost of Flour (see note on "e")		0.73	0.49	0.63	0.62	0.70	0.70	0.70

ITEMS/YEARS	9	10	11	12	13	14	15	16
PROCESSING FACTORY OVERALL COST (Capital, Operating and Administrative) N	122830	123712	155944	125476	126358	127240	128122	129004
Weight of Fruit Kg	1.6005×10^6	1.5390×10^6	2.6675×10^6	1.7785×10^6	1.7785×10^6	1.6005×10^6	1.6005×10^6	1.6005×10^6
Weight of Plantain Flour at 28% fruit weight (e) Kg	448148	430920	746914	497967	497967	448148	448148	448148
Cost of Fruit(A) at Unit Cost of fruit of N0.13/Kg (ie No Sale of Suckers)	200070	200070	213404 (N0.08/Kg)	200070	200070	200070	200070	200070
Unit Cost of Flour N/kg	0.72	0.73	0.50	0.65	0.65	0.73	0.73	0.73
Cost of Fruit(B) at Unit Cost of Fruit of N0.05/Kg N (ie 100% Sale of Suckers)	80000	80000	80026 (N0.03/Kg)	80000	80000	80000	80000	80000
Unit Cost of Flour	0.45	0.47	0.32	0.41	0.41	0.46	0.46	0.46
Cost of Fruit(C) at Unit Cost of fruit of N 0.07/Kg N (ie 75% Sale of Suckers)	112000	112000	106702 (N0.04/Kg)	112000	112000	112000	112000	112000
Unit Cost of Flour	0.52	0.55	0.35	0.48	0.48	0.53	0.53	0.53
Cost of Fruit(D) at Unit Cost of fruit of N0.09/Kg N (ie 50% Sale of Suckers)	144000	144000	160052 (N0.06/Kg)	144000	144000	144000	144000	144000
Unit Cost of Flour	0.59	0.62	0.42	0.54	0.54	0.61	0.61	0.61
Cost of Fruit(E) at Unit Cost of fruit of N0.11/Kg N (ie 25% Sale of Suckers)	176000	176000	186728 (N0.07/Kg)	176000	176000	176000	176000	176000
Unit Cost of Flour	0.66	0.70	0.46	0.61	0.61	0.68	0.68	0.68
Cost of Fruit(F) at Unit Cost of fruit of N0.12/Kg N (ie 10% Sale of Suckers)	192000	192000	213400 (N0.08/Kg)	192000	192000	192000	192000	192000
Unit Cost of Flour (see note on "e")	0.70	0.73	0.50	0.64	0.64	0.72	0.72	0.72

Table 6.3(c) Unit Cost of Flour Production

Notes for tables 6.3(a) and 6.3(c)

(a) The expenditure on capital equipment is assumed to be in the first and ninth years respectively.

(b) The price for the cabinet dryer and trays was quoted by APV Dryers Ltd, Carlisle, England for 1981. Other figures are based on quotations obtained from suppliers in Nigeria for 1981.

(c) Tables, bins and knives are to be replaced every four years while the other machinery and equipment are to be replaced after eight years. Buildings will be replaced after sixteen years.

(d) The only operating cost in the form of administrative overhead in the first year is the employment of the factory manager, who would be required to plan and organise the factory start-up.

(e) The total flour obtainable from a given quantity of fruit was found to be 28 per cent of the fruit weight under laboratory conditions.

(f) The numbers of brackets denote the number of shifts operated.

6.3.4. Cash Flow for the Plantation and Factory

Table 6.4(a) shows the estimated cash flow for a 100 hectare plantation and the processing factory. The annual input costs for the plantation and the factory are given and both are added to give the total annual cost. The only income in the first year is from the sale of suckers and from the second year onwards estimates of revenues are made from the sales of flour and varying percentage of saleable suckers.

The price of suckers differs with individual farmers and organisations but falls within the range ₦0.25 and ₦0.50 per sucker. Suckers from the plantations owned by the National Horticultural Research Institute , Nigeria, were sold for ₦0.25 each in 1981. but private farms sell them at higher prices. The revenue from suckers in this project was estimated at an assumed selling price of ₦0.25. This low selling price was used to avoid overestimation of the revenue obtainable from the suckers. However, an entrepreneur will naturally respond to the market demand by selling the suckers at a price obtainable at the time of sale.

The retail price of plantain flour at Dugbe Market, Ibadan was ₦1 per kilogram for 1981. The flour, produced usually on a small scale by individual households, was sold in open bowls with no packaging. The revenue from flour shown in table 6.3(c) was calculated at the wholesale price of ₦0.65 per kilogram. It is expected that the packaged flour with good keeping quality could sell at a retail price of ₦1.20 per kilogram in the supermarkets in Nigeria. Even if sold at the current retail price of ₦1 per kilogram, there would still be an adequate profit margin after deductions are made for both transport and selling costs. Total income streams and net cash flows under different assumptions about the number of suckers sold are shown in

Table 6.4(a) NET CASH FLOW FOR PLANTATION AND FACTORY FOR THE DISCOUNTED CASH FLOW ANALYSIS

TMS/YEAR		1	2	3	4	5	6	7	8
NT COSTS									
For Plantation Estate		303813	180083	179453	179923	183693	180863	181333	181803
For Processing Factory		304038	93556	124788	94320	97302	96084	96966	97848
TAL COST		607851	273639	304241	274243	280995	276947	278299	279651
OME									
Weight of Plantain Flour at 28% fruit weight	kg		430920	746914	497967	497967	448148	448148	448148
Revenue from Flour at N0.65 per kg (1)	N		280098	485494	323678	323679	291296	291296	291296
Total Income (No sale of suckers)	N		280098	485494	323678	323679	291296	291296	291296
T CASH FLOW (A) = (Income - Cost)		-607851	6459	181253	49435	42684	14349	12997	11645
Revenue from 10% Sale of Suckers (2)	N	8100	12150	12150	12150	12150	12150	12150	8100
Total Income (1) + (2)	N	8100	292248	497644	335828	335829	303446	303446	299396
T CASH FLOW (B) = (Income - Cost)		N-599751	18609	193403	61585	54834	26499	25147	19745
Revenue from 25% Sale of Suckers (3)	N	20250	30375	30375	30375	30375	30375	30375	20250
Total Income (1)+(3)	N	20250	310473	515869	354053	354054	321671	321671	311546
T CASH FLOW (C) = (Income - Cost)		N-587601	36834	211628	79810	73059	44724	43872	31895
Revenue from 50% Sale of Suckers (4)	N	40500	60750	60750	60750	60750	60750	60750	40500
Total Income (1) + (4)	N	40500	340848	546244	384428	384429	352046	352046	331796
T CASH FLOW (D) = (Income - Cost)		N-567351	67209	242003	110185	103434	75099	73747	52145
Revenue from 75% Sale of Suckers (5)	N	60750	91125	91125	91125	91125	91125	91125	60750
Total Income (1) + (5)	N	60750	371223	576619	414803	414804	382421	382421	352046
T CASH FLOW (E) = (Income - Cost)		N-547101	97584	272378	140560	133809	105474	104122	72395
Revenue from 100% Sale of Suckers (6)	N	81000	121500	121500	121500	121500	121500	121500	81000
Total Income (1) + (6)	N	81000	401598	606994	445178	445179	412796	417796	417296
T CASH FLOW (F) = (Income - Cost)		N-526851	127959	302753	170935	164184	135849	134497	133145

TMS/YEAR	9	10	11	12	13	14	15	16
NT COSTS								
For Plantation Estate	252573	183843	183213	183683	187453	184623	185093	18556
For Processing Factory	231720	99612	131844	101376	104358	103140	104022	10490
TAL COST	484293	283455	315057	285059	291811	287763	289115	29046
OME								
Weight of Plantain Flour at 28% fruit weight	448148	430920	746914	497967	497967	448148	448148	4481
Revenue from Flour at N0.65 per kg (1)	291296	280098	485494	323678	323678	291296	291296	2912
Total Income (No sale of suckers)	291296	280098	485494	323678	323678	291296	291296	2912
T CASH FLOW (A) = (Income - Cost)	-222997	-3357	170437	38619	31867	3533	2181	83
Revenue from 10% Sale of Suckers (2)	8100	12150	12150	12150	12150	12150	12150	1215
Total Income (1) + (2)	299396	292248	497644	335828	335828	303446	303446	3034
T CASH FLOW (B) = (Income - Cost)	-214897	8793	182587	50769	44017	15683	14331	1298
Revenue from 25% Sale of Suckers (3)	20250	30375	30375	30375	30375	30375	30376	3037
Total Income (1)+(3)	281546	310473	515869	354053	354053	321671	321671	3216
T CASH FLOW (C) = (Income - Cost)	-202747	27018	200812	68994	62242	33908	32556	382
Revenue from 50% Sale of Suckers (4)	40500	60750	60750	60750	60750	60750	60750	607
Total Income (1) + (4)	331796	340848	546244	384428	384428	352046	352046	352
T CASH FLOW (D) = (Income - Cost)	-152497	57393	231187	99369	92617	64283	62931	615
Revenue from 75% Sale of Suckers (5)	60750	91125	91125	91125	91125	91125	91125	9112
Total Income (1) + (5)	352046	371223	576619	414803	414803	382421	382421	3824
T CASH FLOW (E) = (Income - Cost)	-132247	87768	261562	129744	122992	94658	93306	919
Revenue from 100% Sale of Suckers (6)	81000	121500	121500	121500	121500	121500	121500	1215
Total Income (1) + (6)	417296	401598	606994	445178	445179	412796	412796	4127
T CASH FLOW (F) = (Income - Cost)	-71497	118143	291937	160119	153368	125033	123681	1223

Table 6.4(a) Net Cash Flow for Plantation and Factory for the Discounted Cash Flow Analysis

ITEM/YEARS		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
INPUT COSTS																	
For Plantation Estate	₦	303813	180083	179453	179923	181693	180863	181333	181803	252573	183843	183213	183683	187453	184623	185093	185563
For Processing Factory	₦	304038	93556	124788	94320	97302	96084	96996	97848	231720	99612	131844	101376	104358	103140	104022	104904
TOTAL COST	₦	607851	273639	304241	274243	280995	276947	278299	279651	484293	283455	315057	285059	291811	287763	289115	290467
Debit Service																	
Interest Payment on Loan 3%	₦	-	9524	9524	9524	9524	9524	-	-	-	-	-	-	-	-	-	-
Loan Amortisation	₦	-	-	-	-	-	-	31747	31747	31747	31747	31747	31747	31747	31747	31747	31747
TOTAL CASH OUTFLOW	₦	607851	283163	313765	283767	290519	286471	310046	311398	516040	315202	346804	316806	323558	319510	320862	322214
INCOME																	
Loan of 75% Capital Cost	₦	317470 (a)															
Revenue from Flour at ₦ 0.65 per kg(1)	₦		280098	485494	323678	323679	291296	291296	291296	291296	280098	485494	323678	323678	291296	291296	291296
Revenue from 10% Sale of Suckers (2)	₦	8100	12150	12150	12150	12150	12150	12150	8100	8100	12150	12150	12150	12150	12150	12150	12150
Total Income = Loan + (1) + (2)		325570	292248	497644	335828	335829	303446	303446	299396	299396	292248	497644	335828	335828	303446	303446	303446
NET CASH FLOW(G) (Income - Cash outflow)		-282281	9085	183879	52061	45310	16975	-6600	-12002	-246644	-22954	150840	19022	12270	-16064	-17416	-19764
Revenue from 25% Sale of Suckers (3)	₦	20250	30375	30375	30375	30375	30375	30375	20250	20250	30375	30375	30375	30375	30375	30375	30375
Total Income = Loan + (1) + (3)	₦	337720	310473	515869	354053	354053	321671	321671	311546	281546	310473	515869	354053	354053	321671	321671	321671
NET CASH FLOW(H) = (Income - Cash Outflow)		-270131	27310	202104	70286	63535	35200	11625	148	-234494	-4729	169065	37247	30495	2161	809	-589
Revenue from 50% Sale of Sucker (4)	₦	40500															
Total Income = Loan + (1) + (4)	₦	357970	340848	546244	384428	384429	352046	352046	331796	331796	340848	546244	384428	384428	352046	352046	352046
NET CASH FLOW(I) = (Income - Cash Outflow)	₦	-249881	57685	232479	100661	93910	65575	42000	20398	-184244	25643	199440	67622	60870	32536	31184	29832

NOTE:
(a) The initial cost of suckers was included in the capital cost on which 75 per cent loan was obtained.

Table 6.4(b) Net Cash for Plantation and Factory for the Discounted Cash Flow Analysis Assuming Low Interest Government Loan table 6.4(a).

Different values for the annual net cash flows were obtained (table 6.4(b)) under the following assumptions:

- that the government would provide 75% of the initial total capital cost for the plantation and factory at a soft loan of 3% ;
- that the loan would be paid back after five years in ten equal instalments; and
- that the entrepreneur would provide 25% of the initial total capital cost. The basis for these assumptions will be discussed in section 6.6.3.

6.3.5. NPV and IRR for an Integrated Plantation and Processing Factory in Nigeria

In order to determine the NPV and IRR for the plantain project an acceptable commercial rate of discount is required. The cost of capital(i.e. the interest on borrowed money from Nigerian banks) was 8% for 1981 and the interest on deposit account was 6%. It seems that the government controls the rate of interest for both loans and deposits which does not indicate the true opportunity cost of capital if the rate of inflation is taken into consideration.

The current acceptable commercial rate of return in UK is around 15% and ranges from 10% to 30% depending on time and location. In appraising projects in developing countries, the World Bank usually requires a minimum of about 12% rate of return in real terms.

Little and Mirrlees (1977) suggested two rules - "Do everything which yields 11 per cent or more" or "Do everything which has zero or more NPV at a discount rate of 11 per cent". Since the businessman will usually seek a higher rate of return, the discount rate of 15 per cent was chosen to represent the cost of capital as well as the minimum acceptable rate of return.

A computer programme was used to analyse the cash flows and determine the rates of return. Although both the NPV and IRR were determined as shown in the computerised charts APP.-6:1.., only the values obtained for IRR are shown in table 6.5.

Looking at table 6.5, the obvious conclusion will be that a minimum of 50 per cent sale of saleable suckers is required for the project to be considered attractive because the chosen rate of interest is 15 per cent in this case. This is the case when all the initial capital cost is provided by the entrepreneur. But if 75 per cent of the initial capital cost is provided by the government under a soft term, then a minimum of 25 per cent sale of saleable suckers would make the project attractive. More discussions on the effect of government incentives on the viability will be carried out in section 6.5.2. The overall conclusion, irrespective of the assumed rate of discount, is that at least 25 per cent sale of saleable suckers is required for the project to be viable if the flour is to be sold at a wholesale price of ₦0.65 per kilogram. Without the sale of suckers, the flour will have to sell at a wholesale price of at least ₦0.75 in order to achieve about 5 per cent rate of return (table 6.3(c)).

Table 6.5

INTERNAL RATE OF RETURN ON INVESTMENT

Income from Flour and suckers	100% Initial Capital Cost(₦423290) Provided by the Entrepreneur	25% Initial Capital Cost(₦105820) Provided by the Entrepreneur and 75% Provided by the Government on Soft Loan Terms
1. At 100% Sale of Plantain Flour (No Sale of Suckers)	Negative	Negative
2. At 100% Sale of Plantain Flour (With 10% Sale of Suckers)	Negative	Negative
3. At 100% Sale of Plantain Flour (with 25% Sale of Suckers)	4.57%	13.31%
4. At 100% Sale of Plantain Flour (with 50% Sale of suckers)	14.28%	37.83%
5. At 100% Sale of Plantain Flour (With 75% Sale of Suckers)	22.52%	More than 50%
6. At 100% Sale of Plantain Flour (with 100% Sale of Suckers)	31.40%	More than 50%

6.3.6. Market Size for Plantain Suckers:

What is the market size for plantain suckers is an important question to be considered since the profitability of the integrated project is very sensitive to the number of suckers that can be sold and their price. The question can be partly answered by considering the market situation up to the end of 1981. The great demand for plantain fruit as a starch staple diet has resulted in a high price for the fruits. This had implied a high return on investment for the farmers. This has resulted in many plantain farmers changing from subsistence farming to small scale plantation farming (section 6.1.2). In turn this has resulted in a large increase in the demand for suckers.

Wachuku(Personal Communication - 1981) maintains a 12 hectares of plantain plantation in the Rivers State of Nigeria and claimed that the demand for suckers was so great from 1980 to 1981 that he concentrated on producing and selling suckers alone. He sold the suckers at ₦0.50 per sucker. He supplied 25,000 suckers to government farms and 20,000 to Prison farm, all in the Rivers State and 10,000 suckers to Nsukka farm belonging to the University of Nigeria.

In Ondo, Oyo, Ogun, Bendel, Kwara, Rivers and Cross River States, where cocoa is grown, the demand for plantain suckers is great because a new cocoa plot normally starts as a plantain plot which requires suckers. Plantain is grown to provide shade for the cocoa plant for the first three years of the life of the cocoa plant and is then destroyed. The Cocoa Development Unit in each of the above states has plans to establish plantain plantations in order to raise the required quantity of suckers.

Adigun (Personal Communication - 1980) said that the Cocoa Development Unit of Oyo State has a plan to produce 6 million suckers at a cost of 1.8 million naira annually for the period 1981-85 in co-operation with the World Bank. Although the cost of raising suckers is ₦0.30 per sucker, they are sold to the farmers at the subsidised price of ₦0.15. The loss incurred by selling the suckers at half the cost of production is recovered through the high annual profit of about 100 million naira usually made by the Cocoa Board of which the Cocoa Development Unit is a part.

There is a great deal of uncertainty about how many suckers could be sold but there is considerable evidence suggesting a rapidly growing market in which the plantation should be able to sell a substantial proportion of its suckers at ₦0.25 which is probably less than the market price.

Ucheagwu (1981) reported that plantain fruits were sold at a retail price of ₦0.20 per kilogram by NIHORT for the period 1979-81 and in the same period, fruits were sold at Dugbe Market at a retail price of ₦0.80 per kilogram. The unit cost of production of fruit from the 100 hectare estate was shown to be between ₦0.05 and ₦0.13 corresponding to 100% sale of saleable suckers and no sale of suckers (section 6.3.2).

It could be argued that if it is more profitable to sell the fruits in the fresh market, there should be no need to embark on a costly operation of processing the fruits into flour. This argument is not entirely convincing in the case of a perishable fruit like plantain. The points favouring the production of plantain flour have been discussed in section 1.3. The demand for plantain flour varies from state to state because of differing availability of other competing food products. The crops that compete with plantain in flour production and the specific advantages which plantain has over these crops are discussed in the next section.

6.3.7 Demand for Plantain Flour and other Competitive Products

The main traditional use of plantain flour is for gruel production (APP-1) Both cassava and yam flour can be used as alternatives for the production of gruel. From the proximate analysis shown in Table 6.6, it is apparent that there is no major difference in the food values of the three staples. However, the use of plantain flour has the added advantage of its iron, potassium and carotene (pro-Vitamin A) contents. Other advantages include low labour requirement and costs (table 6.7 & 6.8). Plantain exploits an environment that is not suitable for either yam or cassava. For example plantain can be grown without fear of erosion on steep slopes which would not be suitable for cassava and yam. It requires very little land preparation and is ideal for rough terrain that is left after the forest is cleared (Devos 1978).

The demand for these flours for gruel making differs from one state to another according to the intensity of production. In Ondo, Bendel and Rivers States, where plantain is grown very extensively, plantain flour is produced and used for the preparation of gruel. The farmers in Anambra and Imo States cultivate more yam and cassava than plantain and produce cassava and yam flours for the preparation of gruel. In general, the main reasons for showing preference for either plantain, yam or cassava flour are availability of raw material and eating habits. For example a group of farmers in Oduno Village, Oyo state, claimed that they felt lighter after eating plantain gruel than yam or cassava gruel. This might result in greater market demand for plantain flour due to price advantage resulting from low cost of fruit production and the fact that similar processing method is used for all of them.

