STUDIES ON THE EFFECT OF POSTHARVEST FACTORS ON PLANTAIN QUALITY

BY

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ABSTRACT

This study was undertaken to evaluate the social and technical factors affecting plantain handling in Nigeria, with a view to recommending measures of minimising losses and improving product quality.

Questionnaires on the effect of production, transportation and marketing practices on postharvest losses were administered to farmers, transporters and traders respectively in a survey of three plantain producing states and one non-producing State in Nigeria. Based on the findings of this survey, physical characteristics of plantain which are likely to change as the plantain matures were investigated using two cultivars of plantain namely, Agbagba, a false horn type and Obino l'ewani, a French type, harvested between 8 to 14 weeks after anthesis, to obtain indicators for determining harvest maturity. Also, a methodology for measuring qualitative and quantitative losses in plantain was development. In addition, the effect of maturity at harvest, packaging and the vibration experienced during transportation on mechanical damage were investigated in simulated transit studies, as well as selected quality

attributes of processes products from the Agbagba plantain harvested between 8 to 12 weeks after anthesis, in order to establish optimum handling conditions for plantain for the distribution and processing outlets.

The measurement of finger weight and finger length have been developed as new objective and non-destructive methods for harvest maturity determination in plantain cultivars. It was also oberved that the measurement of bruise area on the peel and percentage weight loss were associated with aesthetic quality, whilst the measurement of trimming losses on the pulp was a good indication of quantitative losses and the number of days to full ripening was an indication of the storage life of the two cultivars. Harvesting at the immature stage increased the susceptibility of the plantains to underpeel bruising leading to significantly ($p = 0.05$) higher trimming losses and weight losses in the two cultivars. Lining the packaging containers with polyethylene reduce the damage significantly. The sensory quality of flavour and texture were affected by the stage of maturity at the time of harvest. Chips and 'dodo' prepared from immature plantain scored significantly ($p = 0.05$) lower points than mature ones. Even though it might be adviceable to harvest plantain at an immature stage in order to extend its green-life, this work clearly shows that this would be at the expence of quality.

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Adelusola, M.A.

DEDICATION

To my God and my King, my all -

THE LORD JESUS CHRIST

AND

My parents, Mr. & Mrs. S.O.A. Adelusola

and the entire ADELUSOLA family

CERTIFICATION

This is to certify that this work was carried out by M.A. Adelusola in the Department of Food Technology, University of Ibadan.

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CHAPTER ONE

INTRODUCTION

In 1975, the United Nations general assembly resolved to reduce postharvest losses in developing countries by up to 50% in 1985 (FAO, 1975). This ambition has not been realised in most countries including Nigeria.

Incidentally, most of the developing countries in the world lie within the tropics where prevailing temperatures and relative humidity together with high incidence of pests and diseases favour rapid deterioration, making the problem of food preservation more difficult (NAS, 1978).

A conservative estimate on the magnitude of losses which occur annually between harvest and consumption with tropical horticultural produce is said to be about 25% of production (Coursey and Proctor, 1975), with concurrent reduction in market quality. Even though the emphasis on postharvest research has been mainly on grains, postharvest losses are much higher for highly perishable fresh fruit and vegetables than for cereals and other

TABLE 1

Plantain Production, FAO Statistics 1000 MT

Country	1979-81	1986	1987	1988
World	23180	23558	23876	23971
Africa	15660	16836	17132	17397
Cameroon	1022	980F	1000F	1100
Cent. Africa Rep	61	85F	65F	66F
Congo	51	59	64	65F
Cote d'Ivore	1013	1010	1045	1076
Gabon	165	170F	175F	180F
Ghana	793	680F	700F	700F
Guinea	350	350F	350F	350F
Guinea Bissau	25	25F	25F	25F
Kenya	233	265F	268F	270F
Liberia	31	33F	33F	33F
Malawi	106	112F	113F	114F
Nigeria	1328	1700*	1700*	1800F
Rwanda	22	27F	28F	28F
Tanzania	992	1100F	1200	1300F
Uganda	5896	6660	6726	6630*
Zaire	1435	1500F	1510F	1520F

F = FAO estimate
Source: FAO 1988
* = Unofficial figure

field crops (Harvey, 1978). This is because perishables are much more susceptible to mechanical injury than grains and legumes because of their shapes and structure and their relatively soft texture associated with their high moisture content (Pariser, 1987). One of such commodities is plantain (Musa sp. AAB group).

Plantain is a staple crop and an important dietary source of carbohydrate in Nigeria and in the humid tropical zones of Africa, Asia and South America (Simmonds, 1970; Olorunda, 1976; Karikari *et al*., 1979). In 1988, Africa alone produced 73% of the world's production of plantain (Table 1) (FAO, 1988). Plantain is rich in vitamins A, C, and B group as well as minerals such as calcium and iron (Marriott and Lancaster, 1983). Plantain could be processed into many products at different stages of physiological maturity; ripe, unripe, overripe, in a number of ways; frying, grilling, boiling. Plantain could also be utilised as an industrial raw material for products such as plantain flour, chips and puree (Peleg and Gomez, 1977).

However, despite all these attributes, there are certain problems that limit the availability of plantain. These problems such as leaf spot (black sigatoka) disease

(Anon, 1983), seasonality, or perishability occur either prior to or after harvesting. Although black sigatoka can be controlled by fungicides at high cost, the only long term solution to the disease in plantain is the development of resistant clones (IITA, 1987/88). Plantain is a seasonal crop, at peak period of production the market is flooded with it; consequently, postharvest losses are very high during this period because of the perishable nature of plantain at the onset of ripening. This problem could be solved through processing into more stable products such as plantain flour and chips or through preservation in the fresh form by chemical preservation or controlled or modified atmosphere storage (Liu. 1970; Scott and Gandanegara, 1974; Ndubizu, 1976; Olorunda, 1976; Olorunda and Aworh, 1984). However, these technologies even though available are not utilised. This is because most of the plantain produced in the country is by small-holder farmers, and although these methods are technically feasible, they may not be economically feasible as at now.

Heavy postharvest losses in many producer countries have been reported for plantain (Kabeya, 1976; Olorunda and Aboaba, 1978; Karikari <u>et al</u>., 1980; Njoku and Nweke, 1985). Plantain is bulky and fragile even in the green form. This situation is made worse because it ripens very fast, limiting the shelf life in the fresh form.

According to Olorunda and Aboaba (1978) losses of about 35-100% have been reported during storage and transportation of plantain in Nigeria. Unfortunately, there has been very little effort made to reduce these losses (Onayemi 1981). This is because qualitative losses are much more difficult to assess than quantitative losses (Kader, 1983b). Even in the developed countries, Coursey (1983) observed that losses due to mechanical damage are serious and difficult to estimate. The situation in developing countries including Nigeria is much more serious since sophisticated equipments required for measuring losses in quality and quantity are lacking, despite the heavy postharvest losses experienced. Quantification of losses is vital to formulating guidelines on handling improvement, therefore, methods of measuring quality loss must be established for plantain. Moreover, since all the aspects of the postharvest life of a produce; susceptibility to damage, processing quality, storage life are influenced by maturity at harvest (Thompson et al., 1972; Liu, 1980; Tindall and Proctor, 1980), the effect of maturity at harvest on quality must be evaluated. Also, certain measurable parameters of plantain which could be used in establishing objective harvest maturity must be investigated.

There is need for an accurate and specific identification of the causes and extent of losses in quality and quantity for plantain at each stage between harvest and consumption. This information is vital in order to set priorities for loss prevention, maintain quality in the commodity system and reduce postharvest losses through the adoption of improved handling practices suited to local conditions. It is with this intention that the present studies directed to the investigations of the effect of various factors, including age at the time of harvesting, mechanical damage and packaging on plantain quality was undertaken with the following objectives:

1. To carry out a survey of the postharvest system of plantain trade in Nigeria, in order to obtain primary data on the handling practices from the operators of the system. To pinpoint the stages in the distribution system where major losses occur and to establish the cause of these losses.

2. To screen plantain harvested at ages between 8 and 14 weeks after anthesis for characteristics that could be used as harvest maturity index.

3. To develop a methodology for measuring qualitative and quantitative losses in plantain and

4. To establish optimum handling conditions for plantain cultivars during distribution and for the processing outlets.

CHAPTER TWO

LITERATURE REVIEW

2.1 Plantain: Botany and Production

Plantain belongs to the family Musaceae, genus Musa (Simmonds, 1970). Wild plantain and banana species are said to have originated from Southeast Asia and subsequently introduced to Africa around 500 A.D. (Palmer, 1971).

The edible banana and plantain cultivars are believed to have developed from hybridization of two species Musa acuminata (AA) and Musa balbisiana (BB). Plantains are of AAB genomic constitution as a result of natural crossing between these two species (Simmonds and Shepherd, 1955). The letters A and B refer to the relative distribution from the two species to the cultivar (Simmonds, 1970).

The plantain AAB group can be sub-divided into four main series of cultivars: the French plantain, resembling a normal banana bunch; the true horn plantain; the false horn plantain and the French horn plantain; which are intermediate between French and False horn plantains

(Devos, 1978). Each cluster of fruit within a bunch is called a "hand" and it is borne upon a nodal protuberance called the "cushion", while the individual fruit is called "finger" (Simmonds, 1970).

According to Wilson (1986), over 70 types of the French, Horn and Intermediate types are known. Different communities have developed preference for different types, even though the most popular types are the French plantain with 7 to 10 hands per bunch and the horn plantains with 3 to 5 hands per bunch having fewer individual large fingers (Burden and Coursey, 1977). Swennen and Vuylsteke (1986) have described the bunch characteristics of 25 major plantain cultivars in West Africa, among which are the Agbagba cultivar (False horn type) and the Obino l'ewai cultivar (French type) shown on Table 2.

According to Aviles (1987), plantain production is relatively efficient given the limited resources available in a traditional production system. They are usually grown in areas with high rainfall pattern since they require monthly rainfall means of 120-160mm (Tezenas du montcel, 1987). In Nigeria, plantains are ususally grown as shades for cocoa or intercropped in compound gardens with cassava, cocoyam, yam etc. (Ndubizu, 1981). Nweke et al. (1988) found that production under compound

TABLE 2

Some bunch characters of two cultivars of plantain grown in Nigeria

Cultivars	Bunch Characters			
	Bunch Weight (kg)	Number of hands*	Number of Fruits	Fruit weight (kg)
Obinol'ewai	13.6 ± 1.6	6.4 ± 0.9	80.8 ±18.80.	0.16 ± 0.02
Agbagba	11.2 ± 2.3	7.4 ± 0.5	31.8 ± 4.3	0.35 ±0.04

Source; Swennen and Vuylsteke, 1986.

* Fruit - bearing hands only.

system results in nearly four times as much as non-compound system. This they attributed to regular application of kitchen and other compound wastes, close cultural attention given by farmers and nutrient recycling to the benefit of the compound plantains from the interplanted deep-rooted perenial tree crops. The economic production of the French type is restricted to high rainfall areas in Nigeria, while the False horn type is more widespread because it is hardier (Ndubizu, 1976). Fig. 1 shows the map of Nigeria and major areas of plantain production. Nweke et al. (1988) showed that the yield of plantain is seasonal and followed the rainfall pattern. Obiefuna (1982) observed that bunches that develop during the rainy months are more robust than those that develop during the dry months because of more favourable soil moisture during the rainy season. Sanchez et al. (1971) planted plantain throughout a subsequent 12 months of the year, even though it was possible to harvest fruit throughout the 12 month period, a definite production peak resulted, showing that the effect of seasonality could not be avoided by establishing plantings throughout the year.

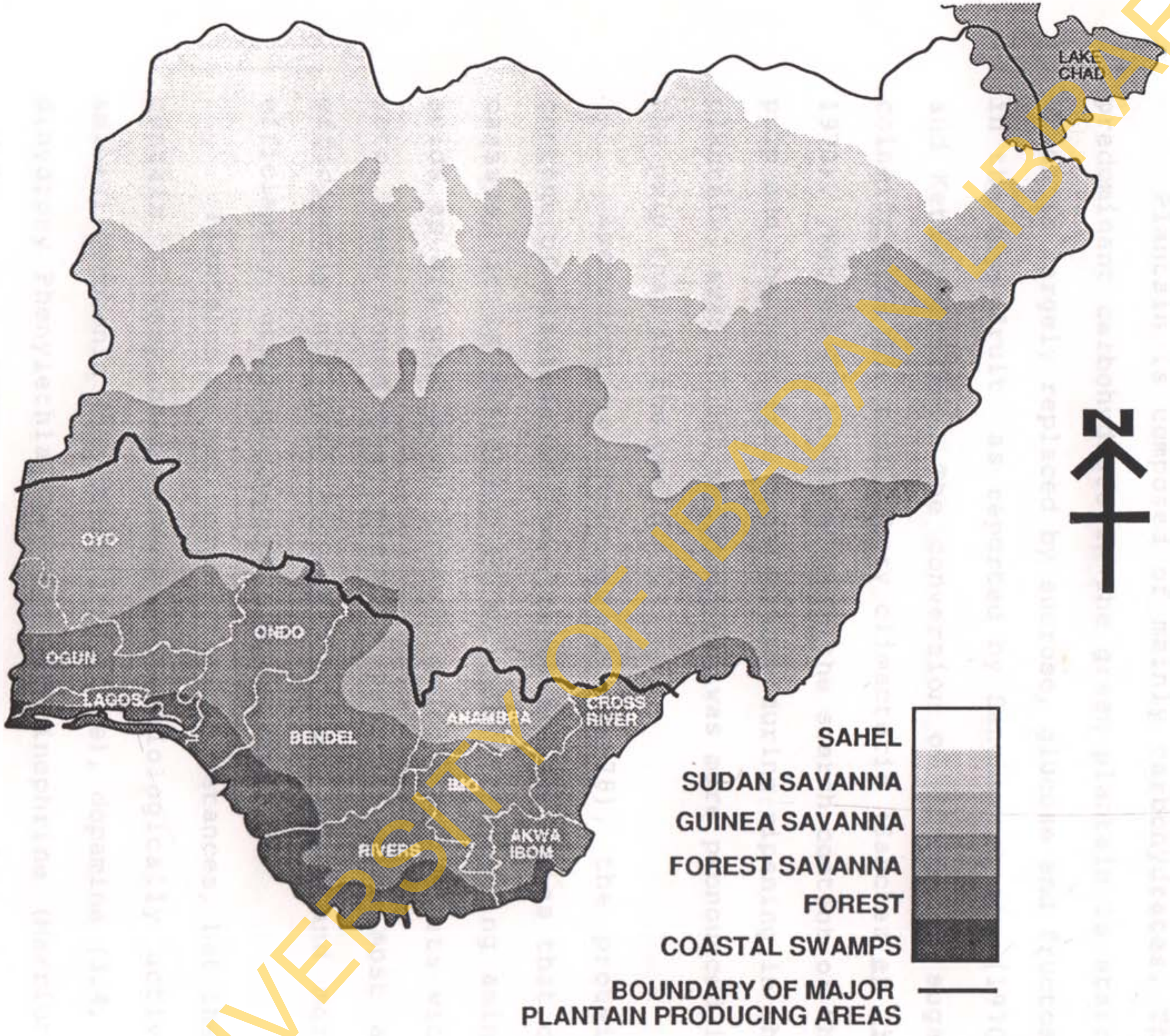

Fig. 1 Map of Nigeria showing vegetation zones and major areas of plantain production
Source: Agboola, S.A. (1979) An Agricultural Atlas of Nigeria (Adapted)

2.2 Composition and Utilization

Plantain is composed of mainly carbohydrates. The predominant carbohydrate in the green plantain is starch which is largely replaced by sucrose, glucose and fructose in the ripe fruit as reported by Sanchez *et al.* (1970) and Ketiku (1973). The conversion of starch to sugar coincide with the respiratory climacteric (Sanchez *et al.* 1970). Ketiku (1973) found that the starch content of the pulp and the peel fall considerably during ripening in the plantain, even though the decrease was more pronounced in the pulp than in the peel.

According to Omole *et al.* (1978), the protein content of plantain is low, though not as low as that of cassava, it is deficient in sulphur - containing amino acids as are most plant protein sources. In tests with rats, they found that plantain protein was almost as efficiently utilized as was that of maize and more efficiently utilized than that of cassava.

Plantains do not contain toxic substances, but they contain a very high level of physiologically active amines; serotonin (5-hydroxy tryptamine), dopamine (3,4, - dihydroxy Phenylethlamine) and norepinephrine (Marriott and Lancaster, 1983). It has however been shown by Ojo

(1969) that serotonin is rapidly removed from curculating plasma and that plantain ingestion is not accompanied by elevated serum serotonin levels in healthy Nigerians .

2.3 ECONOMIC SIGNIFICANCE AND MARKETING

2.3.1 ECONOMIC SIGNIFICANCE:

The genus Musa is important to the region of production either as a foreign exchange earner and/or as a staple food. In some countries, both aspects are important, but in most, only the staple food aspect is relevant (Wilson, 1986). Marriott and Lancaster (1983) stated that the economic significance of plantain within the forest zones is mainly in their contribution to subsistence economies.