Table 6.6. Proximate Analysis of Plantain, Cassava and Yam (Percent of dry matter)

	Dry Matter	Crude Protein	Ether Extract	Crude Fibre	N-free Extract	Ash
Plaintain(Musa paradisiaca)	44.0	3.0	1.10	0.5	93.4	2.0
Cassava (Manihoc esculenta)	29.0	2.1	0.53	1.2	94.2	1.8
Yam(Dioscorea rotundata)	22.5	5.3	0.38	1.5	90.4	2.3

Source: Ketiku, A.O.(1973) and Omole,A. et al (1978)

Table 6.7: Labour Requirement and Efficiency of some Staples of Humid Tropics

	Plantain	Cassava	Maize	Rice
Man days/ha	80	310	122	162
Man days/ton	20	31	122	162

Source: Johnston, B.F.(1958)

Table 6.8: Cost Ranking of some staples of the Humid Tropics

Ranking	per ha	per kg	per 100 Calories
1. Costliest	yam	Rice	Yam
2	Sweet Potato	Maize	Rice
3.	Cocoyam	Yam	Cocoyam
4.	Cassava	Cocoyam	Maize
5.	Rice	Sweet Potato	Sweet Potato
6.	Maize	Cassava	Cassava
7. Cheapest	Plantain	Plantain	Plantain

Source: Johnston, B.F.(1958)

The sale of products from this small factory will be relatively easy comparing the high demand for flour in Nigeria. But for a larger production of flour, more detailed market research will be required. The extension of the use of plantain flour in the manufacture of bakery products creates a new market outlet for the flour. The economic impact of this new use in the baking industry is discussed in the next section.

6.4 Bakery Products Production using plantain - Economic Aspects:

6.4.1 The Nigerian agricultural sector and the Nigerian food balance sheet

The demand for bakery products (bread, biscuits and cakes) in Nigeria is increasing rapidly. Two important factors in explaining this rapid growth are (a) increasing demand for convenience foods such as bread, biscuits and cakes by the rapidly urbanising population and (b) a switch from indigenously produced traditional foods to the preferred bakery products as a result of increasing household incomes. At present, almost all bakery products are made from wheat flour produced from imported wheat. It is estimated that the consumption of wheat flour will rise from 20kg per capita in 1981 to 33kg per capita in 1990, (Federal Ministry of Industry - Personal Communication, 1980). Owing to the rapid growth in population over this period, the total demand for wheat flour is expected to rise from about 1.7 million tonnes in 1981 to 3.6 million tonnes in 1990. There is some evidence to suggest that consumption of wheat flour and bakery products would be even higher were it not constrained by the restriction on imported flour and the inability of the domestic flour mills to meet demand, as shown by the quotation in the last paragraph of section 6.5.2 below.

There is much concern in Nigeria about the heavy and growing dependence on imported food. The import of food products rose from 766.5 million naira in 1979 to 1091 million naira in 1980 an increase of 42.3%. The increase in the importation of food continued in 1981 and if the 1980 percentage increase was maintained for 1981, the food import bill would be about 1.56 billion naira. The rise in food imports reflect both a slow-down in the rate of increase in local food production in the face of increase in demand and the consequent relaxation of restrictions on the importation of food items, particularly rice, wheat flour and stockfish which were placed under open general licence (Central Bank of Nigeria - Annual Report and Statements of Accounts 31st December 1980).

Under an open general licence, any importer is permitted to import the commodity, without any restriction from the Central Bank on availability of foreign exchange. On items placed under specific import licence foreign exchange supply is controlled by the Central Bank. The number of people allowed to import the items and the quantity to be imported are therefore determined by the Central Bank.

It can be argued that if food consumption is higher than production, food will be imported and imports will be paid for by exports of other goods in whose production Nigeria has comparative advantage. This is an unconvincing argument in the Nigerian context since resources in the rural sector are poorly utilised giving rise to rural poverty, unemployment and under-employment and rural to urban migration causing severe urban problems. That local food supply has not kept pace with demand is possibly because of (a) short-term adjustment problems arising from the fact that demand for food is growing faster than the production resulting in food shortages, (b) unsuitable climatic conditions for crops for which there is heavy demand eg wheat as discussed below (c) characteristics of the agricultural sector ie predominently small farms which produce small quantities of food not enough to meet the demand, (d) lack of sufficient incentive to the small farmer to increase agricultural production and improper channelling of incentive to small farmers.

Policies to reduce dependence on food imports are currently being considered and implemented. Some of the measures taken in April 1982 by the Government are (a) the requirement that advance deposits of 50% of the cost of the food import bills are placed with the Central Bank and (b) the placing of wheat flour and stockfish under specific import licence. Dependence on imported wheat is clearly an aspect of this overall dependence on imported food. One way of reducing dependence on imported wheat is to increase domestic production of wheat or substitute.

Wheat is grown in the ecological belts of Sokoto Rima, Hadejia-Jama and Chad Basin. The main centres of production are Gwadabawa, Wurno, Talata Mafara and Sokoto Local Government areas of Sokoto State, Katsina Emirate of Kaduna State, Rano, Hadejia, Kazaure, Dambarta, Min-jibir and Gezawa Local Government areas of Kano State and South Chad. Kirenowa Poler, Bega Polder and Yedsenam project areas of Borno State.

Table 6.9 Estimated projections of wheat production

Year	Taken from Agricultural Development in Nigeria 1973-1985 (Tonnes)	Expected production from the three River Basins (Personal Communication, Federal Ministry of Industry, Lagos). (Tonnes)
1981	46,000	23,000
1982	50,000	37,000
1983	57,000	52,000
1984	64,000	63,000
1985	71,000	86,000

Source: As indicated above each column.

As table 6.9 shows, domestic wheat production is expected to grow rapidly up to 1985 but will still remain a small fraction of the total demand. It is estimated that if all the land suitable for wheat cultivation is utilised, the maximum production will represent only about 15 percent of the estimated wheat consumption in 1990 (Federal Ministry of Industry - Personal Communication 1980). The production of flour from local starch staples, if feasible, would make a further contribution.

6.4.2. Plantain flour production and national economic policy

Since the production of wheat in Nigeria is limited as shown above, it is important to assess the contribution to be made by producing flour from a traditional crop like plantain. The national economic policy should be considered in assessing the project since the objectives of an entrepreneur may differ from those of the government. Market prices as used by an enterprise for making its own estimates of profitability may be distorted by taxes or subsidies. The social cost of inputs and social value of outputs are arrived at by using "accounting prices" or "shadow prices" which reflect the value to society of the resources used or output produced (Little and Mirrless 1977).

The appraisal of the project for plantain flour production from the point of view of the Nigerian economy should take account of the economic costs of resources. In order to do this, it is necessary to reappraise the project using shadow prices for resources used by the plantain flour processing industry as well as resources saved by the industry. The main resources that it is usually necessary to shadow price are labour, capital and foreign exchange.

In many developing countries, the wage rate does not reflect the true economic cost because of the minimum wage policy. The shadow price of labour in Nigeria may well be lower than the ₦5 which was the minimum wage rate per day in 1981. However, there are other factors to be taken into consideration. The government wants to see a more equal income distribution and reduce the gap between the high incomes in the high-productivity, high-technology sector and the low incomes in the low productivity, low technology sector. If a lower wage rate is offered, the individuals might refuse to work and prefer to remain unemployed so as to enjoy their leisure which would be the opportunity cost of taking up the employment for some.

There is evidence that there is scarcity of labour in the villages even at the minimum wage of ₦5. The reason being the unattractive working conditions prevalent in the villages which results in the drift of young people to the urban centres. Although there are very few jobs available in the urban centres, the youths prefer to remain unemployed for as long as it takes to find a job instead of taking some jobs in the villages.

Therefore the wage rate of ₦5 a day was used in the determination of the wages of the unskilled labour for the project as a reasonable estimate of the opportunity cost of employing the labour which also takes account of the value of leisure to employee.

Nigerian firms have a variety of sources of finance which include personal savings, bank loans, shares and aids. For the financial appraisal of the flour production, it is assumed that capital was provided by the government and private entrepreneurs. It is, however, understandable that any resource tied up in a particular project will have an opportunity cost which will be the return to be received in the best alternative project. The opportunity cost of committing the capital for the project would be the interest it would yield if deposited in the bank or the increase in consumption power for other goods. The current interest rate of about 6% on bank deposit account in Nigeria is less than the 15% discounted rate of return assumed for the project. In addition the social value of the capital devoted to the project is higher than depositing it in the bank to yield interest. Therefore no shadow pricing was applied to the capital. The rate of inflation has not been taken into account as it is normal to adjust the bank interest rate and the expected rate of return on investment in accordance with the rate of inflation.

The shadow price of the foreign exchange resource used for the importation of wheat is now considered. The proposed wholesale price of the flour based on a 1981 estimate is ₦ 0.65 per kilogram (Section 6.3.3 , table 6.3(c)). The controlled wholesale price of wheat flour is ₦ 0.28 per kilogram for 1981 as shown below in table 6.10 . The cost of transporting flour is excluded in comparing plantain and wheat flour costs since transport costs will be similar for both type of flours. The government has set down a freight charge of ₦0.65 per 50kg bag per 1000km , but the open market freight charge is about ₦3 per bag per 1000 km . The reluctance of millers to transport the flour at the regulated rate has made it necessary for individual bakers to arrange the transport of flour themselves.

If the above price estimates are taken on face value and a direct comparison is made between plantain and wheat flours, then the production of plantain flour as substitute for wheat flour in bakery product production does not appear to be an economically viable proposition. In considering the viability of producing plantain flour for wheat flour substitution in bakery products we need to ask whether the above cost comparison reflects the resource costs to the Nigerian economy of importing wheat and producing plantain flour. The federal government of Nigeria is concerned with efficient resource allocation and other national economic objectives. In principle, if import cost of wheat and other prices reflect the true resource costs to the economy, then the commercial return would be identical to the return to the economy. There is evidence to show that this is not the case. The resulting implications for an economic evaluation of plantain flour production and for national economic policy are now considered.

Table 6.10 . Cost of wheat flour production in Nigeria

		Wheat flour production cost (₦ per tonne)
1.	Landed cost of 1.33 tonnes of wheat(a) at Lagos harbour (c.i.f.) at ₦130 per tonne(b)	₦ 172.90 per tonne
2.	Cost of transporting 1.33 tonnes of wheat to warehouses at ₦40 per tonne	₦ 53.20 per tonne
3.	Estimated milling and other processing costs	₦ 23.90 per tonne
4.	Total cost	₦ 250 per tonne or ₦ 12.50 per 50kg. bag
5.	Wholesale price (excluding transport and distribution costs)	₦ 13.80 per 50kg.bag.

Notes:

(a) Production of each tonne of wheat flour required 1.33 tonnes of wheat (or 4 tonnes of wheat required to produce 3 tonnes of wheat flour).

(b) Flour Mills of Nigeria achieves the required 12.5 per cent protein content by blending 75 per cent of Hard Red Winter Wheat from the U.S. (12 per cent protein content) with 25 per cent of Dark Northern Spring Wheat, (14 per cent protein). The landed cost of wheat was U.S. $235 per tonne or ₦130 per tonne at the exchange rate of ₦1=$1.8 for 1981.

The Federal government has limited the importation of wheat and wheat flour by placing them under specific import licence. If there is no restriction, the consumers might want to buy 50 per cent more as indicated by a recent study on the feasibility of Integrated Flour Milling in Nigeria which has shown that only about 50 per cent of the market demand for wheat flour is currently met by the five mills operating in Nigeria, (Federal Ministry of Industry - Personal Communication, 1980). Let us consider the cost of buying 1000 tonnes of wheat at the official exchange rate of $ 1.8 = ₦1 in 1980. The 1000 tonnes of wheat will cost ₦130,000 at the rate of ₦130 per tonne. The foreign exchange cost will be $234,000. If there is no limit and consumers import 50 per cent more wheat, the foreign exchange cost will be $351,000.

The government policy can be construed as having considered wheat imports in the overall context of the whole economy and allocated $234,000 as the maximum foreign exchange expenditure for wheat. The government can restrict the quantity imported by raising the tax on wheat import or place it under licence so that only the quantity equivalent to the allocated foreign exchange is imported. It appears that the government has chosen the second measure. The minimum guaranteed price for wheat for 1980/81 in Nigeria was ₦235 per tonne, (Central Bank of Nigeria- Annual Report and Statement of Accounts, December 1980).

Figure 6.2

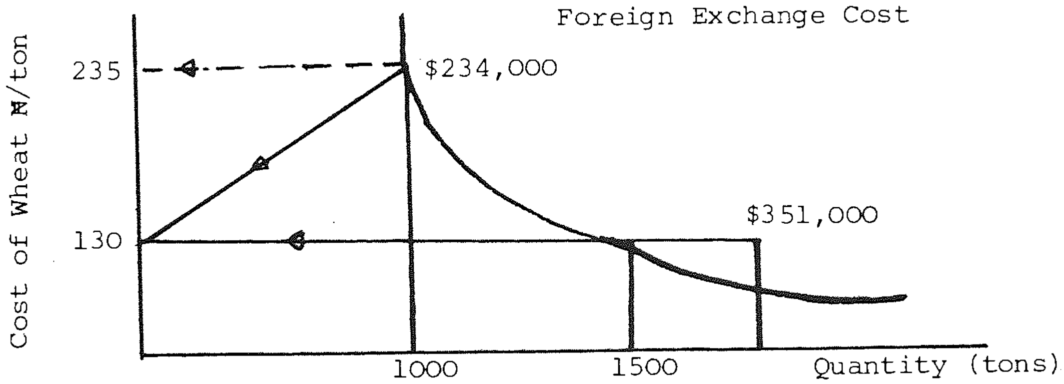


Figure 6.2 illustrates the demand curve for wheat. This might indicate the value government puts on foreign exchange. Increasing the quantity of wheat import will definitely increase the foreign exchange expenditure and this might mean that the shadow foreign exchange rate is higher than is reflected in the official exchange rate. The marginal import cost, an estimate of the amount of which the Foreign Exchange cost exceeds the price paid is ₦(235-130) = ₦105 = $189. From the graph, the shadow price of wheat will be ₦235/tonne which would be taken as the true cost to the economy. Therefore to reflect the social cost, the true exchange rate would be $235 = ₦235.

Import price of wheat at the administered exchange rate	=₦130/tonne
Import price of wheat at the shadow exchange rate	=₦235/tonne
The cost of wheat flour based on the shadow price = 4(235 +40)/3000	=₦0.37 per kg =₦18.50 per 50kg bag

If the processing cost of about 10 per cent and the profit level of 15 per cent assumed are taken into consideration, the actual cost of the flour will be ₦ 23.13 per 50kg bag.

The comparison can be represented as follows:-

Cost of wheat flour at the mill based on the current exchange rate	=₦ 13.80/50kg
Cost of wheat flour at the mill based on the shadow exchange rate	=₦ 23.13/50kg
Cost plantain flour based on financial calculations in table 6.3(c)	=₦ 32.50/50kg

Shadow price adjustments of the kind illustrated above are difficult to make precisely. In order to provide supportive evidence for this assessment, it is therefore proposed to compare wheat flour prices in markets in which prices are not regulated, (e.g. the retail market) with the price at which plantain flour can be sold profitably. In 1981 the retail price of wheat flour ranged between ₦30 and ₦40 per 50kg bag. The frustration and anger of the bakers in Nigeria is shown by the following extract from the Daily Times of Nigeria:

> "The artifical scarcity of flour is being caused by some of the millers who approve direct supply of flour to dealers instead of bakers. The dealers in turn sell the flour at exorbitant prices within the premises of the flour mills, especially Calabar, Port Harcourt and Kano mills. In some states, flour is distributed on local government basis where flour is given not necessarily to the bakers but on political basis. There is a collusion between the dealers and some officials of the mills as a result of which flour, which normally sells at ₦13.80 can be got by the bakers at the cost of ₦35 or ₦40",

(Chief M.A. Ogunyanwo, National Chairman, the Association of Master Bakers, Confectioners and Caterers of Nigeria Daily Times of Nigeria, 11th August 1981).

A more careful assessment of evidence is required since the retail price also includes distribution costs and retailer's margins. As has been shown above, making an adjustment for foreign exchange cost of wheat imports raises the resource cost of wheat flour to almost double the cost of the current exchange rate. Inspite of the allowance due to shadow price,the cost of wheat flour was still not comparable to that of plantain flour. However,it is by no means certain that the appraisal carried out for plantain flour project has allowed for all the distortion's that favour the import of wheat flour. Therefore the government may still agree that more subsidies are necessary for the production of plantain flour in order to make it competitive to wheat flour in bakery product production.

6.4.3. Use of fresh green plantain pulp in bakery products production

Green plantain pulp has been used successfully as composite in the manufacture of bread and cake. Also plantain short-cake biscuit was manufactured using 30 per cent plantain pulp and 70 per cent plantain flour, (section 5.10.6). The economic impact of the new processes in the production of plantain baked products is in the lowering of the cost of production since the drying process will be eliminated completely for both bread and cake production. The overall impact will be the development of local bakery industry for small bakers.

The application of the new processes will significantly lower the cost of plantain bakery products production only if applied by bakers in the villages where the plantain is grown. If the plantain is to be transported to the urban centres where most of the people who consume bakery products live, then the new processes will be as costly as the use of plantain flour, if not more costly. The cost of the plantain fruit would be very high because of the transport costs and the high level of spoilage of the fruits during transportation and storage. Also the bakers will be competing with the consumers in the market for fresh fruit. There is also the possibility that the quality standard will not be adhered to in the case of bread and cake manufacture as bakers might be tempted to use ripe and overripe plantains.

A more detailed study is required to assess the potential of and constraints on the new processes which is beyond the scope of this project.

6.4.4. Conclusions

1. There is need to produce flour from local starchy staples like plantain to reduce dependence on imported wheat. Wheat can be grown in the ecological belts of Sokoto Rima, Hadejia-Jama and Chad Basin but it is estimated that if all the land suitable for wheat cultivation in Nigeria is utilised, the maximum production will represent only about 15 per cent of the estimated wheat consumption in 1990.

2. The specific government objectives are to reduce dependence on food imports, increase rural incomes, and to reduce rural-urban migration. Establishment of a plantain flour industry would assist in the achievement of these objectives.

3. Since entrepreneurs are usually concerned with commercial return and not the broader economic and social objectives, comparison of the cost of plantain flour and wheat flour for plantain baked products production indicates that initially government subsidies will be required to encourage the production of plantain flour. However, a careful study is required to weigh up the benefits of a plantain flour industry against the subsidies and incentives required to sustain it.

4. The proposed wholesale price of wheat flour of 65 kobo/kg for 1981 does not compare favourably with the controlled wholesale price of wheat flour of 28 kobo/kg. The above comparison, however, does not reflect the resource costs to the national

economy of importing wheat. The shadow price of wheat has been estimated to be ₦235/tonne and this raises the cost of wheat flour to 47 kobo/kg. The estimate is confirmed by the observation that in 1981, the retail price of wheat flour ranged between 60 kobo and 80 kobo/kg.

5 The cost comparison of wheat flour with plantain flour are further distorted by the intensive price fluctuations of the world market for wheat and where aid is given in the form of wheat would act as disincentive for the production of composite flour in the countries receiving this type of aid.

6 The use of plantain pulp as partial substitution for wheat flour in the manufacture of bread and cake would naturally lower the cost of production of the plantain baked products as the cost of drying to produce flour would be eliminated. The products could be competitive to wheat flour products if produced by bakers living in the villages where the plantain is grown. The use of the direct pulp in the urban centres could be as costly as the use of the plantain flour because of the high cost of the fruit. A more detailed study is required to access the potential and constraints of the new processes.

7 Since plantain bread, biscuit and cake are different food products from the products made with 100% wheat flour, the price paid for them should reflect both the economic and social values. A preliminary test marketing carried out at the South Bank Polytechnic Bakery Shop London in June 1981 showed that over 80% of the people who bought the biscuit indicated that they would be willing to buy it again even though the price was 50% more than the ordinary wheat shortcake biscuit (section 5.10.8.5). However, further test marketing should be carried out in the countries where commercial production is to take place so that the demand and market share will be determined.