Plantains account for one-fourth of bananas produced in the world (FAO, 1986). Since most of these plantains are not exported, they are more important as food for local consumption. According to Wilson (1986), plantain plays an important role in bridging what is popularly known as hunger gap, this is because the major harvest comes in the dry season (January to May) are in short supply and therefore expensive. However, De Langhe

(1986) found that in countries where plantains are not exported, their importance in the economy is often underestimated.

2.3.2 Marketing

Nwekė *et al.* (1988) found that the price of plantain is highly sensitive to supply and demand. Prices are determined by the demand in the urban centres and the supply available in its collection area at a given point and time and are subject to seasonal and regional variations. They observed a 60% difference between the highest price in June and the lowest in October. Ndubizu and Okafor (1976) found that very often, prices are low in production centres but high in urban areas in Nigeria. They attributed this to the absence of a well-organised distribution system.

Aviles (1987) discovered that collection and transportation are the most important constraints in marketing plantain. Poor conditions of feeder roads and transport are said to increase the cost of plantain and that a delay of more than 24 hours leads to heavy losses hence, the high costs of plantain often experienced in the urban centres. This poses a serious problem especially since a considerable proportion of plantain, according to Dorosh (1988), is consumed in urban centres.

In a survey carried out in Southwest Nigeria, by Njoku and Nweke (1985) they found that transportation costs alone, including the value of damaged plantains during transportation is 68% of handling costs for all market participants; wholesalers, retailers and producers interviewed. In their work on fruits and vegetables in Queensland, Australia, Schoorl and Holt (1985) stated that the direct costs of transport of fruit and vegetable are 20-25% of the wholesale price, while the indirect costs due to produce deterioration and package damage are often substantial.

Marketing costs vary according to a crop's perishability, seasonality and distance from the urban centre (Aviles, 1987). For plantain, producer prices vary from one country to the other. Distances to urban centres are extremely important because they translate into high costs and because plantains are highly perishable, serious losses are incurred. The longer the supply channel, the greater the losses incurred.

The marketing system for commodities is characterised by operations of many individual entrepreneurs resulting in frequent handling and transfer of goods from one middleman to another, losses and inefficiences all adding to the cost of the final product but of no benefit to the producer (Wills and Lee, 1989).

The greatest loss reduction can be made through changes in the packaging, transportation and handling systems. These improvements can often be made at little cost, thus dramatically improving the economics of the system. Fig. 2 showed that reducing post harvest losses has the potential to reduce the price of food paid by the consumer without reducing the price paid to the farmer. If the savings are passed on, the consumer can purchase food at a lower price with no reduction of income to the farmer or trader.

2.4 PHYSICAL DISTRIBUTION OF PLANTAIN

Physical distribution of plantain is a term which is used to describe the wide range of activities associated with the movement of goods from producer to consumer (Sayers, 1984). These activities can include materials handling, packaging, inventory control, transport, storage

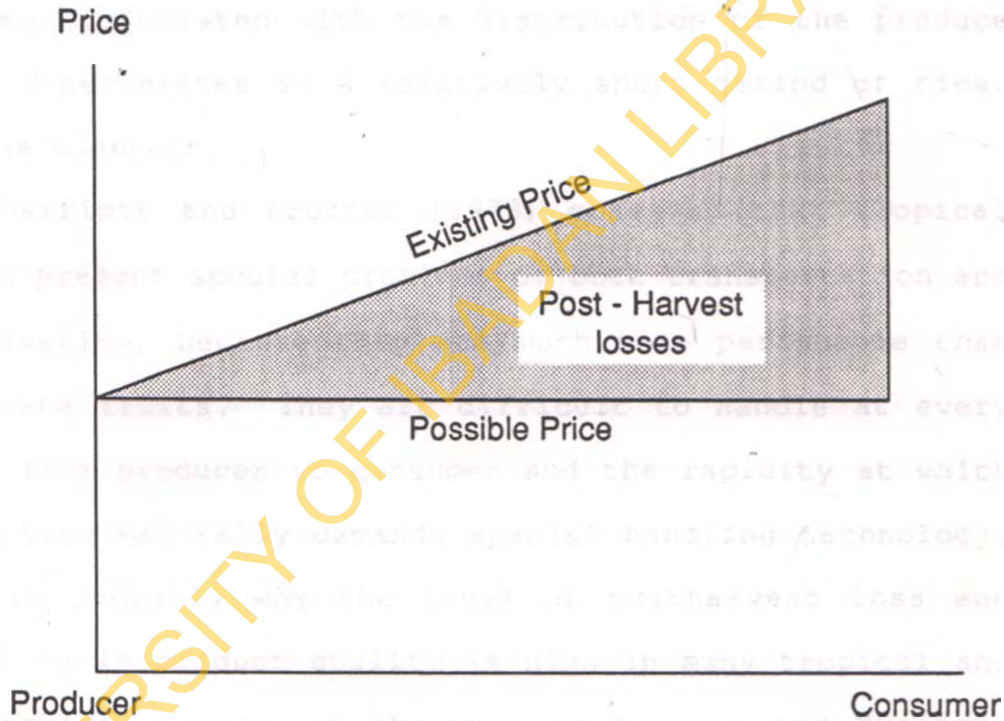

Fig. 2 Schematic representation of how reducing post-harvest losses have the potential to reduce the price of food paid by the consumer without reducing the price paid to the farmer.
Source: Palmer (1977)

and other processing operations (Sayers, 1984). However, Schoorl and Holt (1986) stated that the extensive literature on physical distribution management generally fails to emphasize or satisfactorily deal with the special problems associated with the distribution of the produce which deteriorates in a relatively short period of time, such as plantain.

Marriott and Proctor (1978) observed that tropical fruits present special problems of both transportation and conservation, because they are much more perishable than temperate fruits. They are difficult to handle at every stage from producer to consumer and the rapidity at which they ripen naturally demands special handling technology. This is probably why the level of postharvest loss and reduction in product quality is high in many tropical and sub-tropical areas as observed by Coursey and Proctor, (1975). In many developing countries, most commodities are transported by traditional methods with minimal input costs with no specific postharvest treatment systems or purpose-built storage or ripening facilities. The implication of physical distribution on post harvest losses in plantain is considered in this thesis.

2.5 PACKAGING AND TRANSPORTATION

Sayers (1984) observed that probably the most important physical distribution consideration in container designs are those of materials handling, transport and storage.

In the case of bananas for exportation to North America and Europe, the most critical quality factor is presentation of well-graded, fully yellow, unblemished bananas to the retail consumer. There is therefore heavy investment in export industries in handling systems and packaging to minimise abrasion of fruit. This protection which starts in the field is described extensively by Marriott and Lancaster (1983). Simmonds (1970) grouped means of preparation of bunches for long distance transportation under four major categories namely; transportation as naked bunches, use of plastic covering, the enclosure of the bunch in a paper or straw parcel; the packaging of the fruit in boxes or cases. He stated further that the first two methods are normally used in trades which sell by grade, the last two in trades which sell by weight or by a constant weight unit. (Scott et al., 1971) observed that where fruits have to be transported for exceptionally long periods; or where transportation is without temperature control, they may be packed into large Polyethylene bags to create a modified atmosphere and extended storage life.

Transportation is a great constraint to plantain distribution within producer countries in developing countries where they are not exported. Kabeya (1976) reported extreme difficulties in transporting plantain to urban centres in Zaire because of the long distance and bad state of infrastructure such as road and vehicles. In Ghana, it is estimated that one third of the yield of plantain is lost through transportation from the farmers to the market (Karikari, 1970). In Cameroon, Fongyen (1976), reported that the traditional methods of harvesting and handling cause a lot of mechanical damage which leads to rapid storage losses. Similar reports of losses during storage and transportation have been reported in Ivory Coast (Dorosh, 1988) and Nigeria (Olorunda and Aboaba, 1978).

The mechanism for food distribution in Nigeria comprises 3 distinct systems which are sumarised in Fig. 3

```
1.   FARMGATE ----------->  CONSUMER
2.   FARMGATE -----------> WHOLESALER ----------->CONSUMER
                            | |
                            | |------> RETAILER
                            |
                            |-------->CONSUMER

3.   FARMGATE -------->CORPORATION ----------> CONSUMER
                        | | |
                        | | |----------->WHOLESALER
                        | |
                        | |----------->RETAILER
                        |
                        |----------->CONSUMER
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Fig. 3 Schematic representation of the food distribution machinery (source : Olorunda, 1985).

Improved handling of plantain require a total system approach at all the three points in the distribution system (1) at the farmgate (2) at the wholesale and (3) at the retail levels. There is need to sell the concept to all levels from producer to wholesaler to retailer.

Sayers (1984) reported that the traditional containers of timber and jute used in Australia during the last 20 years have been largely replaced by improved containers. The same approach is being adopted in the South east Asian countries according to Wills and Lee (1989), In these instances, improved containers have been used on returnable basis to minimize the cost due to container improvement.

In addressing the task of a returnable container system, in depth research into several aspects of the system in which the container is to be used is of utmost importance to ensure a viable system. This is because post harvest losses are location - specific and time- dependent (NAS, 1978). They vary from season to season among different crops, from location to location and under different kinds of postharvest treatments. Therefore some considerations must be given to the commercial environment in which the system must operate, as well as the distribution paths and the infrastructure that exists for movement of produce between the farmgate and the consumer. The design of the container to be used is an essential ingredient to the returnable container system.

In the South east Asian countries, returnable containers are operated under some organizational framework that maximizes their efficiency, namely, the captive system, the unrestricted pools system and the restricted pools system full details of these have been described by Wills and Lee (1989).

2.6 MATURITY AT HARVEST

Wills *et al.* (1982) drew a clear distinction between "physiological maturity" and "commercial maturity". They stated that the former is a particular stage in the life of a plant organ while the latter is concerned with the time of harvest as related to a particular end-use and can be translated into market requirements.

Physiological maturity refers to the stage in the development of the fruit when maximum growth and maturity has occured. It is usually associated with full ripening in a fruit. Commercial maturity bears little relationship with physiological maturity and may occur at any stage during development. In this thesis, the term "age at harvest" will be used to mean commercial maturity. This is because age is a more precise parameter than maturity in this instance, in which case commercial maturity could be measured in terms of age at the time of harvesting.

2.6.1 Maturity Standard

In the case of banana for export, maturity standard for harvesting vary, bunches for nearby markets are harvested at full maturity while those for distant markets are harvested at a less mature stage. Simmonds (1970), stated that fruit growth accelerates in the later stages of development with the result that export fruit which is cut after about two thirds of the full time of development have elapsed, weighs only about one half as much one half as much as fully mature fruit and contains less than one half as much edible pulp. As a result of this, the time of harvesting must be at optimum maturity. However, even for local and domestic use, bananas and plantains are never deliberately allowed to commence ripening prior to harvest, since tree-ripe fruits have an inferior flavour and tend to drop from the bunch either prior to or during harvesting (Marriott and Lancaster, 1983).

This could be explained by the work of Barnell (1941) (as quoted by Simmonds, 1970) with bananas. He found that bunches left on the plant until long after the time at which they would normally have been cut, show various signs of incipient ripening. These signs were among others; the dry matter content rose steadily until about 80 days and dropped slightly thereafter, this drop in dry matter was shown to exceed the drop that could be expected from known respiratory activity and has been attributed to hemicelluloses disappearance ; the fact that the loss of starch exceeded the increment of sugars, indicating increased respiratory loss and some splitting of the skin at 100-120 days, a behaviour related to the rise of sugar content of the pulp, increased water uptake and therefore swelling. The inferior flavour could be due to the trend in the acidity and especially flexions found in the skin and pulp at 100-120 days.

Hedge and Srinivas (1989) concluded that early harvesting may reduce the yield by lower fruit weight while late harvesting may increase the losses by peel splitting and fruit cracking, besides reducing the productivity per unit time by prolonging the crop span.

The stage of maturity at which a fruit is harvested is therefore largely dependent on the distance to the market, the handling, storage and transportation methods and facilities available. Unfortunately a fruit harvested at a time when it has optimum eating quality often does not have the best keeping quality; fruit harvested earlier often has better keeping quality but poorer eating quality (Liu, 1988). Consequently in the commercial world there is often a trade off between the two parameters. Therefore in this thesis, age of harvesting would be looked into from the standpoint of age at which plantain could withstand the hazards of handling, as well as the optimum organoleptic qualities of the processed product, and optimum fruit size, to get a balanced view of age at which to harvest plantain.

2.6.2 Harvest maturity indicators

The index of maturity at harvest involves some expression of the stage of development or maturation and requires the measurement of some characteristics known to change as the fruit matures (Wills *et al.*, 1982).

In the case of banana and plantain, it is most commonly judged by assessing the changes in angularity as fruit fingers increase in girth from thin fruit to thicker rounded ones (Simmonds, 1970) which is subject to error of judgement according to Karikari and Agyepong (1983) and Hedge and Srinivas, (1989). However, not much work has been done on objective measurement of maturity at harvest in plantain and this will be looked into in this work.

2.6.2.1 Measurement of pulp to peel ratio

Karikari and Agyepong (1983) studied two cultivars of Ghana plantains Apantu (French type) and Apem (False horn type). They found that the pulp to peel ratio increased up to 65 and 80 days in the Apantu and Apem respectively and then declined with the ratio being higher in the latter than in the former. This they explained, was due to the presence of some substances of the general nature of the coconut milk factor, as was explained by previous workers on bananas (Steward and Simmonds, 1954), providing an autonomous stimuli to the growth of the pulp at the expense of the peel. However, they found pulp to peel ratio to be positively and linearly correlated with maturity at harvest at 1% level of significance in the two cultivars.

Their result is similar to that obtained by Sanchez et al., (1968a) who also found a positive and linear correlation between pulp to peel ratio and maturity at harvest at 5% and 1% levels of significance in the Guayemero and Maricongo cultivars of plantain found in Puerto Rico. They found that pulp to peel ratios have similar values for all hands at any age, but as the bunch matures, the ratio increases, indicating an increase in the weight of the pulp and a decrease in the weight of the peel. In this work relationship between pulp to peel ratio and age at harvest would be looked into as a means of obtaining harvest maturity index in Nigerian plantain.

2.6.2.2 Measurement of fruit diameter

Karikari and Agyepong (1983) found that fruit thickness progressively increased and then slowed down, they explained that probably fruit development which occurred during the first 60 days of emmergence slowed down for fruit filling to take place later. They observed a positive and linear correlation between finger diameter and maturity at harvest at 1% level of significance in the maturity at harvest at 1% level of significance in the two cultivars.

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Hedge and Srinivas (1989) found that in the banana cultivar Robusta, fruit girth increased with maturity to 21 weeks after flowering and then remained constant. The relationship between finger diameter and age at harvest will be looked into in this work as a means of obtaining harvest maturity index in the Nigerian plantain.

2.6.2.3 **Measurement of fruit weight**

Fruit weight in the Apem cultivar increased to 300g at 80 days and then decreased to 200g at 89 days. In the Apantu cultivar, it increased to 250g in 70 days and then decreased to about 200g in 80 days (Karikari and Agyepong, 1983). No reason was given for these. Sanchez et al.

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(1968a) found that the average weight of the fingers from all hands increased with age but levelled off around 92 days. Irrespective of maturity, the same relative difference was observed in the weight of the fingers among the different hands. They found the weight of bunches harvested at any age varied within wide limits and that the increase in the weight of the bunches with age did not follow any definite pattern.

While finger weight was positively and linearly correlated with maturity at harvest at 5% level of significance in the Maricongo and Apantu cultivars, no significant correlation was found in the Guayamero and Apem cultivars found in Puerto Rico and Ghana respectively (Sanchez et al., 1968; Karikari and Agyepong, 1983).

Fruit weight decreased in the order of emergence of the hands from the top (proximal) to the bottom (distal) end of the bunch (Sanchez et al., 1968a; Simmods, 1970; Karikari and Agyepong, 1983). In this present work correlation of finger weight with the age at the time of harvesting plantain will be looked into as a means of obtaining harvest maturity index in the Nigerian plantain.

2.6.2.4 Measurement of fruit length

Sanchez et al., (1968a) found that length of the fingers from the different hands varied according to the order of emergence and that fingers attained their final length before the weights levelled off. A similar result was obtained by Hedge and Srinivas (1989) with banana cultivar Robusta, where fruit length increased with age, to 16 weeks and then remained constant. They found that the quality of fruits harvested and ripened during the last 5 weeks of the study did not reveal large variations.

Karikari and Agyepong (1983) found positive linear correlation of age with finger length at 5% level of significance in the two cultivars Apem and Apantu. However, Simmonds (1970) stated that finger length is a function of cultural practice and not maturity at harvest. In this present work the correlation of finger length with the age at the time of harvesting plantain will be looked into as a means of obtaining harvest maurity index in the Nigerian plantain.

2.6.2.5 Measurement of pulp rupture force and dry matter content

Karikari and Agyepong (1983) found that as growth proceeds, the dry matter contents of both pulp and peel become more concentrated as measured by the peel and pulp rupture force. Sanchez et al. (1968a) found a highly significant correlation between age and shear pressure measurements indicating 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.

2.6.3 Relationship between age at harvest and Postharvest factors

Age at harvest is a very critical factor in the postharvest life of a fruit. It influences susceptibility to damage and disorder, as well as eating and keeping qualities (Thompson et al., 1972; Tindall and Proctor, 1980; Schoorl and Holt, 1983; Liu, 1988). However, very limited work has been carried out in this area. In this thesis, effect of age at harvest on eating quality and mechanical damage are determined for plantain.

2.6.3.1 Age at harvest and preclimacteric period

The reduction in preclimacteric period as bunch age increased was investigated by Marriott and New (1975). They found that by reducing storage temperature from $14^{\circ}C$ <--> $21^{\circ}C$ and harvesting at a low caliper grade, the mean preclimacteric period in the new tetraploid banana clones can be increased. In the case of the Cavendish banana, harvesting 'early' led to a reduction in bunch weight of approximately 9% and a gain in green life of about 3 to 5 days per week (Peacock, 1975). Marriott and Montoya (1981) found that green-life is highly correlated with age but poorly correlated with grade in the banana.

2.6.3.2 Age at harvest and ripening

In an experiment on the effect of maturity at harvest on ripening rate, Karikari et al. (1980) found that 50% of mature fruit ripened in 13-16 days, while full - mature fruit ripened in 5 days. That is, the preclimacteric period in plantain decreases with bunch age. They also found that maturity at harvest is a critical factor in controlling the rate of ripening of plantain in bulk. From the above it seems ripening days and pre-climacteric period are related to age at harvest, which means any factor that increases or reduces the pre-climateric period would also increase or reduce the ripening days. Since mechanical damage is known to reduce the preclimacteric period, ripening days was measured in this thesis as an indirect indication of mechanical damage in plantains harvested at different maturities.

2.6.3.3 <u>Age at harvest and processing</u>

According to Wills <u>et al</u>. (1982), the potential quality of a fruit is determined by many factors, of which the age is the most important.

Sanchez <u>et al</u>. (1986) found that fruit maturity at harvest has a great effect on the eating quality and that it is of greater importance to the processor than production characteristics. However, it was discovered that the processing quality of plantain fruit was not affected by the time of planting and harvesting. Thus processed products of good quality can be prepared from fruit harvested throughout the year provided the plantains are harvested at a proper stage of development (Sanchez <u>et al</u>. 1971).