6.5 Agro-Based Industry and the Government Policy

6.5.1. Plantain Food Products Industry and Economic Development:

The establishment of plantain food products industry falls entirely within the context of the development of agro-based industry intended to explore all possible avenues for producing agricultural raw materials locally. In a developing economy where there is often an acute shortage of food for the rapidly growing population, agriculture and industry raise accusing fingers at each other. Agriculture blames industry for failing to provide market outlet in the form of processing factories for the locally produced agricultural produce. Industry blames agriculture for lack of raw material inputs for the establishment of food processing factories. Does it make sense to ask which should have priority? Streeten, (1976) commenting on the subject said, "Inspite of the Green Revolution and substantial, though patchy, progress in agriculture, we have not yet reversed the role and turned industry into the lagging sector. We need continuing advances in industry in order to provide agriculture with the inputs and with the markets and we need progress in agriculture in order to provide industry with food, raw materials and again markets(as well as, in some cases, exports). Several things are essentially done together for success. The choice is not between industry and agriculture. It is between projects and complexes of projects, many of which like processing local raw materials will cut across the dividing line between industry and agriculture. The argument here is that mutual support and consistency are required".

In Nigeria because of lack of agricultural raw material, very few food processing factories are established and most of them operate below capacity (section 6.1.1.). The proposal for the plantain project is that a plantation will be established to provide the raw material input for the processing factory. There would be some social benefits accruing from such an integrated - agro- industrial project in the rural areas of the country.

Social factors are taken into consideration in the planning process at all levels when the government wants to execute a project alone or in partnership. In actual fact they should determine the ends of economic development. However, most of the social benefits cannot be shown by the rate of return calculations and the overall interrelationship of the effects are shown in chart table 6.11. The benefits are briefly discussed:

1. The plantain industry would provide employment opportunity, reduction in underemployment, greater consumption opportunities and higher living standards. It will thus help reduce the pressure on young workers to leave the farmsteads, for the towns. Every 100 hectare plantation estate provides employment for about 110 people and the processing factory promises employment for 25 people. The wages and salaries of the employees constitute about 70% and 80% of the total operating costs of the plantation and the factory respectively from the second year of operation, (tables 6.2(a) and 6.3(a)).

2. Increase in Food Production: The establishment of the plantain industry will stimulate large scale production of plantain fruits which will help in achieving self-sufficiency in food.

3. The learning Effect: Working in a factory or plantation has the dynamic educative effects of introducing modern technology and organisational skill into the heart of traditional economy. "Education is the most powerful factor in making men modern but occupational experience in large-scale organisations and especially in factory work, makes a significant contribution in

"schooling" men in modern attitudes and in teaching them to act like modern men"(Inkeles 1969).

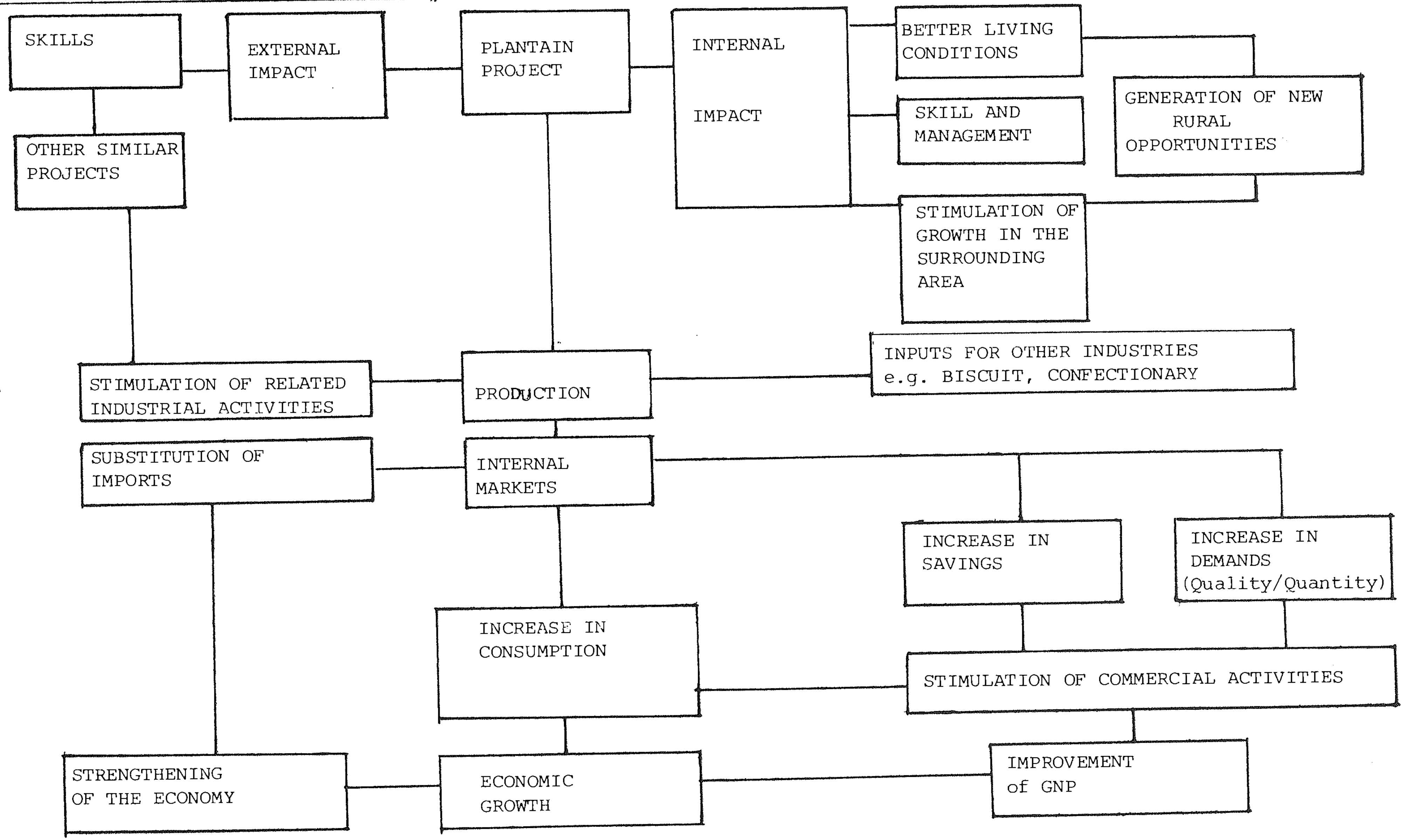
4. Foreign Exchange Savings: Plantain flour/pulp can act a import substitute for wheat flour in bakery products production. This will result in saving and earning of foreign exchange and also contribute an added value to the economy.

5. Even Development: The establishment of plantain agro-industrial project in the rural areas will help to bring about more balanced development which is one of the national industrial objectives of promoting "even development and fair distribution of industries in all parts of the country".

6. Backward and Foreward Linkages: A plantain processing factory would encourage substantial plantain growing and open opportunities for businessmen in marketing plantain products. These activities result in new commercial ventures which are then translated into other new demands and savings which are the key factors in economic growth.

The benefits and external economies presented above are in many cases extremely difficult to quantify. It should, however, be stressed that their aspects dealing with new skills and techniques, the stimulation of agricultural and commercial ventures made these effects the most significant expression of that quality of accelerated development which is crucial to economic growth.

Table 6.11 Economic Development of Plantain Food Products Production



6.5.2. Government Policies for Agro-Based Industry

The main objective of government policy is to increase facilities for agricultural processing with a view to increasing the revenue accruing to farmers and the nation. In the Fourth Plan period (1981-85), the Federal Government would encourage private entrepreneurs to establish large-scale farms and government could participate by way of equity holding in the commercial venture.

It is important that governments should have well formed policy strategies and views about the value of agro-based industry. It is equally important for the government to transform the objectives to the people through good incentives. For the plantain food products industry, there is need for two types of incentives, the ordinary and specific.

Ordinary Incentives: The government gives effective protection to Nigerian industries to save them from unfair competition. The incentives relevant to the plantain project include:

(a) Pioneer Status: By the Income Tax Relief Act, an industry granted the Pioneer Status enjoys a tax holiday of 3 to 5 years.

(b) Accelerated Depreciation of Capital Investment: In order to encourage and assist investor, the Income Tax Act provides for rapid write-down on the capital assets.

(c) Full Integrated Agro-Based and Food Processing Industries: These industries should by their nature utilise local resources to a large extent and be involved in agricultural production for industrial processing. In addition to the encouragement they will enjoy in respect of their agricultural operations, they will also be entitled to substantial concessions in excise duty payments.

(d) Credit Policy: Returns on investment are typically low for traditional agricultural system. For agro-based industry producing new products, the return on investment is low and risky. That is why government provides low term loan.

Faced with competing demands for a limited pool of investment funds and no effective price rationing mechanism, the government responded by creating a number of financial institutions designed to allocate loans among desirable recipients. The two institutions established to fund agro-industrial projects are the Agricultural and Co-operative Bank and the Agricultural Credit Guarantee Scheme. Loans are provided at 3% rate of interest which is very low compared with 6% and 8% for commercial bank deposits and loans respectively.

Vivienne Heston reporting on rice production in Nigeria said among other things, "The Nigerian Agricultural Credit Bank lends money to farmers at low interest rates and under the federal credit scheme viable agricultural projects are guaranteed up to 75 per cent of cost" (West Africa No.3378 3 May 1982).

Assuming this particular incentive, the internal rate of return for the plantain project was recalculated as shown in the second column of table 6.5. The result was a greater return on investment which makes it much more attractive for entrepreneurs to invest in the project.

Specific Incentives: The incentives described above are applicable to any viable agro-based industrial projects and cannot be regarded as special for plantain project. However, inspite of the above incentives the price of plantain flour cannot compare favourably with wheat flour in bakery product production. Hence there is a need for subsidies in the form of special grants for the production of plantain flour if plantain flour would be used as partial substitute for wheat flour in bakery product production.

Two things are at stake here, either the government uses the revenue from oil to strengthen the agro-industrial sector through subsidies or use the foreign exchange revenue from the oil to import food. The revenue from oil could be regarded as short-term asset while the revenue from well established agro-industrial sector will be long term asset. The long time effect of any subsidies towards agro-based industry is that Nigeria would change from being net importer of food to net exporter of food.

The Fourth National Development Plan has agriculture (ie food production) as one of the major priorities. Many incentives have been created to enable the self-sufficiency in food production to be realised by 1985. The government recognises, however, that lending by those above two Institutions which was expected to reach the small farmer has not been carried out successfully due to lack of the right institutional and/or organisational structure for agricultural credit administration. The credit can only be effective instrument for transforming traditional peasant agriculture if it reaches the peasant farmers who account for over 80 per cent of total agricultural output.

6.6. Conclusion

1 A 100 hectare of plantain plantation is to be established to ensure a continuous supply of raw material at a reasonable price to the processing factory. Contract farming involving local farmers should be considered as a supplementary source of supply.

2 The cost of plantain cultivation was estimated from agronomic data and it was assumed that a ratoon crop would be maintained. The yield of 15,000kg of fruit per hactare in the first year and 26,000kg of fruit in the second year due to the ratoon crop was assumed.

3 The initial total cost of establishing and running the plantation for the first year is ₦303813. Thereafter one would require about ₦182,000 yearly to run the plantation for the rest of its life. The overall annual cost when depreciation is taken into consideration is ₦200,000. The unit cost of fruit production including depreciation varied from ₦0.05 to ₦0.13 per kilogram corresponding to the 100 per cent sale and no sale of suckers.

4 The initial cost of establishing the plantain processing factory is ₦321,843. Thereafter one would require about ₦65,000 yearly to run the factory for the rest of the operating years. The overall annual cost including depreciation of the capital equipment on a straight line basis is about ₦122,000 for most of the operational years. The unit cost of plantain flour including depreciation varies from ₦0.46 to ₦0.74 per kilogram corresponding to 100 per cent sale and no sale of suckers.

5. The sale of suckers is very crucial for the plantain project to be profitable. The price of suckers will be kept at ₦0.25 being the minimum market price.

6. The production of plantain flour would be economically viable if the flour is sold at a wholesale price of ₦0.65 per kilogram plus at least 25 per cent sale of saleable suckers. The flour will sell easily judging from the current retail price of ₦1/kg in open market.

7. Even when an allowance is made for the cost of importing wheat we still find that wheat has slight advantage on plantain. This does not take into consideration some of the development benefits which may tilt the balance in favour of plantain flour production. If the government decides to produce plantain flour for bakery products production, a more careful assessment of the overall economic system should be made before this is done.

8. The use of plantain pulp direct as substitute for wheat flour in the manufacture of bread and cake could lower the cost of production and consequently make the plantain baked products competitive. The overall impact will be in the development of local bakery industry for small bakers. However, more detailed study is required to assess the potentials and constraints of the new processes.

9. For a successful agro-based industrial project, there is need for mutual and consistent support between agriculture and industry. The social benefit accruing from such project, although hard to quantify, will include employment opportunity with subsequent higher living standard, help in the realisation of self-sufficiency in food, stimulation of national agriculture and the subsequent benefits for the farmers, even development and fair income distribution, reduction in foreign exchange to be spent on wheat imports and the educative effects of introducing modern technology and organisational skill into the heart of the traditional economy.

10. Plantain flour production for gruel making requires no extra subsidies if the government maximum incentives for agro-based industries will be provided. The incentives will include pioneer status, accelerated depreciation of capital investment, substantial concessions in excise duty payments and up to 75 per cent of the initial capital investment in loans at 3 per cent interest rate.

CHAPTER 7

Conclusion

7 Conclusion

1 Plantain fruit pulp could be processed to good pale flour provided its ripeness was in the correct range. This range corresponded to a skin colour from green to a mixed yellow and green.

2 All the stages of conversion of fruit to flour; peeling, drying and milling were shown to be feasible in simple industrial equipment.

3 The drying of plantain cubes was diffusion controlled for 80% of the necessary drying time.

4 Fick's diffusion model, when applied to plantain cubes, required diffusion coefficients that increased with increasing temperature and were dependent on the cube size.

5 The rate of drying of plantain cubes in air at $60^{o}C$ or greater could be adequately predicted by Fick's law using diffusion coefficients evaluated at a temperature $5^{o}C$ below the air temperature.

6 Drying with air temperature above $70^{o}C$ caused case-hardening of the plantain and an insignificant increase in drying rate.

7 In a pilot-scale cabinet dryer the best throughput of plantain was obtained using double layers of 10mm cubes.

8 Plantain flour milled from dried cubes was successfully used to bake bread, madeira cake and biscuits.

9 Rheological studies of plantain flour showed it to be weak, to lack gluten-forming proteins, and thus unsuitable on its own for bread-making. It could be used to substitute up to 15% strong wheat in white bread and up to 20% in wheatmeal brown bread.

10 Satisfactory madeira cake was baked from a mixture of 50% plantain flour and 50% strong white wheat flour.

11 Plantain biscuits, "shortcake" and "flow type", were baked using 100% plantain flour.

12 Consumer trials, and preliminary test marketing of the plantain biscuits showed their acceptability, even at a price 50% above comparable wheat biscuits.

13 Economic feasibility studies of plantain growing and processing showed that a Nigerian plantain industry could be successful.

14 A plantain plantation would be essential to secure the supply of fruit to a plantain flour factory.

15 Plantain flour production at the target wholesale price of 65 kobo (Nigerian) per kilogram would depend on the sale of suckers (young plantain trees) from the plantation.

16 If at least 25 percent of the suckers produced on the plantation every year can be sold at the market prices, plantain flour for gruel-making in Nigeria would be profitable without any government incentives and would be highly profitable given the present government maximum incentives to agro-industry.

17 Wheat flour for baking would be cheaper than plantain flour, even when allowance was made for the cost to the economy of importing wheat (section 6.4.2).

18 Exploitation of plantain flour for bakery products would depend on a Nigerian government subsidy. The question of weighing the cost of the subsidy against the economic and social benefits of a larger plantain industry is a matter for government policy. The size of the subsidy can be estimated from the feasibility study (chapter 6). Further studies of overall economic and social benefits (such as rural industrialisation, agricultural development, rural employment and foreign exchange savings) should precede any decision to subsidise flour production.

CHAPTER 8

Recommendations

8 Recommendations

1 A plantain and banana industry should be established in Nigeria to grow, process, preserve and market the fruit comparable with the cocoa, cassava and oil palm fruit industries.

2 The state Governments of the plantain growing area, in conjunction with the National Horticultural Research Institute of Federal Ministry of Science and Technology under the Green Revolution Scheme should establish (one thousand) 1000 hectares of plantain plantation with a plantain processing factory.

3 Plantain biscuits appear to be the most promising plantain flour product from the point of view of the market potential and economic viability. Therefore a plant for the production of plantain biscuits should be set up. Initially a full size rotary moulder plant could be set up to produce conventional biscuits from wheat flour while supply of plantain flour is developed. Batches of plantain biscuits could be produced intermittently and test marketed using the outlets developed for conventional biscuits.

4 A Research and Development Centre should be established to identify and develop further range of food products from plantain and to promote the packaging and marketing of plantain food products in Nigeria and eventually abroad. The Research Centre should be closely associated with the plantations set up so as to monitor the economics of plantain production necessary for the assessment of the economic viability of the plantain food products.

CHAPTER 9

Suggestions for Further Work

9 Suggestions for further work

1 Technical and economic study of use of plantain pulp in bakery products production. There is need for simple apparatus for the pulping of plantain which could be incorporated into the existing mixing equipment for small bakers and which could be operated in the rural areas of a developing economy.

2 The production and marketing of alcoholic beverages (eg beer) from overripe plantain. Native wine called "Ogogoro" has been produced from overripe plantain by farmers. The process has not been commercialised due to lack of consistent final product.

3 The production of biogas from plantain peel and waste as a source of energy supply for the plantain dehydration (ie Design of biodigester plant for methane gas production).

4 Further research into the baking potential of plantain flour. Plantain flour could be enriched with soya milk for the production of cracker type bread and biscuits. It could also be enriched with fish meal and water for the production of snack (cereal) product for breakfast.

5 Detailed marketing research of plantain food products. Need to establish consumer requirements with respect to type of products, market size and price structure.

6 Study of the temperature profile and moisture distribution of a heating plantain cube in order to establish the heat penetration curve. This will help in the determination of accurate diffusion coefficient and the prediction of the drying rate for eventual improvement of the plantain drying process.

APPENDICES

APP-P

Description of Proposed Project June 1979

Part 1 Laboratory Scale Plantain Processing

1.1 To establish a quality standard for green plantain by analytical methods in order to follow maturation changes.

1.2 Peeling and pretreatment including the control of enzymatic browning.

1.3 Study of the drying of sliced and mashed plantain material and the effect of drying methods on the quality of the dried product with respect to colour, flavour, properties of the starch and milling characteristics.

1.4 Choice of milling equipment and operating conditions in order to produce a flour suitable for the production of gruel and baked products.

1.5 To examine the baking and storage properties of the flour produced.

1.6 To carry out texture, organoleptic and chemical assessment of the foods produced.

Part 2 Scale up of the plantain flour process

2.1 Consideration of commercial equipment and material.

2.1.1 Peeling

2.1.2 Pretreatment

2.1.3 Drying

2.1.4 Size reduction

2.1.5 Packaging

Part 3 Consumer, Marketing and Economic appraisal of the plantain products

3.1 Test marketing to determine market size and price ranges.

3.2 Consumer reaction to the processed flour

3.3 Economic appraisal of the project on the basis of

(i) Financial - Cost - Benefit Analysis

(ii) Social - Cost- Benefit Analysis

3.4 Economic capacity and capital intensity of plant/Factory.

Part 4. Technology Transfer

4.1 Factors affecting commercial use of the plantain process in Nigeria.

4.2 Examination of Entrepreneurship, Foreign Investment, Government Regulation as alternative methods of introducing the process in Nigeria.

4.3 Set out some recommendations on government policies to encourage the adoption of the process by entrepreneurs.

4.4 General problems of Technology Transfer to developing countries with particular emphasis on the pioneering of new techniques.

APP-1 The Uses of Plantain in Nigeria

THE FOOD AND MEDICINAL USES OF PLANTAIN

It is difficult sometimes to define the specific use of food to man. The purpose of eating food could be said to be to keep life going by supplying the nutrients required by the body cells for growth. It could also act as a means of prevention against certain diseases as it is paradoxically said that an apple a day keeps man away from a doctor for a long time. When food is eaten as a means of curing a disease, it serves a curative purpose like any drug or capsule for the specific disease. In any case, it is important to note that plantain is usually prepared in the form of food even when it is intended to produce a curative effect.