Sanchez <u>et al</u>. (1975b) found that the quality and appearance of fried plantains prepared from green frozen plantains were affected by the age at which the fruits were harvested. They stated that from the standpoint of product quality and to obtain maximum yields of processed products, plantains should be harvested when as mature as possible but still in the green stage. They suggested plantain should be harvested for processing when the pulp content is over 60% which corresponds to a pulp to peel ratio of over 1.5.

In the light of the above, there is a great need for investigations into the relationship between age at harvest and eating quality for plantain cultivars.

2.7 Postharvest physiology of plantain

After harvest, fruits and vegetables continue to respire and carry out certain metabolic processes, they are therefore living entities. However, because they have been severed from the parent plant and the substrates of respiration are not being replenished, they are regarded as perishable commodities, their shelf life depending on how fast the substrates are used up for respiration (Wills et al., 1982).

A group of fruits show a pronounced increase in respiration coincident with ripening, they are known as respiratory climacteric fruits. The commencement of respiratory climacteric coincides approximately with the attainment of maximum fruit size and it is during this climacteric that other changes characteristic of ripening occures (Wills et al., 1982). Plantains exhibit a climacteric pattern of respiration (McGlasson, 1970). According to Holt and Schoorl (1984b), the extensive literature on physical distribution management generally fails to emphasize or satisfactorily deal with the special problems associated with the distribution of produce which deteriorates in a relatively short period of time, an example of which is plantain.

Ripening is generally considered to begin during the later stages of maturation and to be the first stage of senescence. According to Huelin (1980), in physiological terms, senescence is the stage when growth has ceased and there is a progressive loss of organisation and resistance to fungal attack. Ripening is usually accompanied by complex biochemical and physiological changes in colour, flavour and textural parameters of the plantain. Simmonds (1970), Palmer (9171), Marriott (1980), Smith and Thompson (1987) have carried out comprehensive review of postharvest biochemistry of plantain.

Change of colour as a result of loss of chlorophyll and sometimes synthesis of carotenoids generally, but not always, accompany ripening. In the case of banana, the yellow colour is as a result of chlorophyll degradation, with little or no net formation of carotenoids (Matoo et al., 1975). The ripening stages of bananas have been closely linked with the changes in peel colour (Palmer, 1971) and matching of the peel colour against a set of standard colour plates (United Fruits Sales Corp., 1964) is a common practice to assess the ripeness of banana (Ramaswamy and Tung, 1989).

The change of texture in which the fruit becomes softer and more juicy is due to the degradation of the polysaccharides of the primary and secondary cell walls and the middle lamella. The major change being the conversion of insoluble protopectin to soluble pectin. During ripening, protopectin in the banana pulp decreased from about 0.5% to about 0.3% and soluble pectin shows a corresponding increase (Palmer, 1971). There are indications of interconversion of starch and hemicellulose in the early storage of the green fruit, however, hemicellulose disappear whether or not the fruit is normally ripened (Simmonds, 1970). Textural and rheological properties of ripening bananas and plantain have been studied by Finney et al., (1967), Charles and Tung (1973), Peleg and Britto (1977) and Ramaswamy and Tung (1989). The textural parameters of the banana were highly correlated with colour index meaning that textural parameters could be reliably inter-converted and predicted from colour index (Ramaswamy and Tung, 1989).

Flavour changes are complex. They involve loss of acidity, loss of astringency associated with tannins or phenolic substances and changes in the volatile constituents of the aroma (Huelin, 1980). Hexanol and trans - 2 - hexenal are major volatile components of unripe bananas. Esters make the main contribution to the characteristic aroma of bananas. Amyl estesrs are responsible for the banana like flavour and butyl esters for the fruity flavour (McCarthy et al. 1963).

Synthesis of volatiles commences late during ripening relative to starch - sugar conversion and tissue softening. According to Mattei (1973) the total volatile production increases as an exponential function of temperature over a wide range from 5°C to 30°C, but the relative rates of production of individual volatiles differ so that the aroma composition varies according to the temperature selected for ripening.

New flavour constituents are not formed during processing, but changes do occur in the relative proportion of normal volatiles. In an assessment of 31 tetraploid clones relative to cultivar Valery as a standard, it was shown that a good banana-like flavour and sweetness were the main factors governing acceptability (Baldry et al. 1981). Flavour changes associated with chronological age of plantain is therefore important, especially since there may be need to harvest plantain before full maturity for long - distance transportation. The flavour of the finished product must be taken into consideration since the ultimate destination is the consumer plate. Further work into the organoleptic quality of plantain products in relation to age at harvest is needed.

2.8 Postharvest Quality Changes

Fruits and vegetables are synthesized from inorganic compounds like carbon and nitrogen and after harvest, they tend to disintegrate back to these inorganic compounds (Hulse, 1982). They therefore start to deteriorate in quality immediately after harvest (Ke and Hwang, 1988). The deterioration process after harvest can therefore not be reversed, however, the rate at which this deterioration takes place can be controlled (Hulse, 1982). Holt and Schoorl (1984b) found that of the various sources of deterioration in apples, loss of shelf life due to the living processes and injury from handling and transportation shocks are of most concern commercially.

Kramer and Twigg (1966) defined quality as the composite of those characteristics that differentiate individual units of a product, and have significance in determining the degree of acceptability of that unit by the user. As a general principle, if any of the relevant attributes or factors deviate from expected standards, the produce is judged to be of inferior quality and lower prices will be received.

The quality changes in produce appear in their appearance, texture, flavour and nutritive value. This deterioration is the result of biological, biochemical and physical reactions which occur in fresh produce (Ke and Hwang, 1988), as well as pathological, physiological and mechanical damages (Bourne, 1977). Ke and Hwang (1988) reported that the speed of deterioration depends on postharvest treatment and environmental factors.

Schoorl and Holt (1983b) have described and classified quality attributes for produce in general, quality they explain, is a measure of acceptability of the produce to distributors and consumers, it is a function of the initial state at harvest, together with the preparation and sorting for size, colour and blemish and subsequent deterioration as produce moves through the distribution chain . The final quality in distribution is therefore the result of deterioration with time, environment and events, that is, what has happened to the produce since it began its journey at harvest. Time spent in the distribution system, environments experienced by the produce and hazardous events can all be manipulated, however, there is a cost associated with any sort of control measure (Holt and Schoorl, 1984a).

According to Holt <u>et al</u>., (1983), in any particular situation, it is necessary to establish tolerable amounts of deterioration that is, there should be acceptable quality standards against which the cumulative damage can be judged. Acceptable quality standards needs to be defined in terms of those attributes of quality both sensory and objective, which the buyer or consumer perceives to be important.

Jones et al. (1978) used under-peel discolouration, shelf life and water loss as measures of effectiveness of treatments to reduce quality deterioration, in studies of postharvest treatment of bananas. According to Marriott (1980) the main factors affecting banana fruit quality as perceived commercially, are concerned with appearance rather than internal quality, he listed the absence of mixed ripeness adequate fruit girth,size and uniformity; absence of bruises, blemishes or rots as important quality attributes. Hammett et al. (1977) investigated the relationship between various parameters and days from full bloom in an attempt to establish measures of storage quality for Golden Delicious apples Kader et al. (1978) used sensory evaluations and chemical analyses to investigate the effects of various postharvest handling procedures on composition and flavour quality of Cal Ace tomatoes. They found that while chemical analyses can be good indicators of possible effect of quality, they are not adequate substitutes for sensory evaluation.

In the present work, fruit size, days to full yellow colouration, bruise area, under peel bruising, percentage weight loss and sensory evaluations were used to investigate the effects on plantain quality.

2.8.1 Physiological damage

Physiological losses have been sub-divided by Coursey and Proctor (1975) into normal and abnormal. The former refers to respiratory losses that take place in all living materials, the decline in vitamin content and transpiratory loss of water. Abnormal physiological losses are those that arise as a result of extreme heat or cold, or otherwise unsuitable environment.

Wilting, softening, change of colour are all physiological changes that are directly influenced by the produce environment e.g. light, gaseous composition, vapour pressure deficit (Holt *et al.*, 1983). Physiological changes not only influence the quality of the produce but also influence its susceptibility to microbial attack through changes in turgor (Coursey and Booth, 1972).

The soft-green phenomenon of bananas stored in polyethylene bags, characterised by slow colouring and rapid deterioration was studied by Fuchs and Temkin - Gorodeiski (1972) and it was attributed to the accumulation of high concentrations of ethylene and carbodioxide in the bags. Kader (1986), stated that the increase in ethylene production by some commodities during or following exposure to carbon dioxide occurs only when the carbon dioxide concentration is high enough to cause physiological injury to the tissue. It is not known whether this high carbon dioxide-stress-induced ethylene is due to a partial shift from aerobic to anaerobic condition or other mechanisms. He stated further, that exposure of fresh fruits and vegetables to oxygen levels below or carbon dioxide levels above their tolerance limits results in various physiological disorders including improved ripening of climacteric fruits.

Chen et al. (1985) found that the development of physiological disorders including low oxygen injury and alcohol flavour in apple fruit were often a potential risk for the commercial application of low-oxygen storage. However, all these were found to be negligible after post storage treatment and they also indicated that low oxygen storage could effectively counteract the chilling temperature which was injurious to some apple cultivars after a prolonged storage period (Lyons, 1973; Chen et al. 1989). These findings should also be relevant in the postharvest storage of plantain packaged in polyethylene bags.

2.8.2 Mechanical damage

According to Coursey and Booth (1972), mechanical injury may arise at almost any stage of the post harvest chain from harvesting, unsuitable packaging, transport under unsuitable conditions, careless handling during transportation or in the market where they are being exposed for sale.

Mechanical damage of agricultural products are either due to static or dynamic (vibration), external forces for example loads imposed on the produce throughout the distribution system during handling transport and storage (Holt *et al*., 1983) and less rarely by internal forces (Mohsenin, 1978; Sitkei, 1986). The amount of mechanical damage incurred by a produce is directly related to the energy absorbed by the produce during handling (Holt and Schoorl, 1981; Schoorl and Holt, 1982b) and on the mechanical property of the produce (Holt and Schoorl, 1983). According to Holt *et al*. (1983) it is characterised by cell bursting in bruising and tearing apart in cracking. The basic mechanism involved in mechanical damage is energy transformation and has been discussed extensively by Holt and Schoorl (1982). In apples, Schoorl and Holt (1980) observed a strong relationship between the energy absorbed by the fruit and the volume of bruised tissue. This they expressed as bruised resistance coefficient and it varies from one variety to another (Holt and Schoorl, 1984a). Akkaravessapong (1986) found that this principle is also applicable to the banana.

Aworh (1981) and Olorunda and Aworh (1983) have attributed the high incidence of mechanical damage of horticultural produce in Nigeria including plantain, to improper packaging, rough handling during loading and unloading of trucks rough surface roads and extended transport time.

Pantastico and Baustista (1976) found that the main problem in transporting products over land is not the distance, but the condition of the roads from the field to the packing shed or assembly area and finally to the market. This is probably because the damage suffered by fruit and vegetables during transportation is dependent on the severity and number of discrete shocks that occur during a journey, the way in which the resulting energy inputs are distributed throughout the suspension - load - system Schoorl and Holt (1985) found that practically all fruits and vegetables are damaged to some extent during transportation from the field to the processing plants. According to Peggie (1987), the problems occurring during road transportation include vibration, which causes fruits to rotate and skin browning; bouncing which causes bruising and displacement of produce pattern; rough handling during loading and unloading; packers walking over the load, radiation from the sun etc.

Extensive studies have been carried out in developed countries on in-transit vibration damage with temperate crops. O'Brien et al. (1960, 1965) studied the susceptibility of various fruits to damage during transportation. They found that the extent of bruising from in-transit injury is related directly to the magnitude of vibration accelerations and to the frequency of their occurrence.

Schoorl and Holt (1982b) designed a model for road-vehicle-load interractions for multi-layered damage-susceptible loads subjected to energy inputs. The model was extended to predict damage of vehicle traversing potholes and bumps and then tested over a wide range of transport conditions using apple as the test material. They concluded that the model could be used in managing transport damage in horticultural produce distribution by providing the means of selecting optimum vehicles, road and packaging.

However, the situations in developed countries are quite different from what is obtainable in developing countries. Movement of fruit and vegetables from the farmgate to urban centres is generally accomplished by trucks under rough road conditions according to Olorunda and Tung (1985). The bad state of infrastructures such as road and vehicles coupled with bad post-harvest handling practices have resulted in heavy post-harvest losses as a result of mechanical damage in plantain (Karikari, 1970; Kabeya, 1976; Olorunda and Aboaba, 1978 and Aworh, 1981).

Despite all these, very little work has been done on transportation injury associated with handling of foods in developing countries. Karikari et al. (1980) carried out preliminary handling trials to establish a methodology for assessing damage and ripening of plantain in bulk loads. They transported the plantains over a distance of 100km, discovered that even though cartons reduced mechanical damage, ripening was a real problem and they suggested the use of carton with ventilation holes. They experienced high level of mechanical damage within large sacks packed with 70kg produce and moderate levels of damage in bunches and small sacks packed up to 20kg.

Olorunda and Aworh (1983) transported tomato, pepper and onions from the northern part of the country, where they are produced, to an urban market in the south-western part, a distance of over 1,000km. The tomatoes and pepper were packaged in bamboo or cane baskets while the onions were packaged in jute bags. They found that mechanical damage due to improper packaging and rough handling during loading and unloading of trucks, were largely responsible for losses of tomatoes and pepper, and to a smaller extent, of onions. Pathological and physiological damages were found to be more important in losses of onions.

Olorunda and Tung (1985) investigated the effect of vibration, compressive load and type of container on mechanically-induced damage in the tomato. Skin rupture in the tomato was found to be significantly affected by the stage of maturity of the tomatoes, vibration of the containers and by the interactions between compressive load and type of container. With respect to container, they did not find any significant difference among the container types; wood, corrugated paper board and plexiglass (representing a smooth surface) in the incidence of mechanical damage even though there was a lower incidence of rupture and permanent distortion of fruit in the plexiglass container. This they attributed to the differences in the coefficient of friction than to the flexibility of the walls of the containers. They advocated the incorporation of smooth internal surfaces in the design of containers used for transporting perishable produce, particularly under the rough road conditions experienced in many developing countries. They also found that a uniform pressure up to a certain limit applied to the surface of perishable produce in containers, would help significantly to reduce the incidence of mechanical damage in transit. These findings should also be relevant in the physical distribution of plantain.

Adegoroye and Eniayeju (1988) investigated the effect of shape and material of container on impact-induced damage of tomatoes during transportation, using cane, frond and composite materials. They classified quality defects as either physical defect, bruising or decay. Their result showed that fruits packed in cane were more susceptible to impact-induced damage of all defect categories and that there was no significant difference in the amount of physical defect and bruising damage that occured in frond and composite packages. They concluded that shape of package and package material appear to be the most important factors to consider when constructing packages that can withstand impact.

All the work carried out agreed with the observation of Mohsenin (1978), that mechanical damage in every case lowers the quality of a produce and in numerous cases, is followed by rapid spoiling whereby the produce deteriorates completely. Holt et al. (1983) observed that the postharvest deterioration of fruits and vegetables is central to quality management in the distribution of all produce. Mechanical damage also render produce more susceptible to pathological and physiological damages (Coursey and Booth, 1972; Olorunda and Aworh, 1983). However all the reports are lacking in information quantifying the injury associated with machanical damage.

2.8.2.1 Effect of mechanical damage on peel and pulp bruising

The peel of the banana is highly susceptible to mechanical injury at harvest and during transport (Rippon, 1969). Mechanical injury causes loss of visual quality with unsighful marks (Wills *et al.*, 1982). According to O' Brien *et al.*, (1982), the extent of bruising from transportation injury is related directly to the magnitude of vibration accelerations and to the frequency of their occurrence.

Sitkei (1986) stated that a hard core or spot may form inside or on the surface of potatoes as a result of mechanical damage. This deformed inner part blackens in a few days. These aberrant reactions which occur in damaged cells have been attributed to the oxidation of phenolic compounds by phenol oxidases to give coloured end products such as melanin (O' Brien *et al.*, 1978; Wills *et al.*, 1982), since mechanical damage brings hitherto sequestered enzymes and substrates together. Perhaps the same principle applies to plantain.

The enzyme system involved in the browning of the peel and the pulp of the banana have been studied extensively. Enzymes purified from plantains are also known to have similar properties as the banana exzymes (Marriott and Lancaster, 1983).

Dopamine, the primary substrate of enzymatic browning in the banana occur in the Pulp and in very high concentrations in the peel (Griffiths, 1959). Palmer (1963) purified banana polyphenol oxidase (ppo) from the pulp and peel of the fruit. He found that it has a pH optimum of about 7.0 and a higher affinity for dopamine than for any other substrate and that dopamine was oxidised to melanin via indole 5,6 - quinone (Fig. 4). Buckley (1965 as quoted by Palmer, 1970) studied the synthesis and accumulation of dopamine in the Peel of developing banana fruits. Each green peel contained about 70mg of dopamine (1.0-1.2mg/g fruit weight) at harvest. Some 10-15% of the dopamine accumulated prior to emergence, 85-90% accumulated during the first month after emergence and there was little or no change thereafter until ripening was initiated.

The activity of the banana PPO was found to be higher in the interior than the exterior of the pulp tissue (Marriott, 1980). It contains ten Isoenzymes, nine of which are found in the pulp and ten in the peel (Montgomery and Sgarbieri, 1975).

Weaver and Charley (1974) discovered that the rate of browning in the banana appears to be governed by the concentration of dopamine rather than that of polyphenol oxidase responsible for its conversion to pigment. Siriphanich and Kader (1985) found that phenolic production and polyphenol oxidase activity were reduced in the presence of carbon dioxide. However, the symptoms of injury are usually more difficult to detect immediately after injury than they are if the injured fruit had been allowed to ripen (Rippon, 1969; Mohsenin, 1978; O'Brien et al, 1978; Olorunda and Tung, 1988). Thompson et al. (1974) observed that low humidities increased the development of skin blackening during ripening of bruised plantain. The reduction in symptoms of bruising on bananas wrapped in polyethylene film could be partly due to a lubrication effect of the film but also to the high humidity around the fingers which would prevent damaged areas drying out and becoming necrotic.

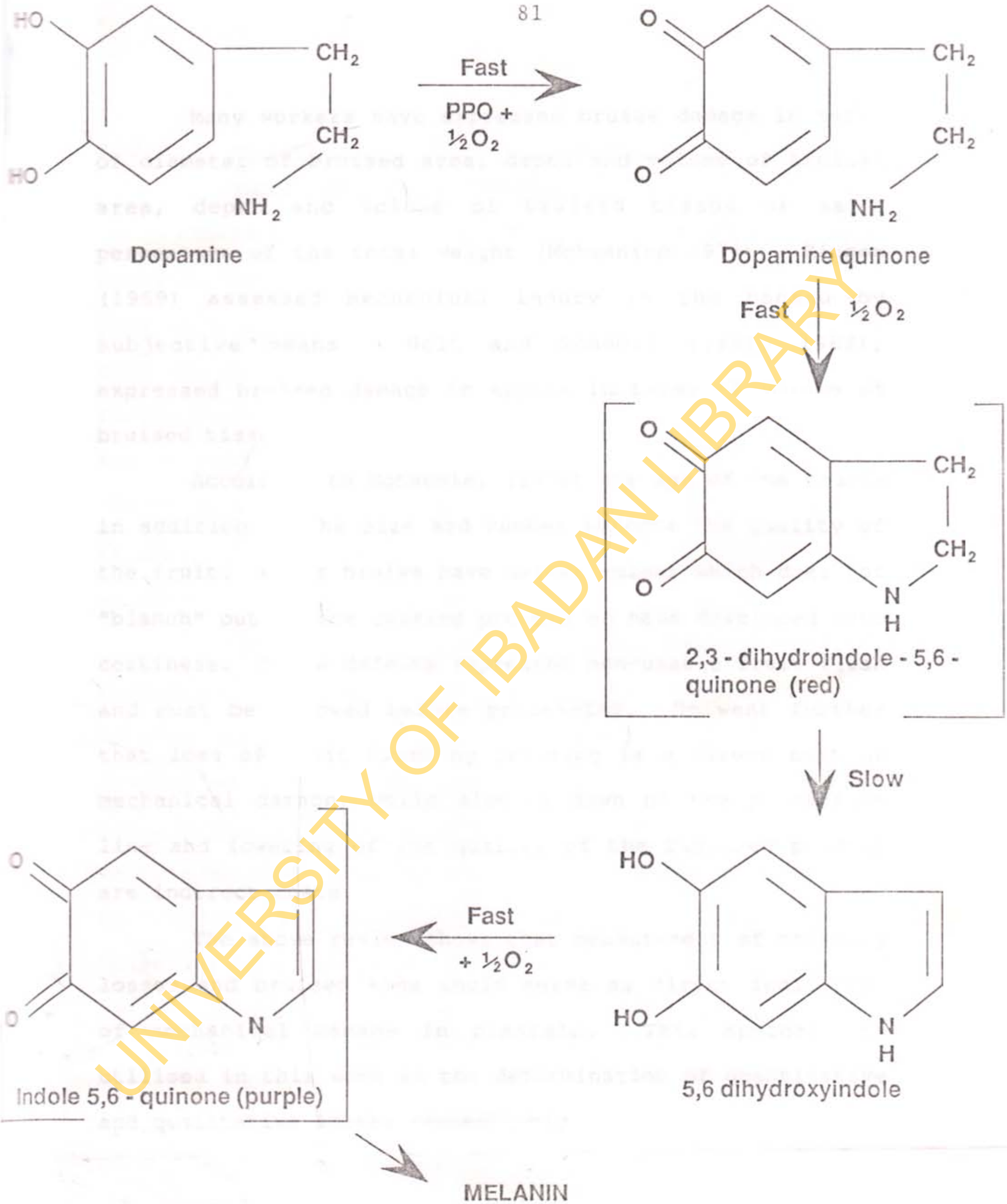


Fig. 4 Proposed reaction mechanism for the oxidation of dopamine by banana polyphenol oxidase

Source: Palmer, 1963

Many workers have expressed bruise damage in terms of diameter of bruised area, depth and volume of bruised area, depth and volume of bruised tissue or as a percentage of the total weight (Mohseninm 1978). Rippon (1969) assessed mechanical injury in the banana by subjective' means. Holt and Schoorl (1981, 1983), expressed bruised damage in apples in terms of volume of bruised tissue.

According to Mohsenin, (1978) the age of the bruise in addition to the size and number affects the quality of the fruit. Older bruise have darker colour which does not "blanch" out in the cooking process or have developed into corkiness. These defects represent non-usable fruit flesh and must be removed before processing. He went further that loss of fruit flesh by trimming is a direct cost of mechanical damage, while slowing down of the processing line and lowering of the quality of the finished product are indirect costs.

The above review shows that measurement of trimming losses and bruised area could serve as direct indication of mechanical damage in plantain. This approach is utilised in this work in the determination of quantitative and qualitative losses respectively.

2.8.2.2 Effect of mechanical damage on preclimacteric period

Mechanical injury such as surface injuries, impact bruising and vibration bruising have been found to affect physiological processes by stimulating high respiration rate and ethylene production (McGlasson, 1970). Injury of banana fruit tissue by crushing induces ethylene evolution and a substantial reduction in preclimacteric period (Maxie et al. 1968). This is because as the produce tries to seal off the damaged tissues because of injury, there is an increase in general metabolism of the tissues.

Littmann (1972b) observed that the rate of ethylene production of bananas under stress increased by factors between two to three compared with unstressed fruits. He discovered further that the respiratory rate during the preclimacteric period increased while the climacteric peak depressed. From this indication, the days it took for the initiation of ripening after mechanical injury could therefore be a measure of the extent of mechanical damage.

2.8.2.3 **Effect of mechanical damage on weight loss**

Transpiration increases with mechanical injury since the natural barrier against water loss have been damaged (McGlasson, 1970; Wills et al. 1982).

Weight loss was explained by Burton (1982) in terms of surface to volume ratio or number of stomata per unit area against age (Burton, 1982). However, Ketsa (1990) found that fruits and vegetables do not lose water at the same rate even when stored under the same conditions. The type of surface and the underlying tissues have a marked effect on the rate of water loss. Burdon et al. (1991) found that stomatal densities of green plantain differ between cultivars. They found a very highly significantly ($P < 0.001$) higher density of stomata on Obino l'ewai than Agbagba, and the former had a higher rate of weight loss at 3.13% per day than the latter at 2.36% per day during storage.

Thompson et al. (1972) showed that much of skin blackening in plantain is associated with moisture loss. The implication of these findings on the present work is that percentage weight loss could be used as an indirect method of measuring the extent of mechanical damage in plantain.

2.9 Scope of the investigation

However, high postharvest losses limits its availability and reduce fruit quality. The quality of the plantain is very poor in most areas of production where plantains are not exported e.g. Nigeria, Ghana, Ivory Coast. Very limited work has been done on the postharvest handling of plantain with a view to minimising losses and improving quality in the postharvest system. It is with this intention that the present study was undertaken with the principal objective of looking into the postharvest factors affecting the quality of plantain in the distribution systems.

CHAPTER THREE

SURVEY OF THE POSTHARVEST HANDLING SYSTEM OF PLANTAIN IN NIGERIA.

3.1 INTRODUCTION

According to Onayemi (1981) the factors responsible for causing losses cannot be isolated from the social and enviromental systems under which food production practices are carried out. Any effort made on reducing postharvest losses must therefore be based on a detailed knowledge of the existing system, since research findings in postharvest studies must be socially and culturally acceptable before they can make an impact on the system.

Similarly an analysis of the alternative methods of processing and distributing fruit and vegetable products, must therefore begin with a survey of where the crops are grown and the products consumed (Huxsoll and Bolin, 1989). It is with this intent that this survey was carried out to obtain first-hand information from the operators of the postharvest handling system of plantain, namely producers, traders and transporters with a view to determining the relationship between production and distribution practices on post-harvest losses in plantain. Also, to identify and describe each point in the harvest chain where people, tools or other physical materials come in contact with plantain, affecting its availability and quality.

3.2 MATERIALS AND MEHODS

Information was collected by visual examination and interviews conducted by a sample survey of plantain farmers, transporters and traders in major producing areas and major market centres using structured questionnaires with preceded responses. Three major producing states namely; Edo, Rivers and Imo were chosen. In each of them one village was purposely selected, these are Ohaji in Imo state, Okwuzi in Rivers state and Ehor in Edo state. The basis of selection was a proven high level of plantain production in the villages.

A distribution survey was conducted in collection centres nearest the production villages selected and in Tejuosho market, a major plantain depot in Lagos metropolis which is a major plantain consumption area.

In each production village, 12 farmers were selected using a list of farmers compiled by the village head as sample frame. In each collection market nearest the villages, 15 plantain traders were selected systematically. Transporters were interviewed in Lagos, Owerri and Ehor.

Three sets of questionnaires were administered (appendix I); production questionnaire for plantain farmers, distribution questionnaire for plantain traders and transporters. The information collected were;

I From farmers:

1. cultural practices
2. Fruit maturity indicators
3. Harvesting methods
4. Storage methods (if any)
5. Accessibility to the farm
6. Distance from farm to the market
7. Method of produce conveyance from farm to the market.

II From transporters:

1. Type of vehicle used/means of transportation.
2. Transport time from village collection centres to urban markets.
3. Distance travelled.

4. Road conditions.

III From traders:

1. Intermediate operations e.g. sorting, dehanding etc. carried out.

2. Identification of points in the commercial system where these operations are carried out.