FOOD USES OF PLANTAIN

Plantain Fufu

When an unripe plantain is cooked, peeled and pounded, a fufu type dish is obtained which can be eaten with vegetable soup. Both unripe and ripe plantain are usually cooked and pounded with cooked yam/ cocoyam to improve the texture of the latter. The resulting fufu, which is regarded as a delicacy, is usually smooth and more elastic when compared with fufu from yam or cocoyam alone. The ohun type of plantain is best used for the production of this food. All the farmers interviewed maintained that plantain is eaten in this form.

Plantain Amala

Plantain flour known as elubo (Yoruba) is used for the preparation of amala food which is like fufu. It is normally prepared by mixing the flour with an appropriate quantity of boiling water to form a very thick paste. This is eaten with green leafy or other types of soup. The same process is used for the preparation of fufu from ground rice, a popular food for Nigerians as well as other Africans in Europe. The Olukemewa or Original Okinima type is best used for plantain flour production. Because of the scarcity of this variety the other types of plantain are also used for flour production. This is a popular food of the Yoruba and the people of Bendel state.

Moi-Moi Ogede (Yoruba)

The dried pieces of green plantain pulp can be ground with water to produce slurry or the plantain flour mixed with water to form slurry. Meat, shrimps, fresh or dried pepper, red palm oil, ripe plantain, salt and onion are added and stirred to form a thick slurry. This is wrapped in small portions in plantain or banana leaves and cooked by steaming. The ripe plantain adds flavour to the mixture. The food is a favourite dish in southern states and has different local names like moi-moi jioko (Ibo), ukpo ogede (Eshan) and emeki (Benin). The agbagba varieties of plantain are used for the production of moi-moi. Almost all farmers interviewed described the preparation of this food from plantain. This type of food is known as 'butte' in Uganda and is a popular dish in the Buvuma Islands in Lake Victoria.

Plantain Pottage

When green plantain is peeled and cut into small pieces, it is cooked with ingredients like palm oil, pepper, onion, fish and salt, resulting in a dish called pottage. When it is prepared without oil, it is more like pepper soup and is called Afia Ukom in the Cross River State. This type of food is obtainable in all the states surveyed.

Roasted Plantain

When green plantain is peeled and roasted it is called 'boli' (Yoruba) and is normally eaten with stew or with palm oil mixed with pepper and salt. It is a very popular food for travellers and is usually prepared along roadsides in the cities. Ripe plantains are also roasted but this is not very common. The ohun type of plantain is used for this purpose. It is a popular food among all farmers interviewed.

Dodo

Ripe plantains are peeled, sliced, salted and fried with palm oil until becoming a golden brown colour. They are popularly eaten with pap or eko (Yoruba) as breakfast. Pap or eko is porridge made from maize flour with boiling water.

Dodo is also served as lunch or dinner with stewed rice or beans. Both ohun and agbagba varieties are used. It is prepared and eaten in all the states surveyed.

Dodo Ikire

Overripe plantain is cut into small pieces. The bits are mixed with salt, dried ground pepper and palm oil to form a paste. It is made into small balls and fried. When dried it is wrapped in banana or plantain leaves and sold as dodo ikire. The name originated from the name of the village "Ikire" in Oyo State where it is usually prepared and sold to travellers. It is popular among Yoruba, especially in Oyo state.

Plantain Chips

Mature green plantain is peeled, sliced cross-sectionally into small bits and fried, either in groundnut or vegetable oil until golden brown. The fried product is packaged as plantain chips and eaten mostly as a snack. For chip production, a rich clear orange shade is preferred to dirty yellow. This quality is found in the agbagba erin (Elephant) variety of plantain. This is prepared by all the farmers interviewed especially in Oyo state where a small scale factory has been established.

Onunu

A very ripe plantain is boiled with yam. Red oil is added to the plantain and yam and the mixture pounded. The resulting fufu type of food is eaten with fish stew. This is a special dish in the Rivers State known as onunu. It is a favourite food in the Rivers State.

MEDICINAL USES OF PLANTAIN

Cure of Sore Throat and Belubelu (Yoruba)

The Ohun variety of plantain, which is usually dwarfish, is used in curing sore throats. A ripe plantain is peeled and mixed with one local raw egg, ripe pawpaw and red palm oil, to form a slurry. When a spoonful is taken three times a day it softens the throat and during coughing, one could cough out any disturbing object along the throat.

Sometimes there is a small growth in the throat, a disease known as belubelu, and after a treatment the growth is coughed out. This information was given by Chief Raimi Onyeniye, of Irewole local government council area, Ikire, Oyo state.

Cure of Diarrhoea and Vomiting

When green plantain is roasted or cooked and eaten with or without palm oil, it cures diarrhoea after a period of treatment. It also helps to restore strength after vomiting. A patient suffering from diarrhoea loses much potassium through excess loss of fluid. This results in weakness, including the muscles of the intestines, and in an acute case can cause paralysis. By eating plantain, the patient recovers the potassium because plantain contains a high quantity of potassium when compared with other staple starchy products. Also during vomiting excessive potassium could be lost, and this is regained through eating plantain. Almost all the farmers interviewed described the use of plantain for this cure. Also a medical doctor gave the information above why it is used for this purpose.

Cure of Sore Tongue

Before plantains start to fruit, the bud usually comes out first and continues to open as fruiting continues. If this bud is ground with pepper and water and the liquid extract applied regularly to the affected tongue or mouth, the whitish substance is cleared and the soreness cured, restoring the appetite. This information was given by Mr Lasisi Onifade of Oduno Village, Oluyole Local Government, Oyo State and Mr B A Adeleke and his collegues of Aiyetoro, Ogun State.

Cure of Gonorrhoea

When Agbagba type of unripe plantain is mixed with black pepper, root of pawpaw tree, potassium and melon pud without the seeds, and the mixture pounded, it is used to cure gonorrhoea. If the person suffering from the disease eats the mixture with pap (eko) every morning, he would be cured after a period of treatment. This was narrated by Mr B A Adeleke, Mr Ishola Obe and Mr Joseph Odejobi all of Aiyetoro Ogun state.

Source of Virility

When sugar is added to a mixture of plantain and corn flour and boiling water added to the mixture, a porridge type of food known as pap or eko is obtained. The food when eaten induces virility especially to old people. The details of the cure was given by Chief Raimi Onyeniye of Ikire, Oyo state.

The unripe plantain can be mixed with a special climbing vine called Ogbolo (Yoruba), sugar, fish, salt and pounded thoroughly to form a homogenous mixture. The mixture, when eaten with pap (eko) is also a source of virility in man. The same claim is made for roasted green plantain. Mr B A Adeleke and his collegues described this method of cure during my survey of Ogun state.

As Brain Tonic

When young plantain stem is cut off, a small, tender bud grows at the centre. If one buys the first cake produced in the bakery in the morning and places it on top of the bud at sunrise, a mixture of the cake and the bud is claimed to act as brain tonic when eaten at sunset. The rate of understanding is claimed to be increased.

For Power Tussle

A fruit of plantain is cut into two halves. A ring is placed in-between the halves and tied with a special rope. It is then kept for seven days, after which the rope is untied. The ring is cleaned and worn on a finger for aid in a power tussle such as wrestling contest or political campaign. The information on Brain Tonic and Power Tussel was given by Chief William F Ogunlewe of Ogbere Headquaters, Ijebu East, Ogun state.

OTHER USES

Peel as a Tenderiser

When peel from green plantain is dried, ground, sieved and preserved in powder form, it has a softening effect on such food products like telfaria, punkin leaf and meat when they are being cooked. This results in a shorter cooking time. This process was described by Mrs C A G Toby (Home Economist) of the Ministry of Education, Port-Harcourt, Rivers State and also by Mr Patrick Ita of Ekang, Cross River state.

EATING PATTERNS OF PLANTAIN FOOD PRODUCTS IN THE SOUTHERN STATES OF NIGERIA

PLANTAIN FOOD PRODUCTS

STATES	AMALA	FUFU	MOI-MOI	POTTAGE	ROASTED	DODO	DODO IKIRE	CHIPS	ONUNU
ANAMBRA	X	XXX	XX	XX	XX	XXX	O	XX	O
BENDEL	XXX	XX	XX	X	XX	XXX	O	XX	O
CROSS RIVER	X	X	XX	XX	XX	XXX	O	XX	O
IMO	X	XXX	XX	XX	XX	XXX	O	XX	O
OGUN	XX	XX	X	X	XXX	XXX	X	XX	O
ONDO	XXX	XX	XX	X	XXX	XXX	X	XX	O
OYO	XXX	XX	XX	X	XXX	XXX	XXX	XXX	O
RIVERS	XX	XX	X	XX	XX	XXX	O	XX	XXX

Notations :
XXX - Very common
XX - Common
X - Less common
O - Not used

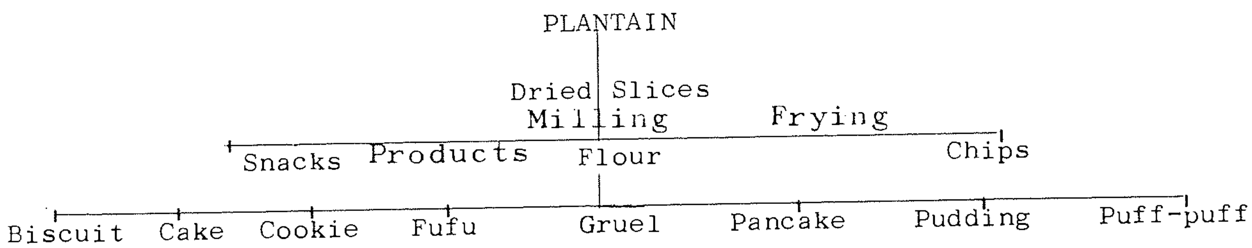
As Dish-Washing Soap

The peel from green plantain and the stalk holding the fruits are normally burnt to produce ash for washing dishes. It is a common practice among the housewives of farmers who produce plantain in substancial quantity especially in Rivers and Cross River states.

EATING PATTERNS OF PLANTAIN FOOD PRODUCTS IN THE SOUTHERN STATES OF NIGERIA

An indication of eating patterns is given on Table 1. This is derived from interviews with, on average, about six prominent farmers in each of the states. The information is only an indication of the eating habits of the people and not of preference/acceptance tests of the plantain products. Many factors affect the demand for a particular product. In general, people like most of the plantain products, even in those areas where they are not shown to be eaten much because of some limiting factors like availability of raw material, method of preparation, and other competitive food products.

THE DIAGRAMMATIC REPRESENTATION OF THE FOOD USES OF PLANTAIN FLOUR



APP-3.1

Data and Calculated Surface Temperatures of 10mm and 15mm plantain cubes dried at 60°C Dry Bulb Temperature.

10 mm Cube

Time (mins)	Cube wt (g)	dWw/dΘ (g/min)	$T_A - T_{(\Theta)}$ °C	$T_{(\Theta)}$
5	1.415	4.75×10^{-4}	44.76	15.25
10	1.320	3.50×10^{-4}	32.97	27.03
15	1.244	2.82×10^{-4}	26.53	33.47
20	1.185	2.430×10^{-4}	22.92	37.07
30	1.097	1.9300×10^{-4}	18.21	41.79
40	1.021	1.6300×10^{-4}	15.39	44.61
50	0.957	1.400×10^{-4}	13.19	46.81
60	0.908	1.22×10^{-4}	11.46	48.54
90	0.806	1.83×10^{-5}	8.32	51.68
120	0.731	1.83×10^{-5}	1.73	58.27
150	0.681	1.55×10^{-5}	1.46	58.54
180	0.648	1.33×10^{-5}	1.26	58.74
210	0.632	5.00×10^{-6}	0.47	59.53
240	0.629	1.40×10^{-6}	0.13	59.87
270	0.620	6.00×10^{-7}	0.06	59.94

Average TΘ (40 min - 270min) = 54.65°C   55°C

15mm Cube

Time (mins)	Cube wt (g)	dWw/dΘ (g/min)	$T_A - T_{(\Theta)}$ °C	$T_{(\Theta)}$
5	3.750	8.87×10^{-4}	37.12	22.87
10	3.523	6.78×10^{-4}	28.40	31.60
15	3.385	5.58×10^{-4}	23.38	36.60
20	3.242	4.93×10^{-4}	20.65	39.34
30	3.050	4.05×10^{-4}	16.96	43.04
40	2.871	3.48×10^{-4}	14.58	45.42
50	2.713	3.05×10^{-4}	12.77	47.23
60	2.597	2.67×10^{-4}	11.16	48.84
90	2.235	2.03×10^{-4}	8.51	51.49
120	2.136	5.60×10^{-5}	2.09	54.90
150	1.984	5.00×10^{-5}	2.09	57.90
180	1.866	4.66×10^{-5}	1.95	58.04
210	1.766	2.16×10^{-5}	0.91	59.09
240	1.692	1.00×10^{-5}	0.42	59.58
270	1.651	3.30×10^{-6}	0.14	59.86

Average $T_{(\Theta)}$ (40 min - 270 min) = 54.24 °C   55°C

APP-3.2 Sample Calculation for the Prediction of Cube Weight with Drying Time.

$$W\theta = (Wo-We)\left(\frac{8}{\pi^2}\right)^3 \left[e^{\frac{-9\pi^2 D(T)\theta}{16L^2}} + \frac{1}{3} e^{\frac{-41\pi^2 D(T)\theta}{16L^2}} + \frac{1}{27} e^{\frac{-105\pi^2 D(T)\theta}{16L^2}} \right] + We$$

For 10mm Cube and $D(T) = D_{55°}$ (0.8858×10^{-9} m^2/S)

Time (S): $(0.5385)\left[e^{-1.9671x10^{-4}\theta} + \frac{1}{3}e^{-8.9614x10^{-4}\theta} + \frac{1}{27}e^{-2.2950x10^{-3}\theta}\right] + 0.5939$

Time (S)							Cube Weight (g)
300	(0.5385)	0.9427	+	0.2548	+	0.0186	1.2488
600		0.8887	+	0.1947	+	0.0093	1.823
900		0.8377	+	0.1488	+	0.0047	1.1277
1200		0.7897	+	0.1137			1.0804
1800		0.7018	+	0.0664			1.0076
2400		0.6237	+	0.0388			0.9507
3000		0.5543	+	0.0227			0.9046
3600		0.4926	+	0.0132			0.8663
5400		0.3457	+	0.0026			0.7815
7200		0.2426	+	0.0005			0.7248
9000		0.1703	+				0.6856
10800		0.1195	+				0.6583
12600		0.0839	+				0.6391
14400		0.0589	+				0.6256
16200		0.0413	+				0.6161
18000		0.0290	+				0.6095

For 15mm Cube and $D(T) = D_{55°}$ (1.2214×10^{-9} m^2/S)

Time (S): $(1.3608)\left[e^{-1.2055x10^{-4}\theta} + \frac{1}{3}e^{-5.4915x10^{-4}\theta} + \frac{1}{27}e^{-1.4064x10^{-3}\theta}\right] + 1.5$

Time S							Cube Weight (g)
300	(1.3608)	0.9645	+	0.2827	+	0.0243	3.2306
600		0.9302	+	0.2398	+	0.0159	3.1142
900		0.8972	+	0.2033	+	0.0104	3.0122
1200		0.8653	+	0.1725	+	0.0068	2.9220
1800		0.8049	+	0.1240	+	0.0029	2.7685
2400		0.7488	+	0.0892	+	0.0013	2.6425
3000		0.6965	+	0.0642			2.5355
3600		0.6479	+	0.0462			2.4449
5400		0.5215	+	0.0172			2.2334
7200		0.4198	+	0.0064			2.0804
9000		0.3379	+	0.0024			1.9635
10800		0.2720	+				1.8705
12600		0.2189	+				1.7402
14400		0.1762	+				1.6934
16200		0.1418	+				1.6558
18000		0.1142	+				

APP-33 Derivation of 3 Dimensional Model Equation based on the Fick's Law of Diffusion

For a solid of thickness 2L drying from 2 faces i.e. one dimensional

(3.2.5) is, $$\frac{W-We}{Wc-We} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left\{-(2n+1)^2 \pi^2 D/4L^2\right\}$$

(equation 3.2.5) (Perry and Chilton, 1973).

It can be shown that for 2 or 3 dimensional solids the effects in each direction are multiplicative. For a three dimensional solid of size $2L_1 \times 2L_2 \times 2L_3$ drying from all 6 faces, we get

$$\frac{W-We}{Wc-We} = \left(\frac{L_1}{L_o}\right) \left(\frac{L_2}{L_o}\right) \left(\frac{L_3}{L_o}\right)$$

$$= \left(\frac{8}{\pi^2}\right)^3 \left[\sum_{l=0}^{\infty} \frac{\exp -(2l+1)^2 \pi^2 D\theta/4L_1^2}{(2l+1)^2} \times \sum_{m=0}^{\infty} \frac{\exp -(2m+1)^2 \pi^2 D\theta/4L_2^2}{(2m+1)^2} \times \sum_{n=0}^{\infty} \frac{\exp -(2n+1)^2 \pi^2 D\theta/4L_3^2}{(2n+1)^2} \right]$$

$$= \left[\frac{8}{\pi^2}\right]^3 \left\{ \exp -\frac{\pi^2 D\theta}{4}\left(\frac{1}{L_1^2} + \frac{1}{L_2^2} + \frac{1}{L_3^2}\right) + \frac{1}{9}\left[\exp -9\pi^2 D\theta/4L_1^2 \times \exp -\frac{\pi^2 D\theta}{4L_2^2} \times \exp -\frac{\pi^2 D\theta}{4L_3^2} + \exp -\frac{\pi^2 D\theta}{4L_1^2} \times \exp -\frac{9\pi^2 D\theta}{4L_2^2} \times \exp -\frac{\pi^2 D\theta}{4L_3^2} + \exp -\frac{\pi^2 D\theta}{4L_1^2} \times \exp -\frac{\pi^2 D\theta}{4L_2^2} \times \exp -\frac{9\pi^2 D\theta}{4L_3^2} \right] + \frac{1}{27}\left[\ldots\ldots\right] \right\}$$

$$= \left[\frac{8}{\pi^2}\right]^3 \left\{ \exp - \frac{\pi^2 D\theta}{4} \left(\frac{1}{L_1^2} + \frac{1}{L_2^2} + \frac{1}{L_3^2}\right) + \frac{1}{9}\left[\exp - \frac{\pi^2 D\theta}{4} \right.\right.$$

$$\left(\frac{9}{L_1^2} + \frac{1}{L_2^2} + \frac{1}{L_3^2} \right) + \exp - \frac{\pi^2 D\theta}{4} \left(\frac{1}{L_1^2} + \frac{9}{L_2^2} + \frac{1}{L_3^2} \right)$$

$$+ \exp - \frac{\pi^2 D\theta}{4} \left(\frac{1}{L_1^2} + \frac{1}{L_2^2} + \frac{9}{L_3^2} \right) + \frac{1}{27} \left[\cdots\cdots \right]$$

For a cube (all faces drying), $L_1 = L_2 = L_3 = L$

$$\therefore \quad \frac{W - We}{W - We} = \left(\frac{8}{\pi^2}\right)^3 \left[\exp - \frac{3\pi^2 D\theta}{4L^2} + \frac{1}{3} \exp - \frac{11\pi^2 D\theta}{4L^2} + \frac{1}{27} \right.$$

$$\left. \exp - \frac{19\pi^2 D\theta}{4L^2} + \cdots\cdots \right]$$

For 5 faced cube (ie drying is taking place from 5 faces)

$$L_1 = L_3 = L$$

$$L_2 = 2L$$

$$\frac{W - We}{Wc - We} = \left(\frac{8}{\pi^2}\right)^3 \left\{ \exp - \frac{\pi^2 D\theta}{4} \left(\frac{1}{L^2} + \frac{1}{4L^2} + \frac{1}{L^2} \right) + \frac{1}{9} \left[\exp - \frac{\pi^2 D\theta}{4} \left(\frac{9}{L^2} + \frac{1}{4L^2} + \frac{1}{L^2} \right) \right.\right.$$

$$\left. + \exp - \frac{\pi^2 D\theta}{4} \left(\frac{1}{L^2} + \frac{9}{4L^2} + \frac{1}{L^2} \right) + \exp - \frac{\pi^2 D\theta}{4} \left(\frac{1}{L^2} + \frac{1}{4L^2} + \frac{9}{L^2} \right) + \cdots\cdots \right\}$$

$$= \left(\frac{8}{\pi^2}\right)^3 \left\{ \exp - \frac{9\pi^2 D\theta}{16L^2} + \frac{1}{3} \exp - \frac{41\pi^2 D\theta}{16L^2} + \frac{1}{27} \exp - \frac{105\pi^2 D\theta}{16 L^2} + \cdots\cdots \right\}$$

.... APP-3·1

Considering the first term only, we get

$$\ln\left(\frac{W - We}{Wc-We}\right) = \ln\left(\frac{8}{\pi^2}\right)^3 \exp - \frac{9\pi^2 D\theta}{16L^2}$$

$$\ln\left(\frac{W-We}{Wc-We}\right) = -\frac{9\pi^2 D\theta}{16L^2} + \ln\left(\frac{8}{\pi^2}\right)^3 \quad \ldots\ldots\ \text{APP-3.2}$$

By plotting $\ln\left(\frac{W-We}{Wc-We}\right)$ against θ we get slope $= -\frac{9\pi^2 D}{16\ L^2}$

The diffusion coefficient "D" can be calculated for any given temperature of drying. For $\theta < 100$ minutes, there is need for more than one term from (APP-3.3) in the summation in order to calculate the correct value of $(W-We)/(Wc-We)$.