3. Identification of equipments used, packaging materials etc.

4. Relationship between the actions and the market requirements.

3.3 RESULTS AND DISCUSSION

The questionnaires were collated and the responses translated into codes. The codes were recorded on data analysis sheets and fed into the computer. Chi-square analysis was performed on some of the results, while most of the responses were categorised by the number ans subsequently, percentage of respondents.

The multi-institutional approach to postharvest handling technology (LaGra, 1990) was utilised in the identification and analysis of the problems encountered in the postharvest system of plantain, as well as in prescribing alternative solutions.

The components in the pre and postharvest systems of plantain were identified and presented in fig. 5. The system is visualized as a circle extending from preproduction through production, harvest and distribution to the ultimate consumer. The components are interdependent and the actions and decisions made at one point affect the quality and quantity of plantain at subsequent points. The whole system was taken into consideration because some of the problems that occur during the postharvest system originated from

Fig. 5: Principal Components for plantain systems assessment

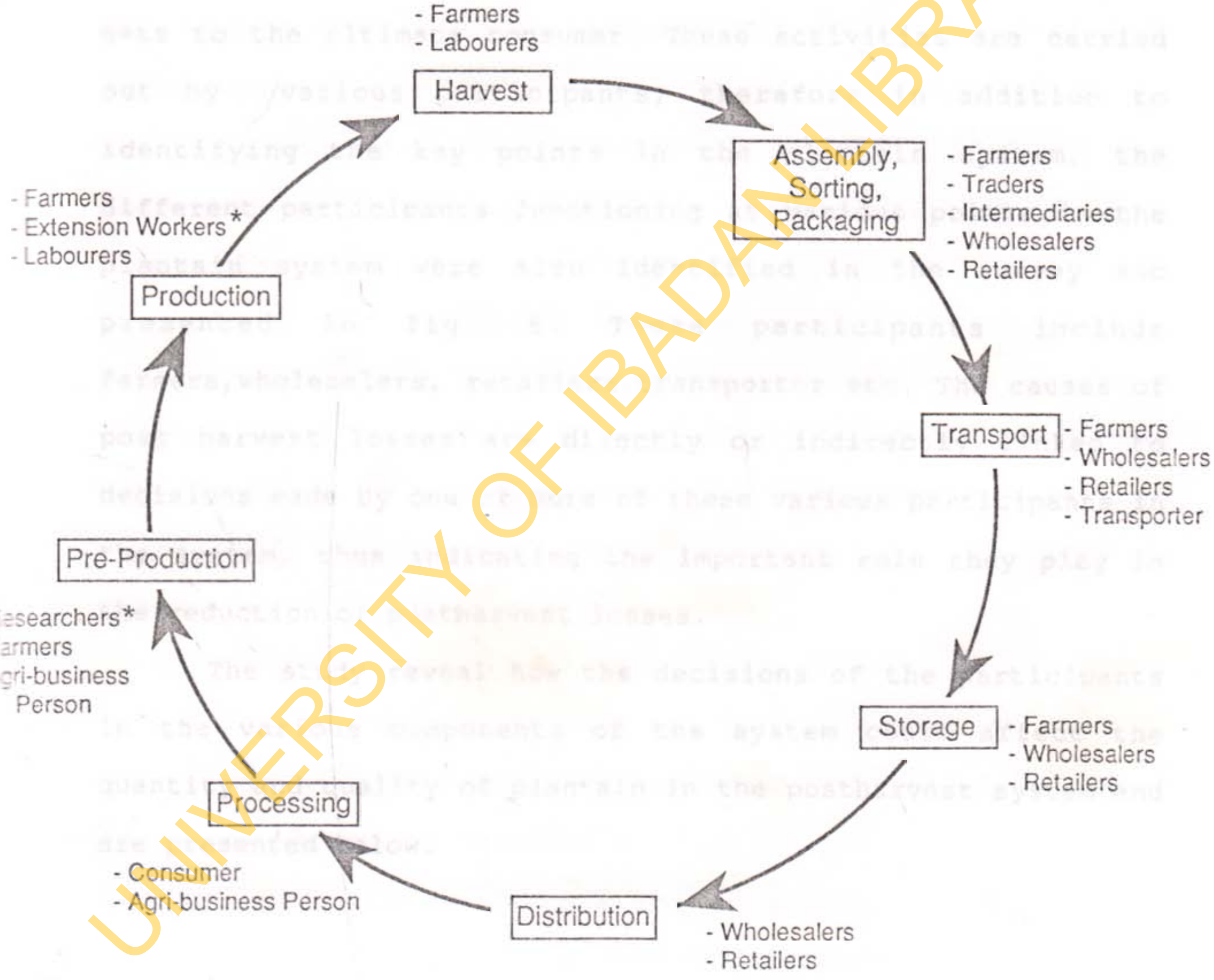


Fig. 6: Participants in the Plantain System

Research and extension services have roles in the whole system, but from the survey, it was limited to production and pre-production.

pre-harvest factors, thus, wrong decisions or problems occuring at an earlier stage of the food system may affect food availability, quality and cost at a later stage.

In the postharvest system, one is considering the series of activities right from when the food is harvested until it gets to the ultimate consumer. These activities are carried out by various participants, therefore in addition to identifying the key points in the plantain system, the different participants functioning at various points in the plantain system were also identified in the survey and presented in fig. 6. These participants include farmers,wholesalers, retailers,transporter etc. The causes of post harvest losses are directly or indirectly linked to decisions made by one or more of these various participants in the system, thus indicating the important role they play in the reduction of postharvest losses.

The study reveal how the decisions of the participants in the various components of the system could affect the quantity and quality of plantain in the postharvest system and are presented below.

3.3.1 FARMER'S CULTURAL PRACTICES

It was revealed that the farmer's motive for growing plantain is mainly commercial; plantain is therefore an important economic crop to the farmer. The source of planting material (suckers) is mainly traditional, none of the farmers interviewed have access to improved varieties. All the farmers interviewed employ traditional methods of farming, none applied pesticides, about 10 percent apply chemical fertilizer while some applied animal droppings, house refuse and ashes on their plantain. The latter are mainly those who planted plantain in the homestead. About 50 percent of the farmers interviewed planted in the homestead, 30 percent in the field outside the homestead and 20 percent planted in the field and the homestead. It was discovered that the location where the plantain is planted often affect the farmer's decision at harvesting time as shown below.

3.3.1.1 HARVEST

The survey revealed that plantains are generally planted at the beginning of the rainy season. The period from planting to harvesting is between 12 and 18 months as reported by Ndubizu (1979). Plantain is harvested throughout the year but the peak period as reported by Nweke et al. (1988) and Wilson (1971) is from October to May. Based on information produced by the farmers the plants are sometimes felled by wind during the rainy season. Since some of these plantains felled by wind may not have reached full maturity, it is not unlikely this is one of the reasons for the preponderance of immature plantain during the rainy season. According to Obiefuna (1986), the change from rainy (March to October) to dry (November to March) season or vice-versa is characterised by destructive thunderstorm which occur during October - November and March - April each year. These thunderstorms devastate plantain orchards especially fruit bearing plants (Arscott et al. 1965; Ndubizu, 1979). This could be avoided by supporting the plants with sticks or by growing dwarf varieties of plantain.

The farmers stated that they harvest their plantain at maturity. The different types of indicators for maturity used by the plantain farmers surveyed are presented in table 3. As could be seen from the Table, maturity indicators differ from farmer to farmer and the decisions made by these farmers determine whether we have mature,

TABLE 3

Different maturity indicators used by farmers in three plantain - producing states.

Indicator	Farmers* (number) Edo	Rivers	Imo
Finger are so strong that they break open	2	-	8
Fingers start ripening	8	1	11
Fingers appear big and strong	10	1	3
Leaves dry up and tear	4	-	5
Colour of fingers becomes darker	1	2	6
About 3 months after flowering	6	1	1
Angularity fades and finger hardens	-	1	1
Nipple at the tip of the fingers darkens	-	-	2
Space between the fingers widen	9	1	-
Neutral flowers on the bunch falls away	-	2	16

* Farmers gave more than one indicator in most cases.

immature or overmature plantains on the retail outlets.

Harvesting when some fingers would be so strong and begin to break open implies that the plantains are over-mature. Peel splitting is a form of mechanical damage which have been attributed to the rise of sugar content of the pulp, increased water uptake and therefore swelling of the pulp according to Simmonds (1970). The exposed pulp would have to be trimmed off during peeling thereby increasing postharvest losses. This situation is common in plantain planted at the homestead. Delayed harvesting is sometimes practised so that the plantain could be cut a day before or on the market day.

Harvesting when some of the fingers start to ripen (Table 3) also implies harvesting at overmaturity stage. Plantain fruits left to ripen on the plant have a tendency to drop prior to or during harvesting (Marriott and Lancaster, 1983).

Harvesting when the leaves dry up and tear (Table 3) could vary depending on the season. The leaves are more likely to dry up and tear earlier during the dry season than at the rainy season leading to over-maturity. Leaf tearing could also be an indicator of presence or absence of leaf diseases

Harvesting when the colour of the plantain becomes darker, when the nipple at the tip darkens, and when the angularity fades and the fingers harden etcetera (Table 3) are highly subjective, yet, they could coincide with the period of full maturity depending on the experience and expertise of the farmers. Sery (1981) observed that the changes in colouration indicate maturity but the method is highly subjective.

Harvesting three months after flowering is probably the best method as it is not only the most objective, but could also be a proper maturity indicator. According to Sanchez et al. (1971), plantain reached the proper maturity level for harvesting in about 90 days after flowering which is about three months. depending on the season, a plantain bunch should be ready for harvesting at three months after flowering. According to Ndubizu and Okafor (1976), fruits formed at the early part of the rainy season (April-July) matured in less than 80 days while those formed at any other time of the year matured in more than 80 days. Farmers who planted in fields outside the homestead generally harvest before they are fully mature. This practice which is primarily to reduce pilferage, increases postharvest losses and results in sale of poor quality plantain.

The survey data shows that the stage of maturity at harvest is not statistically correlated with the distance from farm to the market. This is in contrast to what is obtainable in international banana trade where the stage at which the banana is harvested is directly related to the distance to the market (Simmonds, 1970; Marriott and Lancaster, 1983). The distance the plantain has to travel before reaching the final market should normally affect the stage of maturity at harvest. Those to be taken through longer distances should be harvested at earlier stage of maturity to delay the ripening process in transit, since ripe or ripening plantains are more prone to damage during transportation

Harvesting practice is the same in all the villages visited. The pseudostem is first given a partial cut so that it bends, this puts the plantain bunch within reach, whereby it is held by hand and cut off with a cutlass before being put on the ground. The harvesting operation is a critical one because careless cutting can lead to smashing of the bunch, especially in those with heavy bunches and from tall plants, thus leading to serious bruising and breakages.

Some major losses are connected with the timing of plantain harvest. Quality obtained is poor and losses result when plantain are harvested too early or too late. To avoid these losses, the time of harvesting must be standardized. Moreover achieving high quality and marketability of plantain for the fresh market and processing outlets require that plantain be harvested at optimum maturity. There is a strong need therefore, to come out with some form of maturity index which would be useful for the different outlets that is, processing, fresh market etc.

3.3.2 PACKAGING

Table 4 shows points in the postharvest system where packaging or repackaging takes place and the different types of participants involved.

As could be seen from the Table, packaging at the farmgate is mainly carried out by farmers, packaging at the village market and collection centres are carried out by

TABLE 4

Points at which plantain packaging takes place and the different participants involved.

Points where Packaging takes place	Participants involved	State
Farm-gate	Farmer	Imo
Village market	Small-scale trader	Imo Edo Rivers
Collection centre	Large-scale trader	Edo

small-scale and large-scale traders respectively.

Aside from Imo State where farmers use cane baskets as packaging containers for their plantain at the farmgate, this operation was non-existent in other surveyed areas. In Imo State, intact plantain bunches are strapped unto a cane basket which is placed on the carrier of the bicycle and then conveyed to the next point in the system which is the village market.

Altogether only about 26 percent of the traders across the areas surveyed package their plantain. It was observed that the main purpose for packaging at the different points is to facilitate handling during distribution and marketing. Those who package at the village markets are usually small-scale traders who sell plantain on retail basis at the terminal markets or those who sell grilled plantains (boli) at the urban markets. A large percentage of traders who package their plantain are the large-scale plantain wholesalers who take plantain to Kano in northern Nigeria from the collection centre at Ehor in Edo state (midwestern part of Nigeria) a distance of about 1,050km apart. Collection centers are usually very close to the main road leading to Lagos or the North for easy accessibility. Some are also located in public motor garages where they sometimes resemble mini-markets.

A typical collection centre is the one at Ehor in Edo state, which is by the major road leading to the north. The plantain bunches are brought to the collection centre either from the farmgate or the village market in pick-up vans. They are unloaded in a stack and immediately after unloading, the hired hands (intermediaries) employed by the wholesalers begin a mini-packinghouse operation as illustrated in Fig. 7.

A packinghouse is a sheltered environment with the purpose of assembly, sorting,selection and packaging of produce in an orderly manner with a minimum delay and waste (LaGra, 1990). The principle involved in a packinghouse operation is material handling to improve quality.

The operations illustrated in Fig. 7 are carried out promptly, the cutter holds the bunch by hand and cut the plantain into clusters of about 3 or 4 fingers. This is done while standing which means that the clusters would drop carelessly to the ground. This operation is carried out with very sharp knives and it is not unusual for the plantain to

Fig. 7: Typical packing-house operation at a collection centre (Ehor) in Edo State of Nigeria

receive cuts during the process. These bad handling practices result in mechanical damage which manifests as cuts or bruises in the ripe plantain.

To minimise damage at this point and improve product quality, the plantain bunches should be allowed to hang in a shady place, preferably in the packinghouse itself, for at least 24 hours after cutting. This allows the plantain to wilt slightly and minimizes the incidence of juice staining leading to poor quality, as the latex would have dried up considerably. A special knife like the one used for banana in the international trade should then be used in dehanding the plantain. This should be done on a working table or bench. The fingers should be removed from the hand by breaking, rather than by cutting taking care not to damage the pedicel in the process. Also, there should be left adhering to the pedicel a portion of the cushion on which the fruit was borne.

After cutting, the plantains are then sorted for colour, that is, ripe or ripening fingers are removed from the green ones, since ripening plantains emit ethylene which would initiate ripening in the green ones in transit (Karikari _et al_. 1979). The green plantains are subsequently packed into sacks which are flexible polypropylene bags previously used to package other products such as rice. The size of the sacks is about 75 x 50cm, hey lack rigidity. The unsuitable dimension and design of the sacks and their poor conditions, such as fatigue effects noticed on some of the sacks, lead to excessive mechanical damage to produce in transit. According to (Sayers, 1984) the shape, size and construction material are the most important features of a container affecting the possibility of damage to the produce during transport. The sacks in use therefore are more to facilitate marketing, since the protective aspect of packaging is not the overriding factor in using these sacks.

The sacks are sold by another trader to the wholesaler right at the collection centre, they are therefore readily available. The plantains are not packed by weight, but rather, the bags are filled by experience to a certain point where the open ends can be sewn unto place.