TABLE APP-3-4

Data for the graph of ln $(W_\theta - We)/(W_o - We)$ versus time for 15mm and 10mm plantain cube dried at 40°C.

For 10mm cube

Time (Mins)	Cube Wt (g)	$\frac{W_\theta - We}{W_o - We}$	$\ln\frac{(W_\theta - We)}{W_o - We}$
0	1.715	1.0000	
5	1.615	0.9074	-0.0971
10	1.549	0.8464	-0.1668
15	1.497	0.7982	-0.2254
20	1.448	0.7529	-0.2838
30	1.399	0.7075	-0.3460
40	1.322	0.6363	-0.4521
50	1.275	0.5928	-0.5230
60	1.239	0.5594	-0.5808
90	1.152	0.4789	-0.7362
120	1.083	0.4151	-0.8793
150	1.017	0.3540	-1.0385
180	0.962	0.3031	-1.1938
240	0.875	0.2225	-1.5026
270	0.841	0.1911	-1.6551
300	0.812	0.1642	-1.8064
330	0.787	0.1411	-1.9583
360	0.767	0.1226	-2.0989
380	0.761	0.1170	-2.1453

Equilibrium Moisture Content (W_e) = 0.6346

For 15mm cube

4.551	1.0000	
4.359	0.9330	-0.0693
4.216	0.8832	-0.1243
4.097	0.8426	-0.1713
3.999	0.8075	-0.2138
3.845	0.7538	-0.2827
3.725	0.7119	-0.3398
3.607	0.6708	-0.3994
3.525	0.6422	-0.4429
3.319	0.5703	-0.5616
3.158	0.5141	-0.6652
3.020	0.4660	-0.7635
2.864	0.4116	-0.8877
2.635	0.3317	-1.1034
2.570	0.3091	-1.1742
2.452	0.2679	-1.3171
2.374	0.2407	-1.4242
2.307	0.2173	-1.5263
2.285	0.2097	-1.5623

APP-3·5

Data for the graph of ln $(W_\theta - We)/(Wo-We)$ versus time for 15mm and 10mm plantain cube dried at 49°C,

For 10mm Cube

Time (Mins)	Cube Wt (g)	$\frac{W_\theta - We}{Wo-We}$	$\ln\frac{(W_\theta - We)}{Wo-We}$
0	1.851	1.0000	
5	1.715	0.8834	-0.1240
10	1.622	0.8036	-0.2186
15	1.567	0.7565	-0.2791
20	1.511	0.7084	-0.3447
30	1.442	0.6493	-0.4319
40	1.379	0.5952	-0.5188
50	1.330	0.5532	-0.5920
60	1.282	0.5121	-0.6693
100	1.152	0.4006	-0.9148
120	1.099	0.3551	-1.0353
150	1.035	0.3002	-1.2031
180	0.981	0.2539	-1.3706
210	0.938	0.2171	-1.5275
240	0.901	0.1853	-1.6856
270	0.867	0.1562	-1.8567
300	0.843	0.1356	-1.9980
330	0.821	0.1167	-2.1478
360	0.805	0.1030	-2.2729
390	0.792	0.0919	-2.3874

Equilibrium moisture content (We) = 0.6849

4.428	1.0000	
4.175	0.9093	-0.0951
4.009	0.8498	-0.1628
3.876	0.8021	-0.2205
3.773	0.7652	-0.2676
3.622	0.7111	-0.3410
3.500	0.6673	-0.4045
3.387	0.6268	-0.4671
3.288	0.5913	-0.5254
2.994	0.4859	-0.7217
2.874	0.4429	-0.8143
2.721	0.3881	-0.9465
2.577	0.3365	-1.0893
2.456	0.2931	-1.2273
2.362	0.2594	-1.3494
2.280	0.2300	-1.4697
2.178	0.1934	-1.6428
2.112	0.1698	-1.7733
2.045	0.1458	-1.9258
1.981	0.1228	-2.0971

Equilibrium Moisture content, (We) = 1.6384

For 15mm Cube

APP-3.6

Data for the graph of ln $(W_\theta - We)/(W_o - We)$ versus time for 15mm and 10mm plantain cube dried at 54°C.

	For 10mm Cube Equilibrium Moisture Content(We) = 0.565g			For 5mm Cube We= 0.0958			For 15mm Cube Equilibrium Moisture Content(We) = 1.8[illegible]		
Time (mins)	Cube Wt (g)	$\frac{W_\theta - We}{Wo-We}$	$\ln\frac{(W_\theta - We)}{Wo-We}$	cube wt (g)	$\frac{W_\theta - We}{Wo-We}$	$\ln\frac{(W_\theta - We)}{Wo-We}$	Cube wt (g)	$\frac{W_\theta - We}{Wo-We}$	$\ln\frac{(W_\theta - We)}{Wo-We}$
0	1.404	1.0000		0.238	1.0000		4.455	1.0000	
5	1.311	0.8892	-0.1175	0.213	0.8242	-0.1933	4.247	0.9217	-0.0815
10	1.250	0.8164	-0.2028	0.195	0.6977	-0.3600	4.101	0.8667	-0.1431
15	1.195	0.7509	-0.2865	0.182	0.6063	-0.5064	3.960	0.8136	-0.2063
20	1.152	0.6996	-0.3572	0.174	0.5500	-0.5978	3.857	0.7748	-0.2552
30	1.083	0.6174	-0.4822	0.160	0.4516	-0.7950	3.670	0.7043	-0.3506
40	1.024	0.5471	-0.6032	0.146	0.3531	-1.0409	3.522	0.6486	-0.4329
50	0.974	0.4875	-0.7185	0.135	0.2758	-1.2881	3.377	0.5940	-0.5209
60	0.931	0.4362	-0.8296	0.126	0.2125	-1.5488	3.264	0.5514	-0.5953
80	0.864	0.3564	-1.0318	0.114	0.1281	-2.0547	3.065	0.4765	-0.7413
100	0.807	0.2884	-1.2433	0.110	0.1000	-2.3025	2.903	0.4143	-0.8812
120	0.765	0.2384	-1.4339	0.109	0.0930	-2.3754	2.765	0.3635	-1.0120
140	0.728	0.1943	-1.6385	0.108	0.0859	-2.4540	2.655	0.3220	-1.1332
160	0.696	0.1561	-1.8570	0.108	0.0858	-2.4540	2.550	0.2825	-1.2641
180	0.670	0.1251	-2.0783	0.108	0.0858	-2.4540	2.463	0.2486	-1.3919
200	0.650	0.1013	-2.2896				2.380	0.2185	-1.5210
220	0.633	0.0810	-2.5127				2.309	0.1917	-1.6518
240	0.618	0.0632	-2.7619				2.243	0.1669	-1.7904
260	0.612	0.0560	-2.8821				2.185	0.1450	-1.9310
280	0.609	0.0524	-2.9480				2.136	0.1266	-2.0667
300	0.607	0.0501	-2.9945				2.096	0.1115	-2.1938

APP-3.7

Data for the graph of ln (Wo-We)/(Wo-We) versus time for 15mm and 10mm plantain cube dried at 60°C

Time	For 10mm Cube: Cube Wt	$\frac{W_\Theta - We}{Wo-We}$	$\ln\frac{(W_\Theta - We)}{Wo-We}$	$\frac{W_\Theta - We}{Wo-We}$	$\ln\frac{(W_\Theta - We)}{Wo-We}$	$\frac{W_\Theta - We}{Wo-We}$	$\ln\frac{(W_\Theta - We)}{Wo-We}$	For 15mm Cube: Cube Wt	$\frac{W_\Theta - We}{Wo-We}$	$\ln\frac{(W_\Theta - We)}{Wo-We}$
0	1.605	1.0000		1.0000		1.0000		4.055	1.0000	
5	1.415	0.8150	-0.2045	0.8121	-0.2081	0.8071	-0.2143	3.750	0.8806	-0.1271
10	1.320	0.7225	-0.3250	0.7181	-0.3311	0.7107	-0.3416	3.523	0.7918	-0.2335
15	1.244	0.6486	-0.4330	0.6430	-0.4416	0.6335	-0.4565	3.385	0.7377	-0.3042
20	1.185	0.5911	-0.5257	0.5846	-0.5368	0.5736	-0.5558	3.242	0.6818	-0.3831
30	1.097	0.5055	-0.6823	0.4976	-0.6980	0.4843	-0.7251	3.050	0.6066	-0.4999
40	1.021	0.4315	-0.8406	0.4224	-0.8617	0.4071	-0.8987	2.871	0.5365	-0.6226
50	0.957	0.3692	-0.9965	0.3591	-1.0240	0.3421	-1.0726	2.713	0.4747	-0.7451
60	0.908	0.3215	-1.1349	0.3107	-1.1690	0.2924	-1.2297	2.597	0.4293	-0.8457
90	0.806	0.2222	-1.5044	0.2098	-1.5616	0.1888	-1.6669	2.235	0.2876	-1.2463
120	0.731	0.1491	-1.9028	0.1356	-1.9978	0.1127	-2.1831	2.136	0.2488	-1.3910
150	0.681	0.1005	-2.2979	0.0862	-2.4512	0.0619	-2.7818	1.984	0.1893	-1.6643
180	0.648	0.0683	-2.6832	0.0536	-2.9271	0.0284	-3.5604	1.866	0.1431	-1.9440
210	0.632	0.0528	-2.9419	0.0377	-3.2773	0.0122	-4.4077	1.766	0.1040	-2.2635
240	0.629	0.0498	-2.9989	0.0348	-3.3592	0.0091	-4.6954	1.692	0.0750	-2.5900
270	0.620	0.0411	-3.1922	0.0259	-3.6550			1.651	0.0590	-2.8307
300	0.607	0.0284	-3.5604	0.0130	-4.3424			1.600	0.0390	-3.2440

We=0.5778 =36%Wo

We=0.5939 =37% Wo

We=0.62 =38.63%

We = 1.5004 = 37% Wo

APP-3.8

Data for the graph of ln $(W_\theta - We)/(Wo-We)$ versus time for 10mm and 15mm plantain cube dried at 65°C.

		For 10mm Cube		For 15mm Cube		
		Equilibrium Moisture Content(We) = 0.4847g		Equilibrium Moisture Content(We) = 1.8019 g		
Time (mins)	Cube Wt. (g)	$\frac{W_\theta - We}{Wo-We}$	ln $\frac{W_\theta - We}{Wo-We}$	Cube Wt (g)	$\frac{W_\theta - We}{Wo-We}$	ln $\frac{W_\theta - We}{Wo-We}$
0	1.31	1.0000		4.87	1.0000	
5				4.51	0.8827	-0.1248
10	1.14	0.7940	-0.2307	4.52	0.8859	-0.1211
15	0.97	0.5880	-0.5310	4.26	0.8012	-0.2217
20	1.02	0.6486	-0.4329	4.17	0.7718	-0.2590
30	0.92	0.5274	-0.6397	3.91	0.6871	-0.3753
45	0.79	0.3699	-0.9945	3.59	0.5828	-0.5399
60	0.72	0.2851	-1.2549	3.28	0.4818	-0.7303
75	0.63	0.1761	-1.7369	3.23	0.4655	-0.7647
90	0.57	0.1034	-2.2696	2.86	0.3449	-1.0646
105	0.56	0.0912	-2.3943	2.68	0.2862	-1.2511
120	0.55	0.0791	-2.5368	2.57	0.2504	-1.3849
135	0.55	0.0791	-2.5368	2.46	0.2145	-1.5395
150	0.55	0.0670	-2.7030	2.35	0.1786	-1.7224

APP- 3.9 Data for The Drying Curves of 15mm Plantain Cube

Dry Bulb Temperature of Drying = 57°C

Time (mins)	Air Flowrate = 2.4m/s Cubes Wt. (g)	dW/dθ g/gmin	gH_2O/gDM	Air Flowrate = 2.9 m/s Cubes Wt	dW/dθ g/gmin	gH_2O/gDM	Air Flowrate = 3.4m/s Cubes wt	dW/dθ g/gmin	gH_2O/gDM g/gmin
0	73.947		1.5	75.626		1.5	74.583		1.5
5	73.120	0.0055	1.472	74.579	0.0069	1.465	73.643	0.0070	1.468
10	72.317	0.0054	1.445	73.530	0.0067	1.431	72.520	0.0069	1.431
15	71.522	0.0053	1.418	72.530	0.0066	1.398	71.455	0.0068	1.395
20	70.761	0.0052	1.392	71.567	0.0065	1.366	70.422	0.0067	1.361
25				70.573	0.0063	1.333	69.390	0.0066	1.326
30	69.310	0.0049	1.343	69.622	0.0062	1.302	68.410	0.0064	1.293
40	67.965	0.0047	1.298	67.946	0.0059	1.246	66.525	0.0061	1.230
50	66.676	0.0045	1.254	66.290	0.0055	1.191	64.803	0.0057	1.172
60	65.336	0.0043	1.209						
70				63.254	0.0045	1.091	61.519	0.0045	1.062
80	62.958	0.0031	1.128				60.012	0.0038	1.012
90				60.522	0.0033	1.001	58.590	0.0031	0.964
100	60.649	0.0021	1.050				57.244	0.0026	0.919
110				58.001	0.0022	0.917			
120	58.520	0.0012	0.978				54.987	0.0016	0.843
130				55.662	0.0013	0.840			
140	56.570	0.0008	0.912				52.950	0.0009	0.775
150				53.665	0.0006	0.774	51.922	0.0007	0.740
160	54.286	0.0004	0.835	52.860	0.0003	0.747	51.076	0.0004	0.712
170				52.076	0.0002	0.721	50.278	0.0002	0.685
180	53.144	0.0002	0.797	51.310		0.696	49.528		0.660

Effect of Air Flowrate on the Rate of Drying of Cubes Packed in Trays

Dm = DRY MATTER

TABLE APP-3.10

Data for the drying curves of 10mm plantain cube

Effect of Drying Temperature on the rate of drying of single cube in a tray.

Time (Minutes)	Drying Temperature (40°C) Cube Wt(Wt)		gH2O/gDM	Drying Temperature (49°C) Cube Wt(Wt)		gH2O/gDM	Drying Temperature (60°C) Cube Weight(Wt)		gH2O/gDM
0	1.715	(g)	1.5	1.851	(g)	1.5	1.605	(g)	1.5
5	1.615	"	1.3542	1.715	"	1.3163	1.415	"	1.2040
10	1.549	"	1.2580	1.622	"	1.1903	1.320	"	1.0561
15	1.497	"	1.1822	1.567	"	1.1164	1.244	"	0.9377
20	1.448	"	1.1108	1.511	"	1.0407	1.185	"	0.8458
30	1.399	"	1.0394	1.442	"	0.9476	1.097	"	0.7087
40	1.322	"	0.9271	1.379	"	0.8625	1.021	"	0.5903
50	1.275	"	0.8586	1.330	"	0.7963	0.957	"	0.4907
60	1.239	"	0.8061	1.282	"	0.7315	0.908	"	0.4143
90	1.152	"	0.6793	1.152	(100min)	0.5559	0.806	"	0.2555
120	1.083	"	0.5787	1.099	"	0.4843	0.731	(m.c 9.78%)	0.1386
150	1.017	"	0.4825	1.035	"	0.3979	0.681	"	0.0607
180	0.962	"	0.4023	0.981	"	0.3250	0.648	"	0.0093
210				0.938	"	0.2669	0.632	"	
240	0.875	"	0.2755	0.901	(m.c 9.64%)	0.2169	0.629	"	
270	0.841	"	0.2259	0.867	"	0.1710	0.620	"	
300	0.812	"	0.1837	0.843	"	0.1386	0.617	"	
330(m.c.9.82%)	0.787	"	0.1472	0.821	"	0.1089			
360	0.767	"	0.1181	0.805	"	0.0873			
380	0.761	"	0.1093						
390				0.792	"	0.0697			

m.c = moisture content

APP-3.11

Data for the drying curves of 5mm, 10mm, 15mm plantain cubes:

Effect of thickness on the drying rate of plantain cubes packed in trays.

Dry Bulb Temperature = 58°C Air Flowrate = 3.4m/s

Time	Cube Size = 5mm		Cube Size = 10mm		Cube Size =15mm	
(Mins)	Cube Weight (wt)	gH2O/g (DM)	Cube Weight (wt)	gH2O/g (DM)	Cube Weight (wt)	gH2O/g (DM)
0	48.911	1.5	74.583	1.5	88.102	1.5
5	47.832	1.4448	73.643	1.4685	86.921	1.4665
10	46.743	1.3892	72.520	1.4308	85.776	1.4340
15	45.778	1.3399	71.455	1.3952	84.666	1.4025
20	44.868	1.2933	70.422	1.3605	83.569	1.3714
25			69.390	1.3259	82.484	1.3406
30	43.155	1.2058	68.410	1.2931	81.451	1.3113
40	41.560	1.1243	66.525	1.2299	79.588	1.2584
50	40.097	1.0495	64.803	1.1722	77.814	1.2081
60			63.128	1.1160	76.128	1.1602
70			61.519	1.0621	74.513	1.1144
80	36.432	0.8622	60.012	1.0116	72.990	1.0712
90			58.590	0.9639	71.476	1.0282
100	34.563	0.7666	57.244	0.9188		
110					68.763	0.9512
120	33.138	0.6938	54.987	0.8431		
130					66.386	0.8838
140	32.159	0.6439	52.950	0.7749		
150			51.922	0.7404	64.266	0.8236
160	31.434	0.6067	51.076	0.7121		
170			50.278	0.6853	62.295	0.7677
180	30.509	0.5594	49.528	0.6602	61.337	0.7405

APP-3.12

Data for the drying curves of 5mm, 10mm, 15mm plantain cubes:

Effect of thickness on the drying rate of single cubes in a tray:

Dry Bulb Temperature = 54^{o}C   Air Flowrate = 2.9 m/s.

Time (mins)	Cube size = 5mm Cube weight (Wt)	gH2O/g (DM)	Cube Size = 10mm Cube Weight (Wt)	gH2O/g (DM)	Cube Size = 15mm Cube Weight (Wt)	gH2O/g (DM)
0	0.238	1.5	1.404	1.5	4.455	1.5
5	0.213	1.2374	1.311	1.3344	4.247	1.3833
10	0.195	1.0483	1.250	1.2258	4.101	1.3013
15	0.182	0.9118	1.195	1.1278	3.390	1.2222
20	0.174	0.8277	1.152	1.0513	3.857	1.1644
30	0.160	0.6807	1.083	0.9284	3.670	1.0595
40	0.146	0.5336	1.024	0.8234	3.522	0.9764
50	0.135	0.4181	0.974	0.7343	3.377	0.8951
60	0.126	0.3235	0.931	0.6578	3.264	0.8316
80	0.114	0.1975	0.864	0.5385	3.065	0.7200
100	0.110	0.1555	0.807	0.4370	2.903	0.6291
120	0.109 m.c.9.66%	0.1450	0.765 m.c.24.15%	0.3622	2.765 m.c.36.77%	0.5516
140	0.108	0.1345	0.728	0.2963	2.655	0.4899
160			0.696	0.2393	2.550	0.4310
180			0.670	0.1930	2.463	0.3822
200			0.650 m.c.10.34%	0.1574	2.380	0.3356
220			0.633 m.c. 8.48%	0.1271	2.309	0.2957
240			0.618	0.1004	2.243	0.2587
260			0.612	0.0897	2.185	0.2262
280			0.609	0.0844	2.136	0.1987
300			0.607	0.0808	2.096 m.c.11.75%	0.1762

APP-3.13

	Cube Size = 10mm				Cube Size = 15mm			
	Dry Bulb Temperature = 60°C				Dry Bulb Temperature = 60°C			
Time (mins)	Cube wt (g)	$\frac{W_\theta - We}{Wo-We}$	Calculated Cube Wt using D_{55} (g)	$\frac{W_\theta - We}{Wo-We}$	Cube Wt (g)	$\frac{W_\theta - We}{Wo-We}$	Calculated Cube Wt using D_{55} (g)	$\frac{W_\theta - We}{Wo-We}$
0	1.605	1.0000			4.055	1.0000		
5	1.415	0.8121	1.337	0.7349	3.750	0.8806	3.515	0.7886
10	1.320	0.7181	1.242	0.6410	3.523	0.7918	3.314	0.7099
15	1.244	0.6430	1.174	0.5737	3.385	0.7377	3.170	0.6536
20	1.185	0.5846	1.120	0.5203	3.242	0.6818	3.053	0.6078
30	1.097	0.4976	1.037	0.4382	3.050	0.6066	2.870	0.5361
40	1.021	0.4224	0.974	0.3759	2.871	0.5365	2.727	0.4802
50	0.957	0.3591	0.924	0.3265	2.713	0.4747	2.609	0.4340
60	0.908	0.3107	0.882	0.2849	2.597	0.4293	2.508	0.3944
90	0.806	0.2098	0.789	0.1930	2.235	0.2876	2.276	0.3036
120	0.731	0.1356	0.729	0.1336	2.136	0.2488	2.109	0.2382
150	0.681	0.0862	0.687	0.0921	1.984	0.1893	1.983	0.1889
180	0.648	0.0536	0.659	0.0644	1.866	0.1431	1.884	0.1502
210	0.632	0.0377	0.639	0.0446	1.766	0.1040	1.807	0.1200
240	0.629	0.0348	0.626	0.0317	1.692	0.0750	1.745	0.0957
270	0.620	0.0259	0.616	0.0219	1.651	0.0590	1.697	0.0770
300	0.607	0.0130	0.609	0.0149	1.600	0.0390	1.657	0.0613

10mm (experimental)	10mm (calculated)	15mm (experimental)	15mm (calculated)
We = 0.5939	We = 0.5939	We = 1.5004	We = 1.5004
Wo = 1.605	Wo = 1.605	Wo = 4.055	Wo = 4.055
$D_{EXP} = 11.010 \times 10^{-10}$	$D_{55} = 8.8583 \times 10^{-10}$	$D_{EXP} = 16.120 \times 10^{-10}$	$D_{55} = 12.214 \times 10^{-10}$

APP-4.1

PILOT-SCALE PRODUCTION OF PLANTAIN FLOUR USING ROLLER, DOUBLE CYLINDER (NIP FED) AND TUBULAR DRYERS

At

Richard Simon & Sons "Dryer Division"
No. 8 Factory
Private Road No.3
Colwick Industrial Estate
Nottingham
NG4 2BT
United Kingdom

Tel: 0602-249881 Telex: 37545 12th November 1981

INTRODUCTION

The economics of drying plantain to produce flour can be studied effectively by carrying out plant trials on the equipment to be purchased for the process. This will help to establish the feasibility of producing the flour with respect to equipment performance and the quality of the product.

There are different types of drum dryers (roller dryer) and the state of the raw material affects their individual performances. The production of plantain flour using drum dryers entails the use of steam and the surface temperature of the drum is above 100°C. The flour produced is normally pregelatinised and very suitable for gruel (thick paste) production.

Factors affecting the drying rate and final moisture content of the flour will be (a) the speed of rotation of drum, which controls the contact time, (b) the steam pressure or heating medium temperature, and (c) the film thickness on the drum. High drying rates and efficient use of heat are the advantages associated with the use of drum dryers.

The objective of the plant trial was to study the above parameters so as to select suitable equipment for drying plantain slices for flour production.

MATERIAL

15 kg of green plantain was purchased from the Brixton Market, London, and used for all the plant trials.

EXPERIMENTAL DETAILS

Moisture Content:

The moisture of plantain pulp and the dired flakes produced were determined using an infra red lamp rapid dryer.

Preliminary Preparation:

The plantains were hand-peeled with a knife. Immersing the whole plantain in hot water for about 10 minutes made the removal of the skin very easy. A single sample was blanched in boiling water for 15 minutes and peeled. The peeled plantains were cut into thin slices. Another sample was scraped with a knife to produce a mash-like product which was later fed into the dryer as a thick paste.

Trial Run on Twin Roller:

0.85 kg of thin slices were fed on the thin roller operating at 4.5 r.p.m. and under steam pressure of 90 psi. The drying was uneven and slices were not extruded properly. It was evident that the slices needed to be smashed on to the rollers. 0.397 kg, dry plantain was produced in bands and the operation was completed in 10.5 minutes. The dried product was a bit wet with some quantities of undried slices and milling in an end runner mill was difficult.

The trial run was repeated with 1.25 kg of slightly mashed plantain pulp. The steam pressure was reduced to 80 psi (36.4kg) and drum speed was 2.56 r.p.m. 0.568 kg of dry products were produced after 13 minutes. The latter product was better than the former but was still a little wet because of uneven drying.

Trial Run on Double Cylinder (Nip Fed) Dryer.

0.965 kg of thin slices were fed onto a double cylinder dryer operated at 13.33 r.p.m. and under steam pressure of 90.p.s.i. The drying was uniform and 0.454 kg of well-formed light yellow bands of dried products were produced after 7 minutes 50 seconds. The bands crumbled well and were very easy to mill in an end runner mill.

The trial run was repeated under the same operating conditions using 1.447 kg of thin slices of plantain blanched for 15 minutes in boiling water. The slices were softer and the products were slightly too dry. The speed was then increased to 15.7 r.p.m. and that gave a good dry product of 0.681 kg after 6 minutes.

Trial Run on Tubular Dryer.

1.163 kg of thin slices were fed on a tubular dryer under a steam pressure of 75 p.s.i. The drying was very slow with the slices sticking on the steam tubes. The colour of the drying products darkened as drying progressed. Many hours would be required to ensure the complete drying of the slices and the colour of the final product would be totally unacceptable. The drying was terminated to avoid further waste of energy.

DISCUSSION

The initial moisture content of the green plantain was found to be 58%. The moisture content of the two products produced using twin rollers were 10% and 7.6% respectively. The products were still wet because the drying was uneven and some of the undried slices mixed with the dried product resulting in a wet product. Slices were not suitable feed material for the twin roller which is normally fed with homogeneous slurries of total solid content between 20 and 25%. The total solid content of about 40% for the plantain plus the thickness of the slices resulted in an uneven dried product.

The moisture content of the two products from the double cylinder was 5% and 8% respectively. The product with 5% moisture content was a bit too dry. For good storage life, the moisture content of the final product should lie between 8 and 10%. At 13.33 r.p.m., the product was too dry and the yield was 58 g of dry product per minute. At 15.7 r.p.m., a good dried product was obtained and the yield was 114 g per minute. The effect of increasing the cylinder speed by 20% was to double the yield. This could be explained by the fact that at 8% moisture content 3% more water was retained in the product than in the first product which had only 5% moisture content. Secondly, the feed rate was increased from 123 g/min to 241g/min, thus decreasing the residence time of the feed material on the cylinder.

Tubular dryers are normally used for drying granules and other hard materials and the feed material must be big enough to form a thick bed. The drying is effected by the rubbing action of the hard material on the tubes and tumbling effect caused by their rotation. Plantain slices were too soft for the dryer.

CONCLUSION

The double cylinder dryer was suitable for drying plantain slices. The dried products were produced in bands which could be reduced to smaller particles by hand squeezing or milling in a hammer or end runner-mill. A good product of moisture content between 8 and 10% could be produced with the proper adjustment of the cylinder speed and steam pressure. It is estimated by the manufacturers from practical experience that every kilogram of water evaporated requires 1.4 kg of steam. To obtain good performance with the double cylinder dryer, it is necessary to run it for a minimum of 14 hours a day.

Blanching the plantain for 15 minutes before peeling, although contributing to higher drying rate i.e. higher yield, resulted in a much darker product. The colour of the unblanched plantain was light yellowish and more appealing.

The rheological property of the two sets of flours produced will be studied with particular emphasis on the extent of starch damage which will affect the gelling and viscous properties of the flour.

APP-4.2

PILOT-SCALE DRYING OF PLANTAIN PULP USING CABINET AND SIMULATED BAND DRYERS

At

APV Mitchell Dryers Ltd
Denton Holme
Carlisle
Cumbria
England CA2 5DU
United Kingdom
Tel: 0228 34433 Telex: 64139 1st-3rd December 1981

INTRODUCTION

The best drying method for a food product is determined by quality requirements, raw material characteristics and economic factors and should be the least expensive method that will provide the needed quality and characteristics in the product. A plant intended to air-dry a variety of products must be equipped with dryers that are versatile. Cabinet dryers might be considered, depending upon capacity requirements and labour costs. If a plant is to process a single material over a long operating season, highly specialised, highly engineered dryers such as continuous conveyor/ band dryers can be considered. For such a plant to operate efficiently, the availablity of repair parts, maintenance engineers, and skilled mechanics are essential.

The objectives of the plant trial were to assess the drying performance of both Cabinet and Simulated Band Dryer, Dryers for plantain cubes and slices and obtain price quotations for each equipment. Also the best operating conditions that will give acceptable quality product was established.

Material

30kg of green plantain was purchased from Brixton Market, London and used for all the plant trials.

Experimental Details

Preliminary Preparation: The plantain fruits were hand peeled and a Swedish "HALDE" automatic slicer was fitted with different blades to produce 10 mm cubes, 10mm slices, 3.5.mm slices and 3mm shreds. The moisture content of the pulp was found to be 64% by drying a given sample at 50°C in a cabinet dryer and weighing after drying overnight.

Trial Run on 8-Tray Cabinet Dryer

A total of 3 kg of cubed and sliced plantain pulp was used to study the performance of the dryer with respect to effect of tray loading, (i.e. single, double and triple layers) and effect of shape (i.e. cubes or slices) on the rate of drying at 67$\pm$ 2^{o}C. For economic use of the limited raw plantain pulp available, trays of equal dimension 300mm x 200 mm x 20 mm were used instead of the standard tray of dimension 813 mm x 406 mm x 32 mm.

One of the standard trays was, however, loaded with 4.8 kg of plantain cubes as a typical tray loading for the cabinet dryer and dried at the same time with the smaller tray loads so as to study the rate of drying at the above temperature.

The smaller trays were weighed every 10 minutes for the first 30 minutes and for every 30 minutes for the rest of the drying period using a standard laboratory electronic balance of maximum capacity 2 kg. The weight of the standard tray and its content was determined by using known weights to counter-balance its weight.

The above experiment was repeated at a higher temperature 77 $\pm$ 2^{o}C, using a perforated 813 mm standard tray. The drying lasted for 6 hours for the first run and 4.75 hours for the second run.

Trial Run on Simulated Band Dryer

305 mm x 305 mm square tray was loaded with 2 kg of 3mm shreds of plantain pulp to a depth of 40 mm and dried at 80^{o}C.
A downwards air flow of 6.3 cu. metre per minute through the bed was employed. The tray was weighed every five minutes. The run was repeated, and after 15 minutes, the bed was mixed so as to compensate for shrinkage and reduction in the pressure drop, which is usually experienced during the drying cycle. At the same time the air flow was reduced to 6.15 cu metre per minute.
A third run was carried out with 10 mm cubes under the above conditions.

DISCUSSION

In a separate report the drying data from the trial runs will be analysed to determine the effect of air temperature and tray-loading on the rate of drying, especially on the total drying time (i.e. the time required to reduce the initial moisture content to about 8%). There was no significant difference between the colour of the products obtained after drying at 67^{o}C and 77^{o}C for cubes and slices. The 10 mm slices were not uniformly sliced and there was evidence of wetness on the side of the slice facing the tray. This wetness was also very pronounced in the trays containing three layers of cubes and less in the trays containing two layers. The trays containing three layers showed uneven drying with the surface layer cubes appearing dry while most of the cubes of the innermost layer appeared very wet. There was evidence of condensation taking place because the escape of the very humid vapours from the cubes heated by conduction was apparently obstructed by the dried cubes of the top layer.

This condensation of the warm vapour resulted in wetness of the inside surface of the tray. The trays containing two layers of cube experienced less wetness because after a few minutes of drying, there were enough voids between the cubes due to skrinkage for the vapours to escape.

The use of a perforated tray greatly reduced the tray wetness and improved the rate of drying. Although the perforated tray would cost £9.8 sterling each as against £8.75 for the unperforated tray (i.e. 12% more), the gain in drying rate and the associated evenness of drying caused by good air circulation inside the cabinet can offset the cost in the long run. Attempts to dry two or three layers of slices resulted in the slices sticking together to form a single thick layer, reducing vapour diffusion.

The three trial runs carried out on the simulated band dryer were not enough to establish all the parameters necessary for band dryer design. The drying should be carried out at several air flowrates and temperatures to obtain the best specification for the dryer operation. Although there could be substantial saving in cost of handling the prepared food into and out of the dryer and of maintaining the dryer surface in good condition, the cost of a well-engineered band dryer is quoted to be around £105,000 sterling. The overall size of the unit would be length 15.5 metres, width 3.7 metres and height 2.7 metres.

The colour of the product produced after drying in a simulated band dryer was significantly brighter than the product from the cabinet dryer.

CONCLUSION:

Drying plantain cubes in a cabinet dryer is the best drying method when consideration is given to the proposed throughput of 3500 kg plantain pulp per day, (i.e. 5300 kg plantain fruit).

A price quotation for 10 tray cabinet electrically heated, complete with 10 stainless steel trays for operations at temperatures up to 150°C for pilot scale drying trials has been requested. Also a price quotation for 12 truck unit with steam heated drying oven which is suitable for fruits and vegetable drying was requested. Each truck is designed to accommodate 60 trays and is intended for factory process by individuals or co-operatives.

For the continuous band dryer, more trial runs will be needed to establish all the parameters required for optimum design. The capital cost of the equipment as well as the throughput requirement for economic operation are thought to be too high for the proposed throughput for plantain drying.

APP-4.3

Data for the geometrical effect on the rate of drying of plantain pulp

Time	10mm Cubes DB Temperature = 67°C		10mm Cubes DB Temperature = 77°C		10mm Slices DB Temperature = 67°C		10mm Slices DB Temperature = 77°C	
(mins)	Cubes Wt. (g)	gH_2O gDM	Cubes Wt (g)	gH_2O gDM	Slices Wt (g)	gH_2O gDM	Slices Wt (g)	gH_2O gDM
0	464.19	1.7778	468.57	1.7778	408.12	1.7778	407.53	1.7778
10	450.64	1.6969	459.50	1.7240	406.49	1.7667	393.61	1.6828
20	430.91	1.5788	442.05	1.6206	400.24	1.7241	374.35	1.5516
30	411.42	1.4622	424.27	1.5152	392.86	1.6739	357.38	1.4359
60	360.31	1.1563	375.56	1.2264	371.47	1.5283	323.44	1.2046
90	312.68	0.8712	323.22	0.9161	349.41	1.3782	300.34	1.0472
120	272.51	0.6308			329.25	1.2410		
122			276.50	0.6391			279.68	0.9063
150	240.59	0.4398	254.72	0.5100	308.02	1.0965	264.53	0.8031
180	215.61	0.2903	236.64	0.4028	289.50	0.9704	244.81	0.6687
210	199.89	0.1962	220.44	0.3068	271.98	0.8512	226.58	0.5444
240	188.96	0.1308	202.38	0.1997	256.26	0.7442	210.33	0.4336
270	183.60	0.0988	193.00	0.1441	242.47	0.6503	191.57	0.3058
285			191.05	0.1326			186.17	0.2690
300	180.98	0.0831			230.05	0.5658		
330	179.49	0.0742			218.66	0.4883		
360	178.84	0.0703			207.47	0.4121		

APP-4.4

Data for the effect of tray loading on the rate of drying of 10mm cubes at 67°C Dry Bulb Temperature.

Time (mins)	Three layer filled Tray Tray Dimension: 30 cm x 20cm x 2cm			Double layer filled Tray Tray Dimension: 30cm x 20cm x 2cm			Single layer filled Tray Tray Dimension: 30 cm x 20cm x 2cm		
	Cubes Wt (g)	Moisture Content (%)	$\frac{gH_2O}{gDM}$	Cubes Wt (g)	Moisture Content (%)	$\frac{gH_2O}{g\ DM}$	Cubes Wt (g)	Moisture Content (%)	$\frac{gH_2O}{gDM}$
0	1031.24	64.00	1.7778	666.32	64.00	1.7778	464.19	64.00	1.7778
10	1021.82	63.09	1.7524	656.74	62.56	1.7378	450.64	61.08	1.6969
20	1011.24	62.06	1.7239	639.27	59.94	1.6650	430.91	56.83	1.5788
30	997.38	60.72	1.6866	622.74	57.46	1.5961	411.42	52.63	1.4622
60	959.02	57.00	1.5832	570.37	49.60	1.3778	360.31	41.62	1.1563
90	915.73	52.80	1.4666	532.86	43.97	1.2214	312.68	31.36	0.8712
120	877.39	49.08	1.3634	429.09	37.85	1.0514	272.51	22.71	0.6308
150	837.39	45.20	1.2556	453.80	32.11	0.8918	240.59	15.83	0.4398
180	798.26	41.41	1.1502	416.89	26.57	0.7379	215.61	10.04	0.2903
210	760.97	37.79	1.0498	381.80	21.30	0.5917	199.89	7.06	0.1962
240	724.31	34.24	0.9510	350.37	16.58	0.4606	188.96	4.71	0.1308
270	689.26	30.84	0.8566	325.27	12.82	0.3560	138.60	3.56	0.0988
300	656.50	27.66	0.7684	301.15	9.20	0.2556	180.98	2.99	0.0831
220	625.08	24.61	0.6837	283.83	6.60	0.1832	179.49	2.67	0.0742
360	594.21	21.62	0.6006	271.20	4.70	0.1306	178.84	2.53	0.0703

APP-4.5

Data for the effect of tray loading on the rate of drying of 10mm platain cubes at 77°C Dry Bulb Temperature