It is noteworthy that bananas on the other hand are packaged in cardboard cartons which have been previously used in packaging detergents etc. These cardboard, available in flat form are reformed prior to their being used in packing bananas and then held in place by tieing firmly with a string. Cardboards, rather than sacks are used for bananas presumably because of the greater rigidity of the cartons. Banana being more fragile than plantain would have suffered greater mechanical damage when packaged in sacks and therefore mass rejection by the consumers. This must have led to substantial amount of losses or perhaps outright losses in some instances, thus making the operators to change their method of packaging. According to Marriott (1980), consumers judge quality in terms of appearance such as absence of bruises, bright peel colour, adequate fruit size, absence of mixed ripeness etc and these factors determine the price paid for the produce (Schoorl and Holt, 1983b). This shows how a decision made by the consumers in a commodity system could lead the other operators (traders, transporters) to improve their handling methods. Perhaps it is due to the same reason traders who transport plantain to Kaduna, a distance of about 800km from Edo State do not package their plantain. They stated that consumers in Kaduna rejected packaged plantain and refused to buy. This disagrees with the broad generalization of Kader (1983b) that any produce that is not spoiled (rotten) or totally unusable will have a market, if the price is right, in developing countries.

The rejection of packaged plantain in Kaduna is probably because of high quality deterioration of these produce. This is because the sack, apart from not protecting the plantain against mechanical damage could also constitute a hazard when temperatures are liable to fluctuate, due to condensation inside the bags.

The importance of quality and grading regulations therefore cannot be over-emphasized, the legislation and application of these regulations would improve postharvest handling practices and guarantee that consumers can buy reliable product. Since the rudimentary form of a packinghouse operation is already being practiced in Nigeria, this can be strengthened and improved through the construction and operation of large central packinghouses, probably on cooperative basis in order to improve the efficiency of the system.

The labour costs associated with packaging include money paid to the intermediaries who carry out the packinghouse operations, cost of packaging materials and transportation cost.

TABLES 5

Distance travelled from the farmgate to village market by the farmers surveyed.

Usual distance travelled (Km)	Farmers (number)	(%)
< 1	25	70
1 - 2	1	3
2 - 5	3	9
> 5	6	18

TABLE 6

Farmers means of transporting plantain from the field to the market.

Means of transportation	Farmers (number)	(%)
Headloading	1	2
Wheelbarrow	7	19
Taxi	2	6
Bicycle	20	56
Motorcycle	4	11
Pick-up van	2	6

TABLE 7

Traders' means of transporting plantain to urban markets.

Transport	Level of operation	Traders Number	%
Pick-up van	Small-scale	30	67
Taxi	Small-scale	1	2
Lorry	Large-scale	5	12
Trailer	Large-scale	9	19

Plate 1: Plantain transported as whole bunches intricately loaded in the lorry, with ripe or ripening plantain fingers packaged separately in bags.

3.3.3 TRANSPORT

For a produce to be useful to consumers it must reach the diverse markets on a timely basis. Each time the product is transported from one point to another it is rough handled, delayed, vibrated, placed under pressure, subjected to a variety of conditions which may negatively affect the quality and therefore the marketability.

Transportation occur at various points in the postharvest system from the farmgate to the ultimate consumer. Table 6 and 7 show transportation at the farmgate level and from rural to urban markets respectively.

3.3.3.1 TRANSPORTATION BY FARMERS

As could be seen from Table 5, about 70 percent of farmers interviewed travel less than 1km, while about 18 percent normally travel over 5km to sell their plantain. About seventy-five percent of the farmers stated that the road leading to their plantain field is untarred but good, about ten percent have tarred road passing by their farm, about fifteen percent have very rough roads while about three percent have just a track connecting their plantain field to the market. Fifty-six percent of the farmers transport their plantain to the market by bicycle and twenty-four percent by wheel barrow (Table 6). Taxis, pick-up vans and motorcycles are used for longer distances while bicycles wheelbarrow and headloading are used for shorter distances. The situation is the same in Ivory Coast when narrow roads or tracks connect the farm to the market, transportation is usually by small vehicles such as bicycles, motorcyles etc. When larger vehicles are used on these roads, severe mechanical injury caused by vibration damage have been reported resulting in quality deterioration of plantain (Kuperminc, 1988).

3.3.3.2 TRANSPORTATION BY TRADERS

Plantain is mainly transported by road in open or not-completely closed vehicles. As could be seen on Table 7, pick-up vans and taxis are mainly used by small scale wholesalers and sometimes retailers. Transportation by lorry is mainly utilised by large-scale wholesalers who take plantain to Lagos, the plantains are transported as intact bunches intricately loaded into the lorry (Plate 1). Trailers are mainly utilised by large-scale wholesalers who take plantain to the north.

Almost all the traders interviewed stated that transport is a constraint. This is because there is no organized transport system, the waiting period at the village market or collection centre could be prolonged.

The plantains that are not packaged are exposed to direct sunlight since the packinghouse is not shaded. Fruits that are exposed to direct sunlight can be 20 to 30 degrees higher in temperature than those that are shaded (Bourne, 1977b). This higher temperature in direct sunlight greatly accelerates the rate of deterioration. When the fruits are packaged, there is no proper aeration of the produce and because the plantain is a living entity, heat is generated and there is ethylene build up, thereby hastening ripening and deterioration. Moreover, heat can be slow to disperse from sacked produce, thus the heat generated is not easily dispersed. Availability of transport is therefore an important factor at the collection centre, since waiting time further increases the time between harvesting and consumption thereby increasing loss. The earlier the plantains are transported, the lesser the losses incurred. A delay of more than 24 hours leads to heavy losses and consequently high marketing costs in plantain (Aviles, 1987).

Transporting plantain from villages around Imo and Rivers states takes about 2 to 4 hours excluding waiting time. Sometimes waiting time could be as long as 4 hours or more in this case. From Edo State to Kano and Kaduna takes about 18-24 hours while it takes about 5-8 hours to Lagos. The losses incurred at this stage is dependent on total time spent in transit from the point of collection to the point of unloading. This probably translates into high cost of plantain in places that are far from production areas as could be seen on Table 8.

However, according to Pantastico and Bautista (1976), the main problem in transporting products over land is not the distance, but the condition of the roads from the field to the packinghouse and finally to the market. About 42 percent of the transporters interviewed stated that the road they traverse are good, 26 percent stated they pass through bad roads, 2 percent stated they passed through very good roads while about 30 percent stated that the road they pass

TABLE 8

Plantain Price/kg (₦) at various locations in Nigeria.

City/Village	State	Plantain Price/kg
Zaria*	Kaduna	17.39
Ibadan	Oyo	2.89
Omi-Adio	Oyo	1.81
Umuahia	Abia	2.37

Adapted from commodity prices (1990) National Agricultural Extension and Research Liason Services, A.B.U. Zaria.

through are half way good and half way bad. The poor condition of road surfaces, coupled with unsuitable transport vehicles are two factors which result in much mechanical damage to produce consigned by road.

Vibration damage occurs when the produce moves within the container during transportation. A transport vehicle in motion generates a broad spectrum of vibration frequencies and amplitudes and these are passed via the container to the produce. The inertia of the produce causes it to move relative to the container under the action of high amplitude vibration (Sayers, 1984). Rigid container walls and limited movement of the base will minimize the effect of vibration. The effect of vibration damage to plantain during transportation handling is worth giving further considerations. This information would be of immense help in educating the transporters and traders in better handling practices.

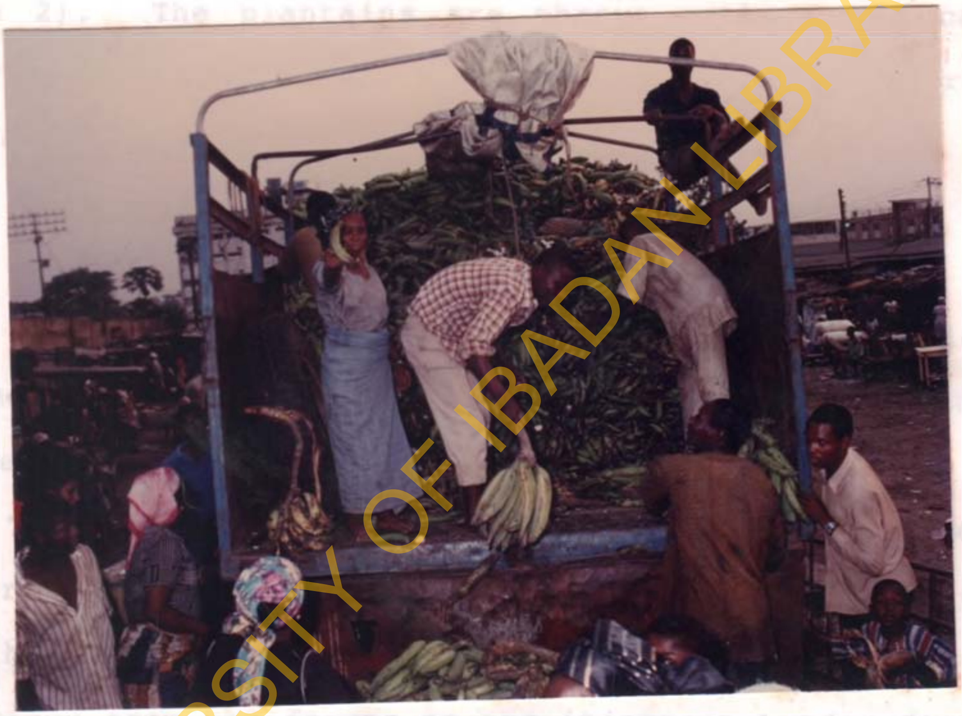


Plate 2. Plantain being unloaded from a vehicle at an urban market. (Poor handling often result in considerable mechanical damage to the plantain).

Another major problem encountered during transportation is rough handling of the plantain during loading and unloading (Plate 2). The plantains are thrown rather than carried gently leading to cuts and bruises which manifest as brownish spots on the ripe plantain.

3.3.4 MARKETING

In the marketing of plantain there are a wide variety of intermediaries such as the rural and urban wholesalers and retailers (Fig 8).

The itinerant trader usually buys plantain at the farm gate or village market very early in the morning around 600 am from the farmer. The rural wholesaler comes later and could either buy from the farmer or the itinerant trader depending on how early he gets there. Usually the rural wholesaler assists in the function of collection, he is usually mobile and buy plantain from farmers over a selected area which are later transported to urban wholesalers. The retailer here refers to the vendor in the urban market. She buys her plantain mainly from the urban wholesaler and very rarely from the rural wholesaler or the producer. They sell plantain in smaller units such as fingers or clusters.

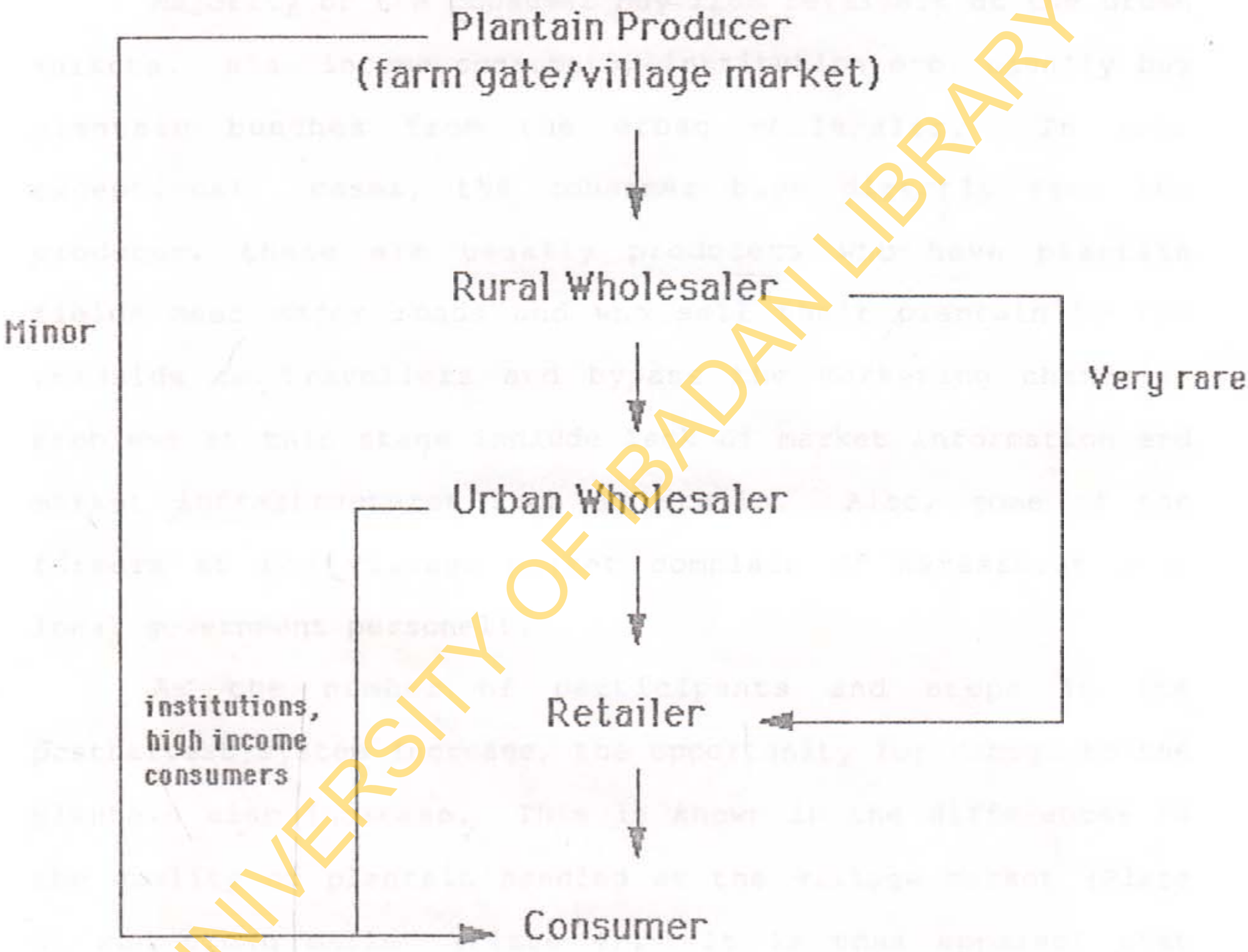


Fig. 8. Plantain marketing channel and the participants.

Majority of the consumer buy from retailers at the urban markets. High income consumers, institution etc. usually buy plantain bunches from the urban wholesaler. In some exceptional cases, the consumer buys directly from the producer, these are usually producers who have plantain fields near major roads and who sell their plantain by the roadside to travellers and bypass the marketing channels. Problems at this stage include lack of market information and market infrastructures such as stalls. Also, some of the farmers at the village market complain of harassment from local government personell.

As the number of participants and steps in the postharvest system increase, the opportunity for damage to the plantain also increase. This is shown in the differences in the quality of plantain handled at the village market (Plate 3) and urban market (Plate 4). It is thus apparent that plantain marketing can probably be more seriously affected by handling and transportation, than either nutritional or processing quality, as plantains are priced according to their physical condition in terms of size, absence of bruises and cuts etc as Marriott (1980) observed in some other fruits.

Plate 3. Plantain displayed for sale at a production area.

Plate 4. Plantain sold in urban markets showing evidence of bruising.

3.3.5 STORAGE

Plantain is a high value commodity and the survey revealed that more than 75 percent of the plantain produced by the farmer is for sale. The plantains that are brought back home for storage are those that are not sold on the particular market day, therefore, the quantity stored per farmer after harvest is not significant. However, since harvesting is more during the peak season, the need for postharvest storage could be high then. The farmers do not employ available modern storage techniques, essentially because they are not considered economically worth-while. The problem of storage causes low prices during peak season (Nweke et al, 1988), as excess plantain produced causes glut and attract low prices since they cannot be stored.

When asked whether they are willing to use improved storage facilities to extend the storage life of plantains, about 90 percent of the farmers replied in the affirmative for several reasons, the most important being that they could sell at higher prices during periods of scarcity. Also it would eliminate the losses incurred as a result of perishability and that it would avoid plantain being left on the plant to over-mature.

TABLE 9

Reasons given by surveyed farmers for accepting improved storage methods.

Farmers Reason	Number	%
For preservation, to sell during scarcity	21	58
New invention, willing to experiment	1	3
To eliminate losses due to lack of sale	8	21
To avoid delayed harvesting	6	18

When asked how much they are willing to spend on storage facilities, more than 75 percent refused to give a specific amount, mostly because they have never heard of or seen any such structure as modified atmosphere storage facility. They therefore found it difficult to put a price on what they have never seen. However, prices quoted by the remaining few ranged from N15.00 to N1,000.00.

Storage losses can be reduced by phasing plantain production such that the effect of seasonality, hence glut, is minimised or by breeding cultivars that mature at different times. However, Sanchez, et al (1971) planted plantain throughout the 12 months of the year and even though it was possible to harvest fruit throughout the year, the effect of seasonality was not avoided, as a definite peak production was still observed. Therefore, the processing of plantain into more stable products such as plantain flour or chips should be given greater attention.

3.4 CONCLUSION

Plantain is mainly consumed in urban centres where it is not produced, hence there is a great need to transport it from production areas to consumption areas.

However, unprocessed plantain is fragile and bulky, this, coupled with its high perishability and the current bad handling practices have led to a high degree of qualitative and quantitative losses in the postharvest system. In agreement with previous workers (Kabeya, 1976; Fongyen, 1976; Olorunda and Aboaba, 1978; Karikari et al., 1979) mechanical damage was found to be the most important source of losses in plantain during postharvest distribution.

Based on the analysis of the plantain system, the problems, both social and technical, in the postharvest system of plantain distribution leading to losses in quantity and quality have been identified and analysed.

Social factors although sometimes indirect are very important in postharvest qualitative and quantitative losses in plantain. These include the human element aspects such as decisions made by farmers, traders, transporters etc. It also include supporting services such as bad road surfaces, poor conditions of vehicles used, inadequate transportation facilities, lack of market infrastructures all of which aggravate postharvest losses. Majority of the losses attributed to these factors are either due to carelessness or ignorance of the nature of the produce handled and of the need for quality. Most of the problems at the social level could therefore be solved through proper information dissemination to the participants involved and improvement of the supporting services.