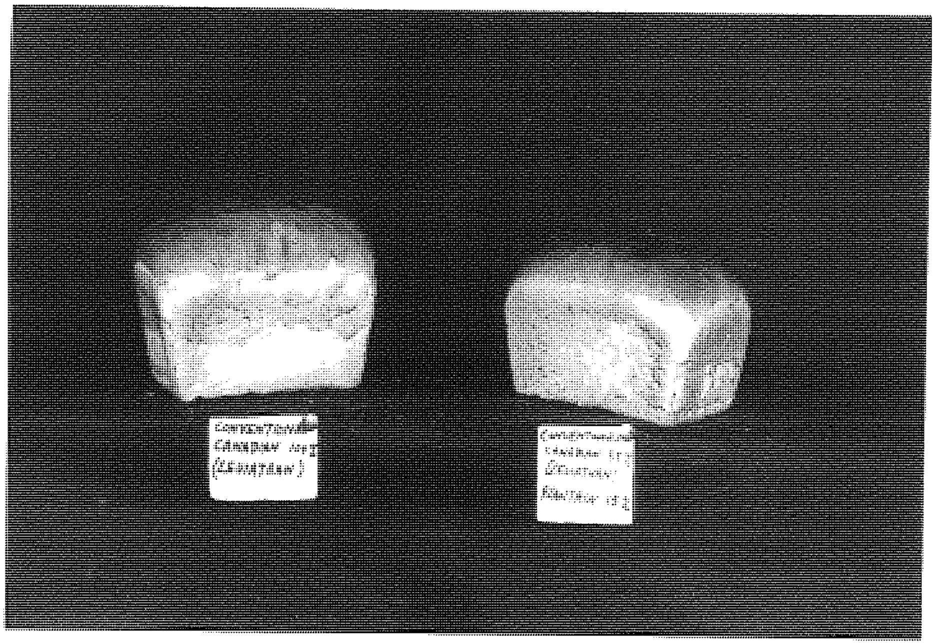
Time (Mins)	Three layer filled Tray Tray Dimension: 30cm x 20cm x 2cm Cubes Wt (g)	Moisture Content (%)	$\frac{gH_2O}{gDM}$	Double layer filled Tray Tray Dimension: 30cm x 20cm x 2cm Cubes Wt (g)	Moisture Content (%)	$\frac{gH_2O}{gDM}$	Single layer filled Tray Tray Dimension: 30cm x 20cm x 2cm Cubes Wt (g)	Moisture Content (%)	$\frac{gH_2O}{gDM}$
0	1031.55	64.00	1.7778	669.50	64.00	1.7778	468.57	64.00	1.7778
10	1022.52	63.12	1.7535	665.22	63.36	1.7600	459.50	62.06	1.7240
20	1009.98	61.91	1.7197	655.98	61.98	1.7217	442.05	58.34	1.6206
30	993.57	60.32	1.6755	644.24	60.23	1.6730	424.27	54.55	1.5152
60	943.22	55.44	1.5400	608.47	54.88	1.5246	375.56	44.15	1.2264
90	886.07	49.90	1.3860	561.31	47.84	1.3289	323.22	32.98	0.9161
122	826.75	44.15	1.2263	515.61	41.01	1.1393	276.50	23.01	0.6391
150	784.71	40.07	1.1131	456.85	32.24	0.8955	254.72	18.36	0.5100
180	737.70	35.51	0.9865	403.08	24.21	0.6724	236.64	14.50	0.4028
210	692.51	31.13	0.8648	356.23	17.21	0.4780	220.44	11.05	0.3068
240	650.43	27.05	0.7515	333.17	13.76	0.3823	202.38	7.19	0.1997
270	609.29	23.07	0.6407	311.10	10.47	0.2908	193.00	5.19	0.1441
285	591.42	21.33	0.5926	302.64	9.20	0.2557	191.05	4.77	0.1326

APP-4.6

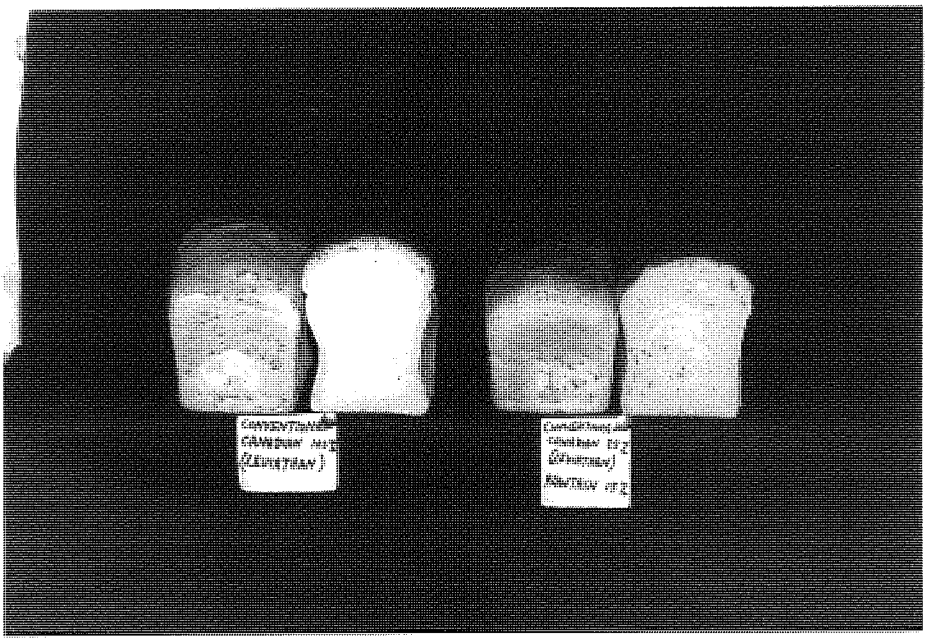
Data obtained from the drying of single layer of 10mm plantain cubes in a cabinet dryer for the plot of $\ln((W\theta - We) / (Wo - We))$ versus time.

Time (mins)	DB Temperature = 67°C: Cube Wt (g)	$\frac{W\theta - We}{Wo-We}$	$\ln(\frac{W\theta-We}{Wo-We})$	DB Temperature = 77°C: Cube Wt (g)	$\frac{W\theta-We}{Wo-We}$	$\ln(\frac{W\theta-We}{Wo-We})$	DB = 65°C For single Cube (10mm): Cube Wt	$\frac{W\theta-We}{Wo-We}$	$\ln(\frac{W\theta-We}{Wo-We})$
0	464.19	1.0000		468.57	1.0000		1.31	1.0000	
10	450.64	0.9537	-0.0474	459.50	0.9693	-0.0312	1.14	0.7940	-0.2307
20	430.91	0.8862	-0.1208	442.05	0.9102	-0.0941	1.02	0.6486	-0.4329
30	411.42	0.8196	-0.1990	424.27	0.8499	-0.1626	0.92	0.5274	-0.6397
60	360.31	0.6448	-0.4388	375.56	0.6849	-0.3784	0.72	0.2851	-1.2549
90	312.68	0.4819	-0.7300	323.22	0.5076	-0.6780	0.57	0.1034	-2.2696
120	272.51	0.3445	-1.0655				0.55	0.0791	-2.5368
122				276.50	0.3494	-1.0517			
150	240.59	0.2354	-1.4465	254.72	0.2756	-1.2889	0.54	0.0670	-2.7030
180	215.61	0.1500	-1.8973	236.64	0.2143	-1.5403			
210	199.89	0.0962	-2.3411	220.44	0.1594	-1.8360			
240	188.96	0.0588	-2.8328	202.38	0.0983	-2.3200			
270	183.60	0.0412	-3.1892	193.00	0.0665	-2.7106			
285				191.05	0.0599	-2.8153			
300	180.98	0.0316	-3.4558						
330	179.49	0.0265	-3.6319						
360	178.84	0.0242	-3.7196						

APP-5.1 Photographs of the Final Bread Produced Using Conventional(Fermentation) and ADD Methods



APP-5.1a Two loaves of white bread manufactured using conventional method, (1) 100% strong wheat flour and (2) 15% substitution of the wheat flour with plantain flour.



APP-5.1b The Crumb Structure of the two loaves.

APP-5.1 Continued

APP-5.1c Two loaves of white bread manufactured using ADD method, (1) 100% strong wheat flour and (2) 15% substitution of the wheat flour with plantain flour.

APP-5.1d The crumb structure of the two loaves.

APP-5.1 Continued

APP-5.1e Two loaves of brown bread manufactured using convectional method, (1) 100% wheat meal (Cerovim) flour and (2) 15% substitution of the wheat meal flour with plantain flour.

APP-5.1f The crumb struction of the two loaves.

APP-5.1 Continued

APP-5.1g Two loaves of brown bread manufactured using ADD method, (1)100% wheat meal (Cerovim) flour and (2) 15% substitution of the wheat meal flour with plantain flour.

APP-5.1h The crumb structure of the two loaves.

APP5.2 Report on the production of plantain shortcake biscuit by the Management of Flour Milling and Baking Research Association, Chorleywood, England.

PILOT SCALE PRODUCTION OF ROTARY MOULDED BISCUITS

BASED ON PLANTAIN FLOUR

Report of a Non-Confidential Sponsored Project on behalf

of the University of Aston in Birmingham

(Enquiry No 29559F)

March - May 1980

Flour Milling and Baking Research Association,
Chorleywood,
Rickmansworth,
Herts.
WD3 5SH.

Pilot scale production of rotary moulded biscuits based on plantain flour

INTRODUCTION

The scope of the investigation was agreed with Mr. P. Ogazi and was detailed in the FMBRA Proposal of 11th March 1980. It involved production of pilot scale batches of plantain biscuits using a recipe supplied by Mr. Ogazi.

The original scheme was extended after the production of small batches of biscuits in order to produce a biscuit with better eating characteristics and colour.

EXPERIMENTAL DETAILS

Recipe

The recipe used in the production of the biscuits was as follows:

Fat	1080g
Pulverised sugar	1344g
Sodium bicarbonate	12g
Ammonium bicarbonate	6g
Water	550g
Plantain flour	3360g

Mixing

All the ingredients apart from 150g of water and the plantain flour were creamed together for 3 min at 75 r.p.m. using a 6kg version of the Simon Vicars Mark II High Speed Mixer. The flour and remaining water were added and mixing continued for $1\frac{1}{2}$ min at the same speed.

Moulding

The dough was allowed to stand for 20 min before moulding to oval dough pieces (Jacobs, Oval Wholemeal).

Baking

The dough pieces were baked in an electrically heated Spooner forced convection oven using the following conditions:-

Air circulation dampers		½ open
Extraction :		
	fan	on
	dampers	closed
Feed section temperature		$300^{o}F$
Delivery section temperature		$330^{o}F$
Baking time		9 min.

The colour of the final biscuits was acceptable and was measured using a Baker Perkins Colour Meter. In this equipment white light is reflected from the surface of the biscuits and the amount reflected expressed as a percentage of the incident light. Thus a white surface gives 100% and a black surface 0% reflectance values.

The measured reflectances of the finished biscuits were:-

Top surface	50%
Bottom surface	45%

DISCUSSION

It was found possible to produce dough pieces from plaintain flour doughs by means of a rotary moulder. However it was observed during the preliminary studies that the dough characteristics were quite sensitive to changes in the dough water level. It was estimated that the range of water levels to produce doughs of mouldable consistency was about ± 5% from the optimum level. All the doughs were slightly sticky and at high water levels it was very difficult to extract the dough pieces from the moulds. The water level used in the production trials was higher than would be expected for wheat flour short doughs, but this may be attributed to the small particle size of the plantain flour.

The biscuits were hard and crisp but tended to form a paste when eaten. This may be as a result of a fine particle size for the plantain flour.

CONCLUSIONS

It is possible to produce rotary moulded short dough biscuits from plantain flour, although this may not be the best type of process for their manufacture.

RECOMMENDATIONS

The following recommendations are made on the assumption that the biscuits produced on the FMBRA pilot plant will be considered satisfactory in general terms and that further work will be undertaken at a later date :-

1. Try to obtain a coarser flour from the dried plantain and test in moulded short doughs.
2. Test plantain flour in the production of extruded doughs, where the sticky character of the dough will be less important than for moulded doughs.
3. Test formulations containing coarser particles in an attempt to improve the eating characteristics of the biscuits. Examples of such materials would included chopped nuts and coarse ground cereals (millet, sorghum, rice, wheat) at a level of addition of say 5% - 15% on the plantain flour.

4. Test formulations containing different ratios of plantain flour, fat and sugar to obtain a range of product characteristics.

APP. 5.3. Preliminary Consumer Acceptance Evaluation of Plantain Biscuits at Federal Institute of Industrial Research Oshodi, (FIIRO), Lagos

The full text of the report of the evaluation as presented by the Management of FIIRO is presented below:

Plantain biscuit, manufactured from 100% plantain flour, is a new type of biscuit being one of the confectionery products Mr P O Ogazi has developed with a view to introducing to the Nigerian market.

Two types of this biscuit were submitted to FIIRO for a preliminary consumer acceptance assessment following the visit of Mr P O Ogazi to FIIRO on 11/80. The biscuits were (a) flow type and (b) shortcake type.

Small scale consumer evaluation

The panel consisted of 34 tasters selected among the staff of FIIRO. Seventeen of the panel evaluated each of the samples. The tasters were asked to express their opinion of the biscuits, after testing, by using the hedonic scale rating (1 = dislike very much to 7 = like very much). The ratings from the 7-point hedonic scale were peeled and analysed statistically by students t-test in order to determine differences in terms of acceptance between the two types of biscuits. In addition, they were asked how the biscuit compared with any familar biscuit. That is better, same or worse, and what they particularly liked or disliked about the biscuits. Finally, their willingness to buy the biscuits should they be available was sought.

Results and Discussion

Results obtained from the statistical analysis indicated that there was a significant difference ($P<0.01$) between the acceptability ratings given to the flow type and shortcake plantain biscuits. The flow type biscuit had a higher score than the shortcake type indicating a better acceptability for flow type plantain biscuit (table 1).

Comparison of the plantain biscuit with the consumer's familiar biscuit (table 2) indicated that a large percentage (41.2%) of the panel found the flow type biscuit better than the biscuits they usually consume, while only 23.5. of the panel found the shortcake type better than their usual biscuits. This is not surprising as about 47% of the panel found the shortcake biscuit worse than familiar biscuit.

Asked what the panel liked or disliked about the two types of plantain biscuits, over half (53%) of those who tasted the flow type liked it particularly for its good taste, while the remaining were partial to it because of soft texture,(12%), good mouthfeel (12%) and aroma (12%), for the shortcake type of biscuit just about one fourth of the panel liked it for its rich appearance.

On the other hand,nearly one fourth of the panel disliked the flow type biscuits, they thought it was too sweet, while about 12% rejected it because of its objectionable odour. For the shortcake nearly half of the panel disliked it because it was too sweet and about 12% each rejected it because it was too soft or had a poor flavour. It is obvious that both type of plantain biscuits had discernible after taste which a large proportion of the panel found unpleasant. Most Nigerians are used to certain flavours in biscuits and therefore any unexpected off flavours detected can easily make them develop some dislike for those biscuits. Both types of biscuits were also found to be much sweeter than familiar biscuits. This is understandable as the panel mambers were all adults.

Children would probably not find the biscuits too sweet.

Asked to indicate their degree of willingness to buy the plantain biscuits about 41% said they would definitely buy the flow type biscuit while 35% categorically stated that they were unlikely to purchase the shortcake type if they were available.

Conclusion and Recommendations

This preliminary evaluation has shown that the flow type biscuit made from all plantain flour is better in quality and more acceptable than the shortcake type. It also stands a better chance in the market than shortcake plantain biscuits.

It is therefore recommended that more attention should be given to the flow type plantain biscuits by improving on the texture with a little addition of wheat flour. This will also assist in improving on the flavour of the biscuit. Consideration should be given to reducing the sugar content in order to make the biscuit more acceptable to both adult and young consumer. Not only will this improve the economic cost of this biscuit but will also help to reduce dental problems in children.

Table 1 Mean Hedonic Scale Scores for Plantain Biscuits

Sample	Rating	Expression
Flow type	5.9	Like Moderately
Short Cake	4.2	Neither like nor dislike

Table 2 Comparison of Plantain Biscuits with Respondents' familiar biscuits

Sample	Better		Same		Worse		Total	
	No	%	No	%	No	%	No	%
Flow type	6	35.3	7	41.2	4	23.5	17	100
Short Cake	4	23.5	5	29.4	8	47.1	17	100

Table 3 Reason for Liking Plantain Biscuit

	Reason	No	%
Flow type	Soft texture	2	11.76
	Good Mouthfeel	2	11.76
	Good Taste	9	52.94
	Aroma	2	11.76
Short Cake	Appearance	5	29.41
	Taste	3	17.64
	Texture	1	5.88

Table 4 Reason for Disliking Plantain Biscuit

	Reason	No	%
Flow type	Too sweet	4	23.53
	Objectionable Odour	2	11.76
Short Cake	Too sweet	8	47.06
	Too soft	2	11.76
	Poor aroma	2	11.76

Table 5 Degree of Willingness to Buy Plantain Biscuit

	Flow Type		Short Cake	
	No	%	No	%
Definitely	7	41.2	4	23.5
Probably	7	41.2	7	41.2
Unlikely	3	17.6	6	35.3
No answer	-	-	-	-
Total	17	100	17	100

APP-5-4 Sample questionnaire for plantain biscuit tasting

BISCUIT TASTING

Name: .... Date: ....

Address: ....

....

Type of Product: Short-cake/Flow type Biscuits

Please taste these three coded samples of Biscuits of which two are identical and the third is different.

(1) Identify the Odd Sample.

Code	Check Odd Sample
555	....
333	....
777	....

(2) From the following lists, give your opinion by ticking only one for the Single Biscuit and the pair respectively.

	Odd Sample	Pair Sample
Like very much	....	....
Like moderately	....	....
Like slightly	....	....
Neither like nor dislike	....	....
Dislike slightly	....	....
Dislike moderately	....	....
Dislike very much	....	....

(3) Would you be prepared to buy any of them if sold in the market?

....

....

....

(4) Any Comment: ....

....

....

APP-5-5 Statistical analysis of the results from the consumer acceptability tests on plantain biscuits

Sample Calculation for Group (1) of Tasters

Judge	Flowtype (Odd) (A)	Shortcake (B)	Difference (A-B)	$(\text{Difference})^2$ (D^2)
1	5	6	-1	1
2	6	5	1	1
3	7	5	2	4
4	5	6	-1	1
5	7	3	4	16
6	7	6	1	1
7	7	7	0	
8	6	6	0	
9	7	7	0	
10	5	4	1	1
11	7	6	2	1
12	7	5	2	4
13	6	6	0	
14	5	2	3	9
15	5	7	-2	4
16	5	7	-2	4
17	7	6	1	1
18	6	6	0	
19	7	6	1	1
20	7	5	2	4
21	6	6	0	
22	5	6	-1	1
23	5	6	-1	1
24	3	4	-1	1
25	6	6	0	
26	5	6	-1	1
Total	154	143	19	57
Mean	5.9	5.5		

T-Test

Average Difference $\bar{d}$ = mean of A - mean of B = 5.9 - 5.5 = 0.4

n = number of pairs = 26

S = Standard error of the mean

$$S = \sqrt{\frac{\Sigma D^2 - \left[(A-B)^2/n\right]}{n-1}}$$

$$\Sigma D^2 = 57 \qquad \Sigma(A-B)^2 = 19^2 = 361$$

$$S = \sqrt{\frac{57 - 361/26}{25}} = \sqrt{\frac{57 - 13.8846}{25}} = 1.3132$$

To find t value from Statistical Chart at 5% significant level, df which is the number of pairs minus one

= 26 - 1 = 25

t value = 2.06

The samples are significantly different if $\frac{\bar{d}}{S/\sqrt{n}} > t$; $\therefore \frac{0.4}{\frac{1.3132}{5.099}} = 1.5532$

1.5532 is not greater than the t value, 2.06. The conclusion is that there is no significant difference between the two types of biscuits.

Sample Calculation for Group (2) of Tasters

	Flowtype (Odd) (A)	Shortcake (B)	Difference (B-A)	$(\text{Difference})^2$ (D^2)
Total	738	1007	276	1269
Mean	4.5	6.1		

T-Test

Average Difference $\bar{d}$ = mean of B - mean of A = 1.6503

$$S = \sqrt{\frac{1269 - 76176/163}{162}} = 2.2245$$

t-value = 2.36 from Statistical Chart at 0.1% significant difference

The samples are significantly different if $\frac{\bar{d}}{S/\sqrt{n}} > t$

$$\therefore \frac{\bar{d}}{S/\sqrt{n}} = \frac{1.6503}{2.2245/\sqrt{163}} = 9.4716$$

9.4716 is far greater than t value 2.36.
The conclusion is that there is significant different between the two types of biscuits.

PLANTAIN BISCUITS ARE NEW!

TRY THEM AT A REDUCED PRICE AND HELP US TO ESTIMATE DEMAND.

BUY A PACK FOR 15p ANSWER OUR SIMPLE QUESTIONNAIRE

....

Country of origin ....

Male/Female (please delete)

Please put X in box of your choice	Yes	No
I like the flavour	☐	☐
I would buy them again at 15p a pack	☐	☐
I would buy them again at 20p a pack	☐	☐

PLEASE RETURN BY NO LATER THAN 10 July 1981

Any comment ....
....
....

MANY THANKS FOR YOUR HELP

R O OGAZI

APP-6.1 Computerised charts for the determination of Net Present Value (NPV) and Internal Rate of Return (IRR)

```
DO YOU WANT INSTRUCTIONS?YES

THIS PROGRAM CALCULATES THE PRESENT VALUE OF A STREAM OF CASH
FLOWS.  THE ASSUMPTION IS MADE THAT THE FLOWS OCCUR AT THE END
OF EACH OF THE PERIODS AFTER THE INITIAL PERIOD WHEN THE INVESTMENT
IS MADE.  EACH PERIOD IS DEFINED AS ONE YEAR UNLESS THE COST OF
CAPITAL PERCENTAGE AND NUMBER OF PERIODS ARE ADJUSTED ACCORDINGLY.
THIS PROGRAM WILL CALCULATE ALL RATES OF RETURN BETWEEN ZERO AND
ONE HUNDRED PERCENT WHICH EQUATE THE P.V. TO THE INITIAL INVESTMENT.

WHAT IS THE INITIAL INVESTMENT IN PERIOD 0?526851
THIS PROGRAM ASSUMES AN INITIAL OUTLAY FOR THE INVESTMENT
THE SIGN HAS BEEN CHANGED TO REFLECT THIS CONDITION
FOR HOW MANY PERIODS DO YOU WISH TO ENTER CASH FLOWS, PERIOD 1 ON?15
PERIOD #        CASH FLOW
********        *********
   1            ?127959
   2            ?302753
   3            ?170935
   4            ?164184
   5            ?135849
   6            ?134497
   7            ?133145
   8            ?-71497
   9            ?118143
  10            ?291937
  11            ?160119
  12            ?153368
  13            ?125033
  14            ?123681
  15            ?122333

ENTER COST OF CAPITAL IN PERCENT?15
DO YOU WANT A LISTING OF THE P.V. IN EACH PERIOD?YES

PERIOD #         P.V.
********       ********
 1             111269.
 2             228925.
 3             112392.
 4             93872.7
 5             67540.9
 6             58146.7
 7             50054.1
 8            -23372.5
 9             33583.6
 10            72162.3
 11            34416.5
 12            28665.6
 13            20321.3
 14            17479.7
 15            15034.

NET PRESENT VALUE OF ALL FLOWS IS $  393640.
THE CALCULATED RATES OF RETURN BETWEEN 0% AND 100% ARE:
 31.4001     %THE P.V. AT THIS RATE OF RETURN IS $  526799.

DONE
```

At 100% sale of Producable Suckers

APP-6.1 Continued

```
RUN
FINFLO

QUERIES TO: M.FINEAN, MANAGEMENT CENTRE, ASTON UNIVERSITY, BIRMINGHAM
.


DO YOU WANT INSTRUCTIONS?YES

THIS PROGRAM CALCULATES THE PRESENT VALUE OF A STREAM OF CASH
FLOWS.  THE ASSUMPTION IS MADE THAT THE FLOWS OCCUR AT THE END
OF EACH OF THE PERIODS AFTER THE INITIAL PERIOD WHEN THE INVESTMENT
IS MADE.  EACH PERIOD IS DEFINED AS ONE YEAR UNLESS THE COST OF
CAPITAL PERCENTAGE AND NUMBER OF PERIODS ARE ADJUSTED ACCORDINGLY.
THIS PROGRAM WILL CALCULATE ALL RATES OF RETURN BETWEEN ZERO AND
ONE HUNDRED PERCENT WHICH EQUATE THE P.V. TO THE INITIAL INVESTMENT.

WHAT IS THE INITIAL INVESTMENT IN PERIOD 0?547101
THIS PROGRAM ASSUMES AN INITIAL OUTLAY FOR THE INVESTMENT
THE SIGN HAS BEEN CHANGED TO REFLECT THIS CONDITION
FOR HOW MANY PERIODS DO YOU WISH TO ENTER CASH FLOWS, PERIOD 1 ON?15
PERIOD #        CASH FLOW
********        *********
    1           ?97584
    2           ?272378
    3           ?140567
    4           ?133809
    5           ?105474
    6           ?104122
    7           ?72395
    8           ?-132247
    9           ?87768
   10           ?261562
   11           ?129744
   12           ?122992
   13           ?94658
   14           ?93306
   15           ?91954
```

At 75% Sale of Producable Suckers

```
ENTER COST OF CAPITAL IN PERCENT?15
DO YOU WANT A LISTING OF THE P.V. IN EACH PERIOD?YES

PERIOD #          P.V.
********        ********
 1               84855.6
 2               205957.
 3               92425.1
 4               76505.7
 5               52439.2
 6               45014.8
 7               27215.9
 8              -43231.7
 9               24949.1
 10              64654.1
 11              27887.6
 12              22988.1
 13              15384.6
 14              13186.8
 15              11300.6

NET PRESENT VALUE OF ALL FLOWS IS $  174431.
THE CALCULATED RATES OF RETURN BETWEEN 0% AND 100% ARE:
[illegible] AT THIS RATE OF RETURN IS $  546944.
```

```
QUERIES TO: M.FINEAN. MANAGEMENT CENTRE, ASTON UNIVERSITY, BIRMINGHAM
.


DO YOU WANT INSTRUCTIONS?YES

THIS PROGRAM CALCULATES THE PRESENT VALUE OF A STREAM OF CASH
FLOWS.  THE ASSUMPTION IS MADE THAT THE FLOWS OCCUR AT THE END
OF EACH OF THE PERIODS AFTER THE INITIAL PERIOD WHEN THE INVESTMENT
IS MADE.  EACH PERIOD IS DEFINED AS ONE YEAR UNLESS THE COST OF
CAPITAL PERCENTAGE AND NUMBER OF PERIODS ARE ADJUSTED ACCORDINGLY.
THIS PROGRAM WILL CALCULATE ALL RATES OF RETURN BETWEEN ZERO AND
ONE HUNDRED PERCENT WHICH EQUATE THE P.V. TO THE INITIAL INVESTMENT.

WHAT IS THE INITIAL INVESTMENT IN PERIOD 0?567351
THIS PROGRAM ASSUMES AN INITIAL OUTLAY FOR THE INVESTMENT
THE SIGN HAS BEEN CHANGED TO REFLECT THIS CONDITION
FOR HOW MANY PERIODS DO YOU WISH TO ENTER CASH FLOWS, PERIOD 1 ON?15
PERIOD #        CASH FLOW
********        *********
    1           ?67209
    2           ?242003
    3           ?110185
    4           ?103434
    5           ?75099
    6           ?73747
    7           ?52145
    8           ?-152497
    9           ?57393
   10           ?231187
   11           ?99369
   12           ?92617
   13           ?64283
   14           ?62931
   15           ?61579

ENTER COST OF CAPITAL IN PERCENT?15
DO YOU WANT A LISTING OF THE P.V. IN EACH PERIOD?YES

PERIOD #        P.V.
********        ********
 1              58442.6
 2              182989.
 3              72448.4
 4              59138.7
 5              37337.5
 6              31882.9
 7              19603.2
 8              -49851.5
 9              16314.7
 10             57145.8
 11             21358.7
 12             17310.8
 13             10447.8
 14             8893.95
 15             7567.71

NET PRESENT VALUE OF ALL FLOWS IS $ -16320.7
THE CALCULATED RATES OF RETURN BETWEEN 0% AND 100% ARE:
 14.28          %THE P.V. AT THIS RATE OF RETURN IS $  567312.
```

At 50% Sale of Producable Suckers

```
GET-$FINFLO
RUN
FINFLO

QUERIES TO: M.FINEAN. MANAGEMENT CENTRE, ASTON UNIVERSITY, BIRMINGHAM
.


DO YOU WANT INSTRUCTIONS?NO

WHAT IS THE INITIAL INVESTMENT IN PERIOD 0?249881
THIS PROGRAM ASSUMES AN INITIAL OUTLAY FOR THE INVESTMENT
THE SIGN HAS BEEN CHANGED TO REFLECT THIS CONDITION
FOR HOW MANY PERIODS DO YOU WISH TO ENTER CASH FLOWS, PERIOD 1 ON?15
PERIOD #        CASH FLOW
********        *********
   1            ?57685
   2            ?232479
   3            ?100661
   4            ?93910
   5            ?65575
   6            ?42000
   7            ?20393
   8            ?-184244
   9            ?25643
   10           ?199440
   11           ?67622
   12           ?60870
   13           ?32536
   14           ?31184
   15           ?29832

ENTER COST OF CAPITAL IN PERCENT?15
DO YOU WANT A LISTING OF THE P.V. IN EACH PERIOD?YES

PERIOD #          P.V.
********        ********
 1               50160.9
 2               175787.
 3               66186.2
 4               53693.3
 5               32602.4
 6               18157.7
 7               7668.36
 8               -60229.7
 9               7289.33
 10              49298.5
 11              14534.9
 12              11377.
 13              5288.
 14              4407.19
 15              3666.18

NET PRESENT VALUE OF ALL FLOWS IS $  190007.
THE CALCULATED RATES OF RETURN BETWEEN 0% AND 100% ARE:
 37.8301      %THE P.V. AT THIS RATE OF RETURN IS $  249876.

DONE
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At 50% Sale of Producable Suckers
With appropriate adjustment for the advantages
for private entrepreneur.

```
QUERIES TO: M.FINEAN. MANAGEMENT CENTRE, ASTON UNIVERSITY, BIRMINGHAM


DO YOU WANT INSTRUCTIONS?YES

THIS PROGRAM CALCULATES THE PRESENT VALUE OF A STREAM OF CASH
FLOWS.  THE ASSUMPTION IS MADE THAT THE FLOWS OCCUR AT THE END
OF EACH OF THE PERIODS AFTER THE INITIAL PERIOD WHEN THE INVESTMENT
IS MADE.  EACH PERIOD IS DEFINED AS ONE YEAR UNLESS THE COST OF
CAPITAL PERCENTAGE AND NUMBER OF PERIODS ARE ADJUSTED ACCORDINGLY.
THIS PROGRAM WILL CALCULATE ALL RATES OF RETURN BETWEEN ZERO AND
ONE HUNDRED PERCENT WHICH EQUATE THE P.V. TO THE INITIAL INVESTMENT.

WHAT IS THE INITIAL INVESTMENT IN PERIOD 0?587601
THIS PROGRAM ASSUMES AN INITIAL OUTLAY FOR THE INVESTMENT
THE SIGN HAS BEEN CHANGED TO REFLECT THIS CONDITION
FOR HOW MANY PERIODS DO YOU WISH TO ENTER CASH FLOWS, PERIOD 1 ON?15
PERIOD #        CASH FLOW
********        *********
    1           ?36834
    2           ?211628
    3           ?78\

??79810
    4           ?73059
    5           ?44724
    6           ?43372
    7           ?31895
    8           ?-202747
    9           ?27018
   10           ?200812
   11           ?68994
   12           ?62242
   13           ?33908
   14           ?32556
   15           ?31208

ENTER COST OF CAPITAL IN PERCENT?15
DO YOU WANT A LISTING OF THE P.V. IN EACH PERIOD?YES

PERIOD #        P.V.
********        ********
 1              32029.6
 2              160021.
 3              52476.4
 4              41771.7
 5              22235.7
 6              18750.9
 7              11990.5
 8              -66278.3
 9              7680.2
 10             49637.6
 11             14829.8
 12             11633.5
 13             5510.99
 14             4601.09
 15             3835.29

NET PRESENT VALUE OF ALL FLOWS IS $ -216875.
THE CALCULATED RATES OF RETURN BETWEEN 0% AND 100% ARE:
 4.57001        %THE P.V. AT THIS RATE OF RETURN IS $  587592.
```

At 25% Sale of Producible Suckers

APP-6.1 Continued

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RUN
FINFLO

QUERIES TO: M.FINEAN. MANAGEMENT CENTRE, ASTON UNIVERSITY, BIRMINGHAM
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DO YOU WANT INSTRUCTIONS?NO

WHAT IS THE INITIAL INVESTMENT IN PERIOD 0?270131
THIS PROGRAM ASSUMES AN INITIAL OUTLAY FOR THE INVESTMENT
THE SIGN HAS BEEN CHANGED TO REFLECT THIS CONDITION
FOR HOW MANY PERIODS DO YOU WISH TO ENTER CASH FLOWS, PERIOD 1 ON?15
PERIOD #        CASH FLOW
********        *********
    1           ?27310
    2           ?202104
    3           ?70286
    4           ?63535
    5           ?35200
    6           ?11625
    7           ?148
    8           ?-234494
    9           ?-4729
    10          ?169065
    11          ?37247
    12          ?30495
    13          ?2161
    14          ?809
    15          ?-539

ENTER COST OF CAPITAL IN PERCENT?15
DO YOU WANT A LISTING OF THE P.V. IN EACH PERIOD?YES

PERIOD #         P.V.
********        ********
 1               23747.8
 2               152820.
 3               46214.2
 4               36326.3
 5               17500.6
 6               5025.81
 7               55.6386
 8              -76656.5
 9              -1344.28
 10              41790.2
 11              8005.98
 12              5699.73
 13              351.223
 14              114.335
 15             -66.2401

NET PRESENT VALUE OF ALL FLOWS IS $ -10546.5
THE CALCULATED RATES OF RETURN BETWEEN 0% AND 100% ARE:
 13.31        %THE P.V. AT THIS RATE OF RETURN IS $  270111.

DONE
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At 25% Sale of Producable Suckers With appropriate adjustment for the advantages for private entrepreneur.

```
RUN
FINFLO

QUERIES TO: M.FINEAN. MANAGEMENT CENTRE, ASTON UNIVERSITY, BIRMINGHAM
.

DO YOU WANT INSTRUCTIONS?YES

THIS PROGRAM CALCULATES THE PRESENT VALUE OF A STREAM OF CASH
FLOWS.  THE ASSUMPTION IS MADE THAT THE FLOWS OCCUR AT THE END
OF EACH OF THE PERIODS AFTER THE INITIAL PERIOD WHEN THE INVESTMENT
IS MADE.  EACH PERIOD IS DEFINED AS ONE YEAR UNLESS THE COST OF
CAPITAL PERCENTAGE AND NUMBER OF PERIODS ARE ADJUSTED ACCORDINGLY.
THIS PROGRAM WILL CALCULATE ALL RATES OF RETURN BETWEEN ZERO AND
ONE HUNDRED PERCENT WHICH EQUATE THE P.V. TO THE INITIAL INVESTMENT.

WHAT IS THE INITIAL INVESTMENT IN PERIOD 0?599751
THIS PROGRAM ASSUMES AN INITIAL OUTLAY FOR THE INVESTMENT
THE SIGN HAS BEEN CHANGED TO REFLECT THIS CONDITION
FOR HOW MANY PERIODS DO YOU WISH TO ENTER CASH FLOWS, PERIOD 1 ON?15
PERIOD #        CASH FLOW
********        *********
    1           ?18609
    2           ?193403
    3           ?61585
    4           ?54834
    5           ?26499
    6           ?25147
    7           ?19745
    8           ?-214897
    9           ?8793
   10           ?182587
   11           ?50769
   12           ?44017
   13           ?15683
   14           ?14331
   15           ?12983

ENTER COST OF CAPITAL IN PERCENT?15
DO YOU WANT A LISTING OF THE P.V. IN EACH PERIOD?YES

PERIOD #          P.V.
********        ********
 1               16181.7
 2               146240.
 3               40493.1
 4               31351.5
 5               13174.7
 6               10871.7
 7               7422.87
 8              -70250.2
 9               2499.52
10               45132.7
11               10912.4
12               8227.08
13               2548.92
14               2025.38
15               1595.54

NET PRESENT VALUE OF ALL FLOWS IS $ -331323.
THE RATE OF RETURN FOR THESE FLOWS EXCEEDS 100 PERCENT
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At 10% Sale of Producable Suckers.

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QUERIES TO: M.FINEAN. MANAGEMENT CENTRE, ASTON UNIVERSITY, BIRMINGHAM
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DO YOU WANT INSTRUCTIONS?YES

THIS PROGRAM CALCULATES THE PRESENT VALUE OF A STREAM OF CASH
FLOWS.  THE ASSUMPTION IS MADE THAT THE FLOWS OCCUR AT THE END
OF EACH OF THE PERIODS AFTER THE INITIAL PERIOD WHEN THE INVESTMENT
IS MADE.  EACH PERIOD IS DEFINED AS ONE YEAR UNLESS THE COST OF
CAPITAL PERCENTAGE AND NUMBER OF PERIODS ARE ADJUSTED ACCORDINGLY.
THIS PROGRAM WILL CALCULATE ALL RATES OF RETURN BETWEEN ZERO AND
ONE HUNDRED PERCENT WHICH EQUATE THE P.V. TO THE INITIAL INVESTMENT.

WHAT IS THE INITIAL INVESTMENT IN PERIOD 0?282281
THIS PROGRAM ASSUMES AN INITIAL OUTLAY FOR THE INVESTMENT
THE SIGN HAS BEEN CHANGED TO REFLECT THIS CONDITION
FOR HOW MANY PERIODS DO YOU WISH TO ENTER CASH FLOWS, PERIOD 1 ON?15
PERIOD #        CASH FLOW
********        *********
    1           ?9085
    2           ?183879
    3           ?52061
    4           ?45310
    5           ?16975
    6           ?-6600
    7           ?-12002
    8           ?-246644
    9           ?-22954
    10          ?150840
    11          ?19022
    12          ?12270
    13          ?-16064
    14          ?-17416
    15          ?-19764

ENTER COST OF CAPITAL IN PERCENT?15
DO YOU WANT A LISTING OF THE P.V. IN EACH PERIOD?YES

PERIOD #          P.V.
********        ********
 1               7900.
 2               139039.
 3               34230.9
 4               25906.1
 5               8439.57
 6              -2853.36
 7              -4511.99
 8              -80628.3
 9              -6524.95
 10              37285.3
 11              4088.65
 12              2293.35
 13             -2610.85
 14             -2461.38
 15             -2428.88

NET PRESENT VALUE OF ALL FLOWS IS $ -125118.
THE RATE OF RETURN FOR THESE FLOWS EXCEEDS 100 PERCENT
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At 10% Sale of Suckers
With appropriate adjustments for the advantages for private entrepreneur.

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QUERIES TO: M.FINERN. MANAGEMENT CENTRE, ASTON UNIVERSITY, BIRMINGHAM
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DO YOU WANT INSTRUCTIONS?YES

THIS PROGRAM CALCULATES THE PRESENT VALUE OF A STREAM OF CASH
FLOWS.  THE ASSUMPTION IS MADE THAT THE FLOWS OCCUR AT THE END
OF EACH OF THE PERIODS AFTER THE INITIAL PERIOD WHEN THE INVESTMENT
IS MADE.  EACH PERIOD IS DEFINED AS ONE YEAR UNLESS THE COST OF
CAPITAL PERCENTAGE AND NUMBER OF PERIODS ARE ADJUSTED ACCORDINGLY.
THIS PROGRAM WILL CALCULATE ALL RATES OF RETURN BETWEEN ZERO AND
ONE HUNDRED PERCENT WHICH EQUATE THE P.V. TO THE INITIAL INVESTMENT.

WHAT IS THE INITIAL INVESTMENT IN PERIOD 0?607851
THIS PROGRAM ASSUMES AN INITIAL OUTLAY FOR THE INVESTMENT
THE SIGN HAS BEEN CHANGED TO REFLECT THIS CONDITION
FOR HOW MANY PERIODS DO YOU WISH TO ENTER CASH FLOWS, PERIOD 1 ON?15
PERIOD #        CASH FLOW
********        *********
    1           ?6459
    2           ?181253
    3           ?49435
    4           ?42684
    5           ?14349
    6           ?12997
    7           ?11645
    8           ?-222997
    9           ?-3357
    10          ?170437
    11          ?38619
    12          ?31867
    13          ?3533
    14          ?2181
    15          ?833

ENTER COST OF CAPITAL IN PERCENT?15
DO YOU WANT A LISTING OF THE P.V. IN EACH PERIOD?YES

PERIOD #         P.V.
********        ********
 1               5616.52
 2               137053.
 3               32504.3
 4               24404.7
 5               7133.99
 6               5618.96
 7               4377.78
 8              -72898.1
 9              -954.268
 10              42129.4
 11              8300.88
 12              5956.16
 13              574.211
 14              308.237
 15              102.371

NET PRESENT VALUE OF ALL FLOWS IS $ -407622.
THE RATE OF RETURN FOR THESE FLOWS EXCEEDS 100 PERCENT
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At No Sale of Suckers.

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