Technical factors affecting postharvest qualitative and quantitative losses in plantain include lack of improved plantain materials, lack of standard maturity index for plantain, inappropriate and inefficient packaging containers, leading to physiological as well as mechanical damage during handling and transportation.

The survey revealed that there is no standard maturity index for harvesting plantain and there are evidences that postharvest losses are related to maturity at the time of harvesting. Establishing the proper time to harvest plantain cultivars to ensure high quality during transportation and handling and for the processing outlets therefore require special considerations. The same opinnion has been expressed by Wainwright and Burdon (1991) in their review on cooking bananas.

Packaging materials currently in use are inadequate in protecting plantain against mechanical damage. They lack structural integrity and mechanical strength, the flexible walls of the containers also allow external forces to be transmitted to the fruit, this coupled with bad roads and vehicles in poor conditions aggravate mechanical damage during produce transport. The effect of vibration damage to plantain during postharvest handling is also worth giving further considerations.

In order to prescribe solutions to the technical problems, further quantification of the losses are required and this would be the subject of attention in subsequent work in this thesis. The information obtained would be of great help in educating the participants of the postharvest system in better handling practices.

CHAPTER 4

SCREENING FOR HARVEST MATURITY INDICATORS IN TWO CULTIVARS OF PLANTAIN

4.1 INTRODUCTION

According to Thompson *et al*. (1972); Tindall and Proctor (1980); Liu (1982) and nearly all the aspects of the postharvest life of a produce for example, susceptibility to damage, processing, storage, are influenced by maturity at harvest. Thus the initial state of a produce at harvest is of tremendous importance in the final quality of the produce, whether in the processed state or in the fresh form.

However, from the result of the survey conducted in chapter three, it is evident that there is no standard method of identifying harvest maturity of plantain in Nigeria. A similar situation has been observed in Ghana, another plantain producing country, by Karikari and Agyepong (1983). The bunches are harvested by subjective assessment depending on the farmers judgement, this practice often lead to the harvesting of poor quality bunches, which may either be immature or overmature, thus predisposing them to high postharvest losses in quality and quantity. The initial state of a produce at harvest is therefore an important factor in the final quality of the produce, whether in the processed state or in the fresh form. The stage of maturity at harvest is therefore a crucial factor affecting the postharvest quality of plantain.

In the commercial production of banana, the girth of the fingers of a selected hand on the bunch is measured in order to determine the harvest maturity and this is known as the 'Caliper grade' (Stover, 1972; Marriott <u>et al</u>. 1979). Preliminary tests showed that measurement of plantain finger with calipers is difficult because of the angularity of the finger. Similar observation was made by Karikari and Agyepong (1983) in their work on Ghanaian plantains, therefore the use of caliper grade as an index of maturity in plantain may be very difficult to be adopted, in which case, a different approach could be used in measuring the finger diameter. Alternatively, other more appropriate parameters could be sought for and adopted in determining harvest maturity in plantain.

It is with this intent that this study was undertaken to find the relationship between maturity, determined by age at the time of harvesting, and certain physical characteristics of plantain such as finger diameter, finger weight, finger length, pulp to peel ratio, dry matter content, with a view to obtaining information on fruit characteristics which may be used as an objective means of identifying harvest maturity in plantains.

According to Simmonds (1970), the hands within a particular banana bunch are of different physiological ages, it would also be worthwhile to study the variation of these parameters within a bunch. In order to study the variation of these parameters within a bunch, mature plantain bunches of about 12 weeks after anthesis were used and the determinations made for the first, third, fifth and seventh hands of the bunch.

4.2 MATERIALS AND METHODS

Plantain bunches of the Agbagba and Obino cultivars were harvested between 8 to 14 weeks after anthesis. The plantain were obtained from the research farm at the IITA Sub-station, Onne; Rivers State. The date of flowering was recorded for each bunch and the age at the time of harvesting was calculated from the dates of flowering. The plantains were carefully harvested, the hand were removed from the bunch with a knife and the fingers were separated by hand, taking great care in order not to damage the pedicel.

Six fingers from the first hand of each bunch from the proximal (top) end was used for the analysis and each finger was carefully labelled indicating the bunch age and the finger number. The parameters measured were recorded for each individual finger and all measurements were carried out on the day of harvesting.

Two bunches at each of the ages were used for the Obino cultivar and three bunches for the Agbagba cultivar.

In order to study the variation of these parameters within a bunch, three mature bunches of about 12 weeks after anthesis were used for each of the two cultivars and the measurement were carried out on hands 1, 3, 5 and 7. The same procedure stated above was used.

4.2.1 Measurement of finger weight

The weights were averaged for the six fingers to obtain a mean reading for each replication.

4.2.2 Measurement of finger length

The length of the individual fingers were measured from the distal to the proximal end, that is from the junction of the fruit stalk with the main bunch stalk to the apex of the fruit according to the method of Karikari and Agyepong (1983). Both the internal and external lengths were measured using a tape measure (stamm-Helvetia) and then averaged for each finger to obtain the finger length.

4.2.3 Measurement of diameter

Finger diameter was measured at a point equidistant from the proximal to the distal end along the longitudinal axis. The plantain was cut transversely at this point and finger diameter measured according to the method of Sanchez et al., (1968a) (Appendix II). The diameter was obtained by averaging the reading of the longer and shorter diameters as carried out by Karikari and Agyepong (1983) on Ghanaian plantains.

4.2.4 Measurement of pulp to peel ratio

Whole and peeled fruits were weighed to obtained gross and pulp weight respectively; peel weight was derived by difference, and the pulp to peel ratio calculated as a quotient of the pulp and peel weight.

4.2.5 Measurement of dry matter content

Ten grammes of the pulp and the peel diced into small pieces were measured separately in duplicates and placed on moisture papers (union camp 1 Tiger). The samples were dried in the oven (Gallenkamp moisture extraction oven) at a temperature of about 70°C until a constant weight was obtained. Dry matter content was obtained from the difference in final weight and initial weight of the samples.

4.3 RESULTS AND DISCUSSION

Plantain bunches of the Agbagba cultivar harvested after 12 weeks had some fingers already ripening as well as splitting of the peel especially on the first hand. Splitting of plantain peel as a result of over-maturity has been attributed to the rise of sugar content of the pulp, increased osmotic pressure, increased water uptake and therefore swelling according to Simmonds (1970). Initiation of ripening on fruit hanging on the tree has been observed by Barnell (1941 as quoted by Simmonds, 1970) in his work on bananas (Gros Michel). He found that banana bunches left on the plant until long past the time at which they would normally have been cut, showed various signs of incipient ripening.

The incident of ripening on the plant and peel splitting were not observed in the Obino cultivar, even in those harvested at 14 weeks after anthesis showing that the Obino is a late maturing cultivar compared to the Agbagba. Perhaps if the experiment had been carried out further, it would have indicated a better comparison.

Measurements of finger diameter, finger length, finger weight, pulp to peel ratio and dry matter content from the first hand of Agbagba and Obino bunches, against maturity, as measured by age at the time of harvesting, were subjected to correlation analysis. Even though the correlation obtained agreed mostly with those of Karikari and Agyepong (1983) who worked on Ghanaian plantains, it was quite obvious from the distribution of the points around the straight line that the relationship was a non-linear one. For instance correlation between maturity and dry matter content was found to be non-significant in the two cultivars, hence there was no relationship between dry matter content and maturity at harvesting. Moreover a regular pattern was obtained in the results whereby the values increase to a maximum and then decrease. Karikari and Agyepong (1983) also obtained similar trends in their work on Ghanaian plantains. The non-significant correlation obtained was therefore taken to mean that the relationship was curvilinear rather than linear. Perhaps it is for the same reason Sanchez et al. (1968b) found no significant linear correlation between finger diameter and bunch age in the Guayamero and Maricongo cultivars of plantain in Puerto Rico even though they observed that the fruit did become more round and plump with age. Because of the reasons advanced the data were then subjected to Polynomial analysis as a result of failure of linear regression to express the relation between the parameters measured and maturity at harvesting.

Results showed that with increasing maturity at harvest, dry matter content of the pulp increased to a maximum point at 11 weeks in the Agbagba cultivar (Fig. 9) and 11 and 12 weeks in the Obino cultivar (Fig. 10) before decreasing again. The decrease in dry matter content is attributable to respiratory activities and loss of hemicelluloses (Simmonds, 1970). The dry matter content of the peel showed a reverse trend to that of the pulp, it decreased slightly from 8 weeks to 9 weeks and remained fairly constant from 9 to 14 weeks in the Agbagba cultivar (Fig. 9). In the Obino cultivar on the other hand it increased slightly from 8 weeks to 9 weeks and then decreased gradually from 11 weeks to 14 weeks (Fig. 10), while dry matter content of the pulp and peel were highly correlated with maturity at harvest in the Obino cultivar (Table 10), dry matter pulp and peel were significantly

TABLE 10

Correlation between maturity (age at harvest) with characteristics of plantain fingers measured from the first hand of the bunches

Correlation tested	Cultivar	Calculated correlation coefficient
Finger diameter (cm)	Agbagba	0.91**
	Obino	0.99**
Finger weight (g)	Agbagba	0.94**
	Obino	0.99**
Finger length (cm)	Agbagba	0.95**
	Obino	0.97**
Pulp to peel ratio	Agbagba	0.98**
	Obino	0.98**
Dry matter (%) (pulp)	Agbagba	0.86*
	Obino	0.98**
Dry matter (%) (peel)	Agbagba	0.73*
	Obino	0.96**

**Denotes significance at p = 0.01
* Denotes significance at p = 0.05

correlated with maturity at harvest at p = 0.05 in the Agbagba cultivar (Table 10).

Pulp to peel ratio, finger diameter, finger weight and finger length all correlated highly and significantly (p = 0.01) with maturity at harvest in the two cultivars (Table 10). Similar trends were observed in all the results, values increased up to a maximum point and then decreased gradually or levelled off. Maximum value of pulp to peel ratio was obtained at 13 weeks in the Agbagba cultivar (Fig. 11) and the Obino cultivar (Fig. 12). Maximum value of finger diameter was obtained at 12 weeks in the Agbagba cultivar (Fig. 13) and 13 weeks in the Obino cultivar (Fig. 14). Figs. 15 and 16 show the changes of finger diameter with maturity in the two cultivars. Maximum values of finger weight (Fig. 17 and 18) and finger length (Figs. 19 and 20) were obtained at 12 weeks in the two cultivars. The increase up to a maximum point and gradual decrease or levelling off could be explained in terms of the physiology of the developmental stages the plantains were going through, that is; growth, maturation and senescence. Most

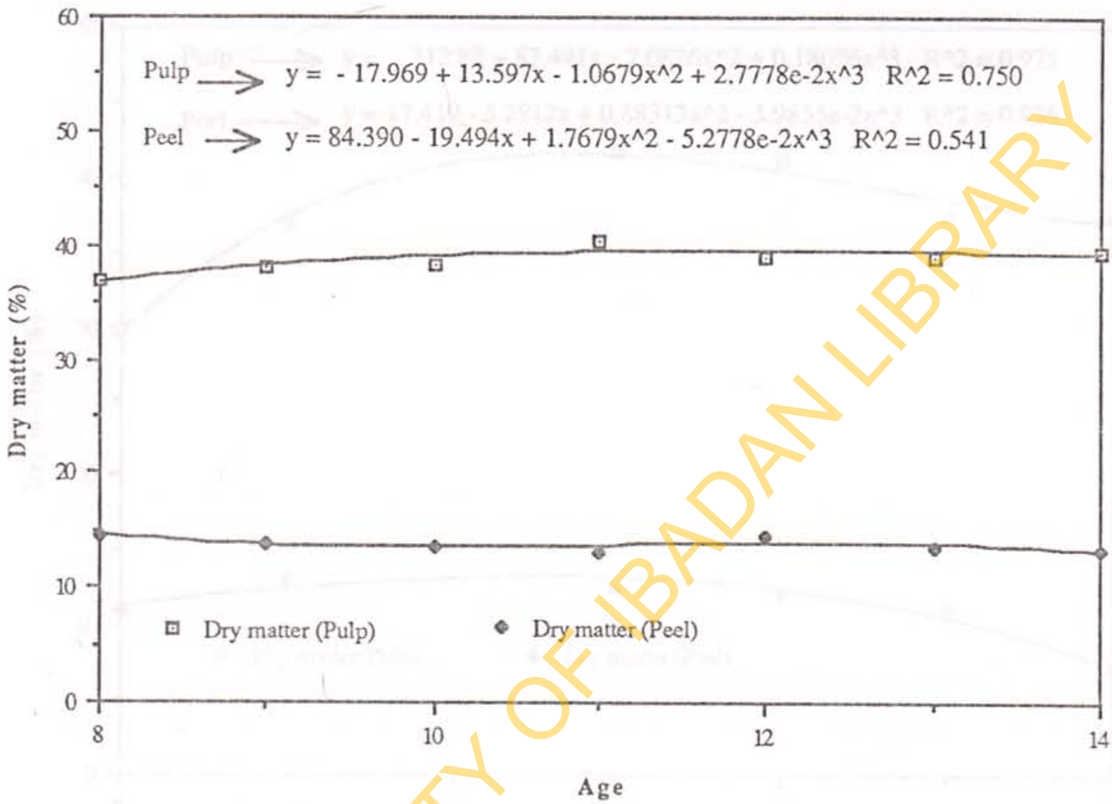


Fig. 9. Graph of maturity at harvest against dry matter (pulp and peel) in the Agbagba cultivar.

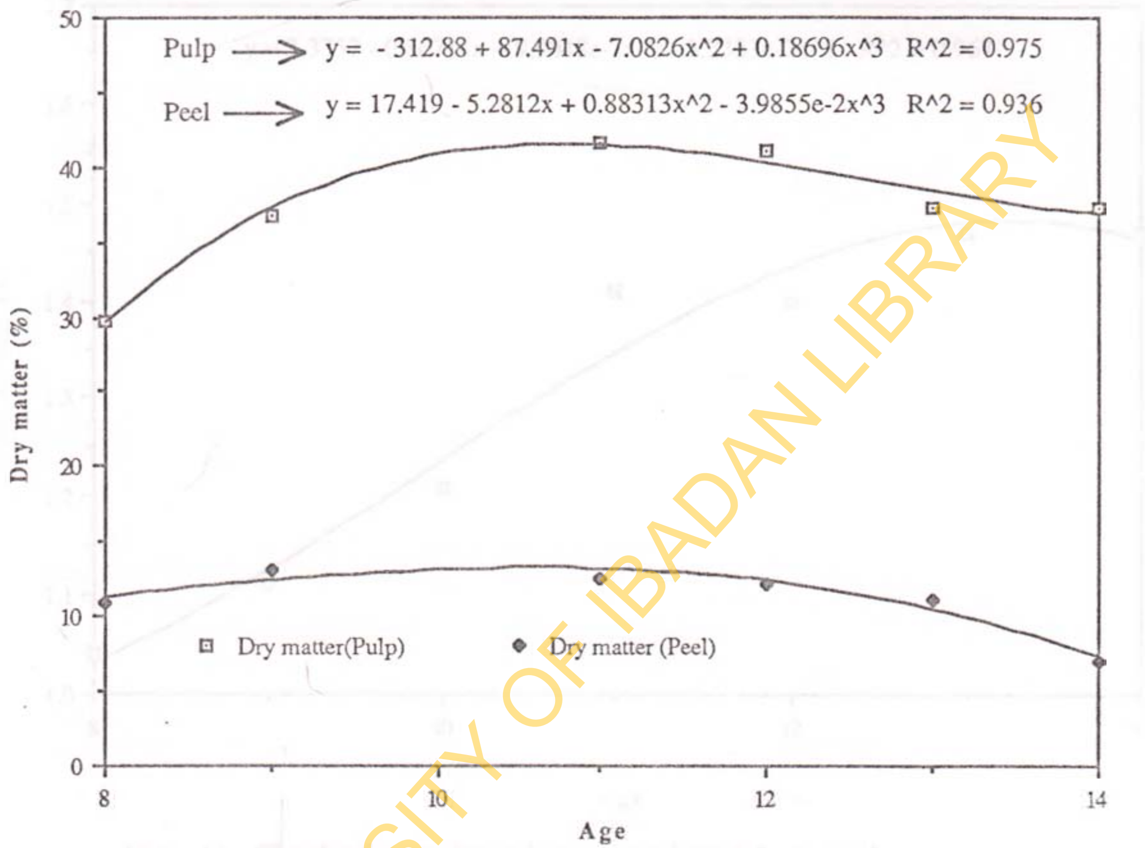


Fig. 10. Graph of maturity at harvest against dry matter (pulp and peel) in the Obino cultivar.

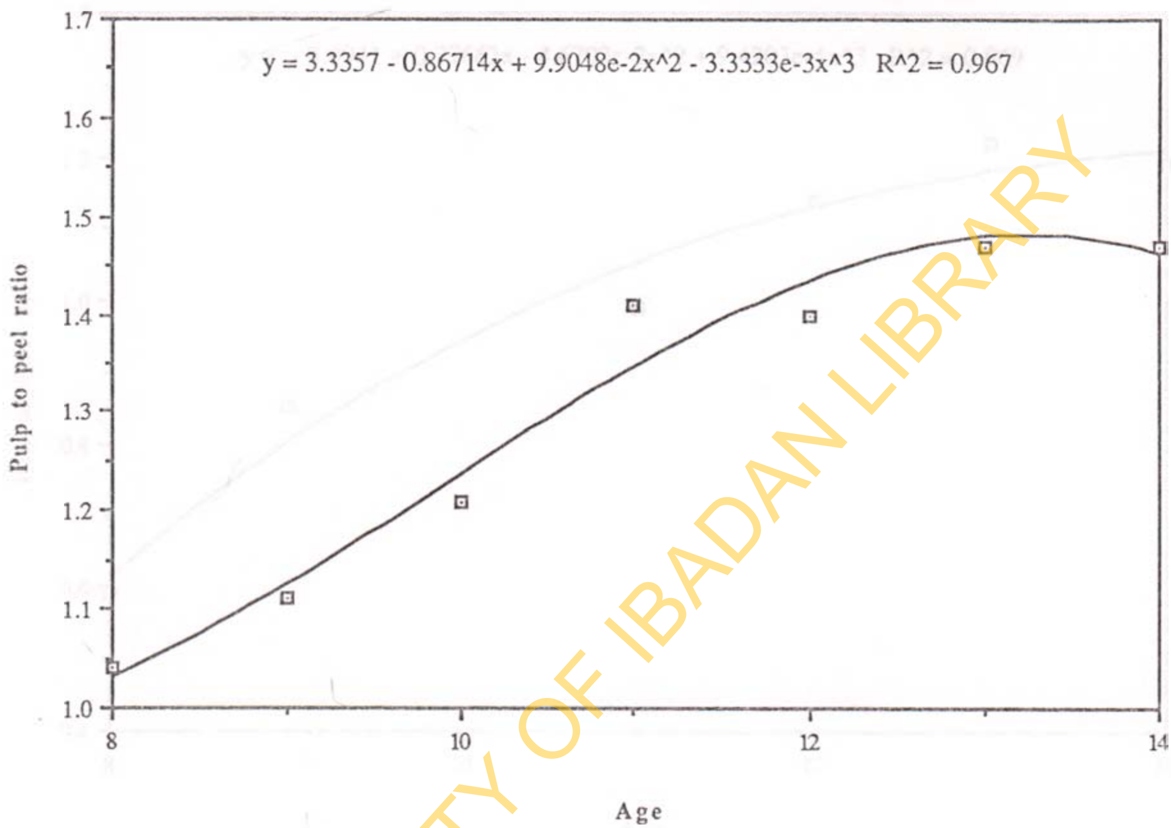


Fig. 11. Graph of maturity at harvest against pulp to peel ratio in the Agbagba cultivar.

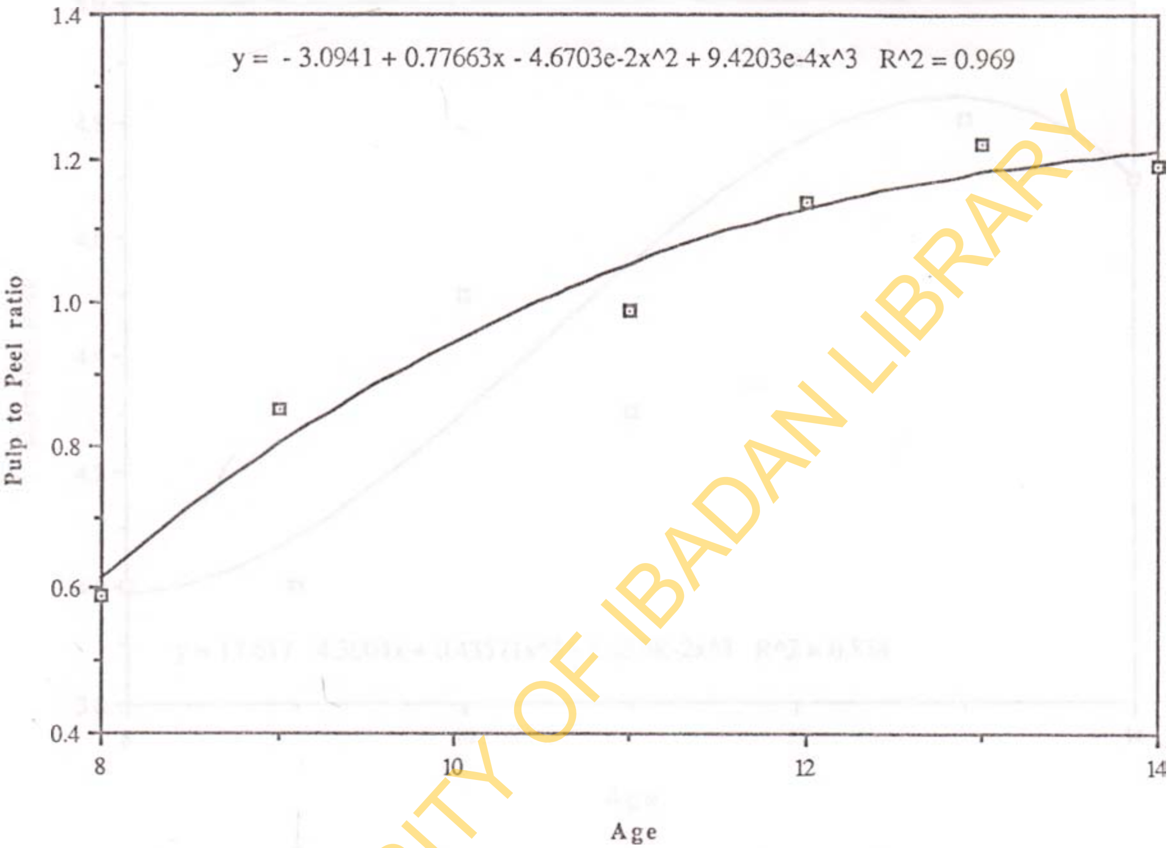


Fig. 12. Graph of maturity at harvest against pulp to peel ratio in the Obino cultivar.

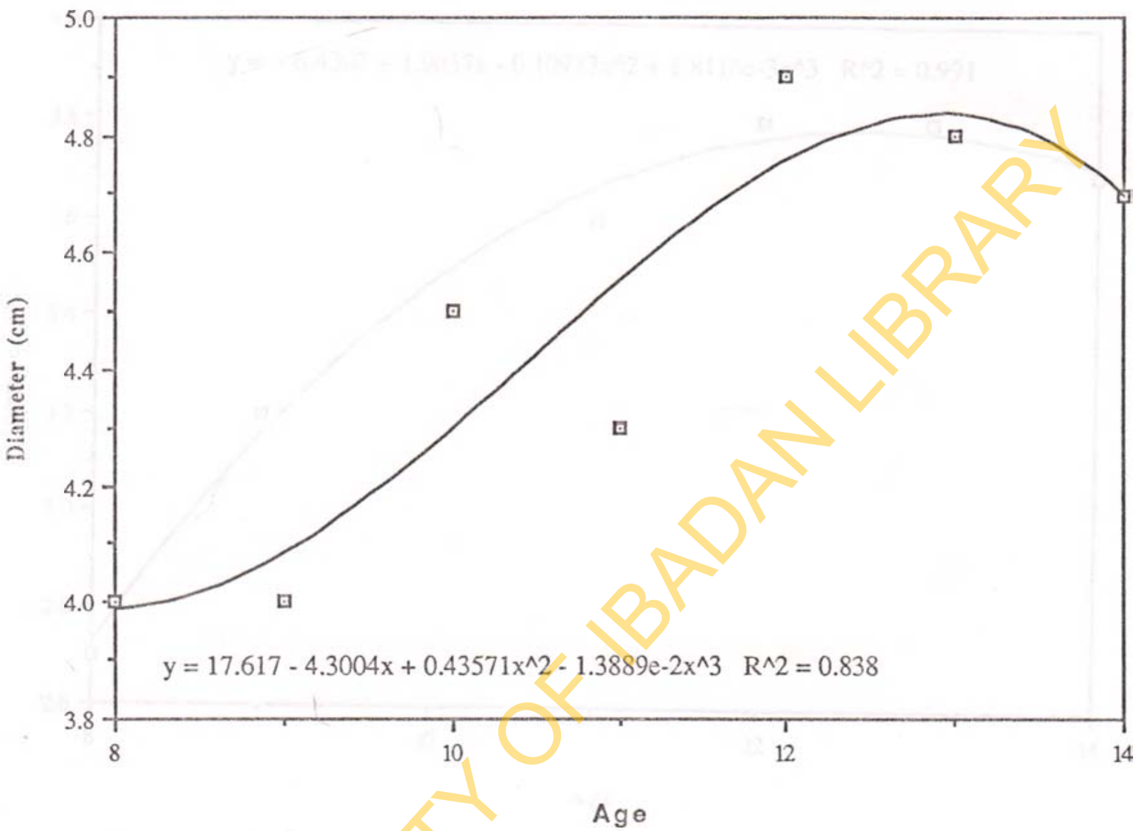


Fig. 13. Graph of maturity at harvest against finger diameter in the Agbagba cultivar.

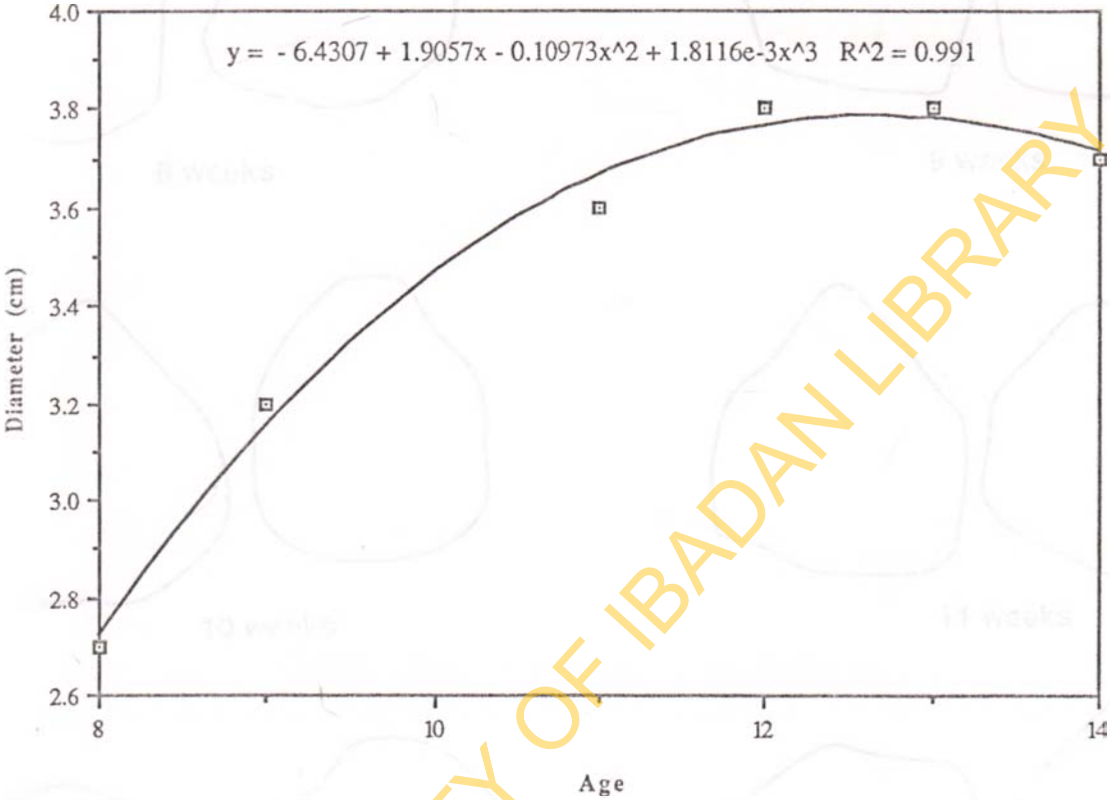


Fig. 14. Graph of maturity at harvest against finger diameter in the Obino cultivar.

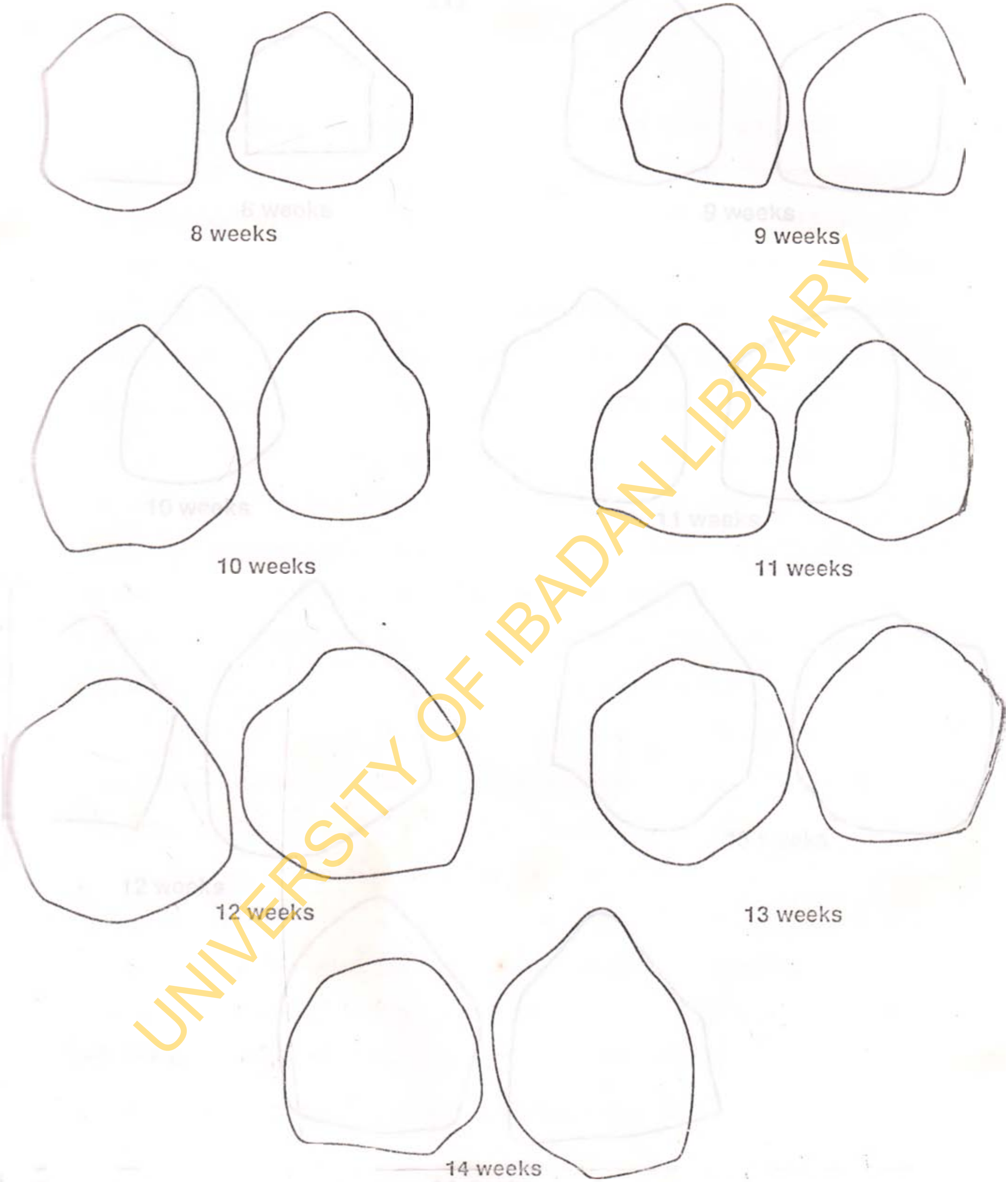


Fig. 5 Changes in the finger diameter of the Agbagba cultivar with the age at harvest

(Maginification x ½)

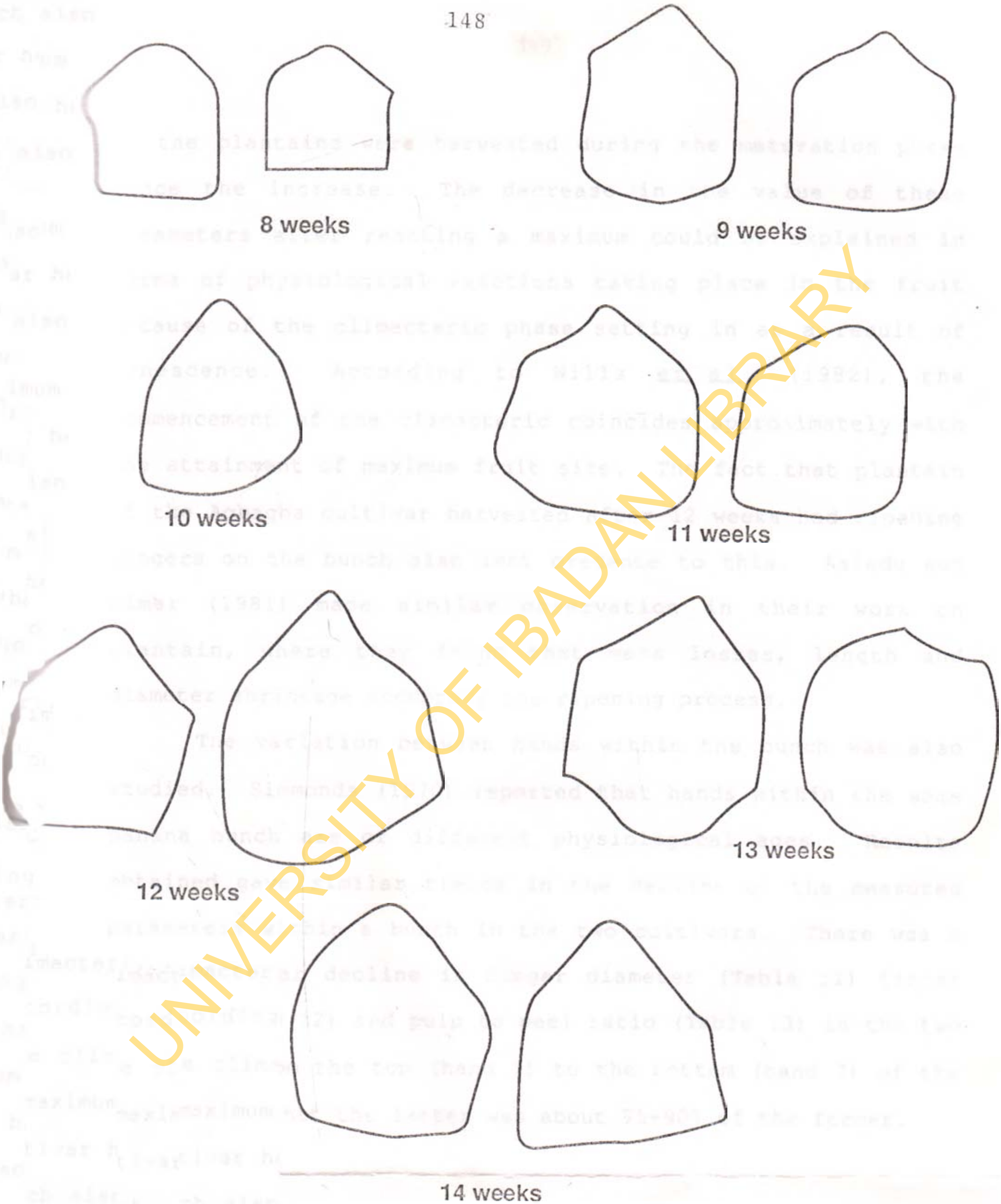


Fig. 16 Changes in the diameter of the Obino Cultivar with age at harvest

(Magnification x ½).

of the plantains were harvested during the maturation phase hence the increase. The decrease in the value of these parameters after reaching a maximum could be explained in terms of physiological reactions taking place in the fruit because of the climacteric phase setting in as a result of senescence. According to Wills et al. (1982), the commencement of the climacteric coincides approximately with the attainment of maximum fruit size. The fact that plantain of the Agbagba cultivar harvested after 12 weeks had ripening fingers on the bunch also lent credence to this. Asiedu and Eimer (1981) made similar observation in their work on plantain, where they found that mass losses, length and diameter shrinkage accompany the ripening process.

The variation between hands within the bunch was also studied. Simmonds (1970) reported that hands within the same banana bunch are of different physiological ages. Results obtained gave similar trends in the decline of the measured parameters within a bunch in the two cultivars. There was a fairly regular decline in finger diameter (Table 11) finger length (Table 12) and pulp to peel ratio (Table 13) in the two cultivars from the top (hand 1) to the bottom (hand 7) of the bunch, such that the latter was about 75-90% of the former.

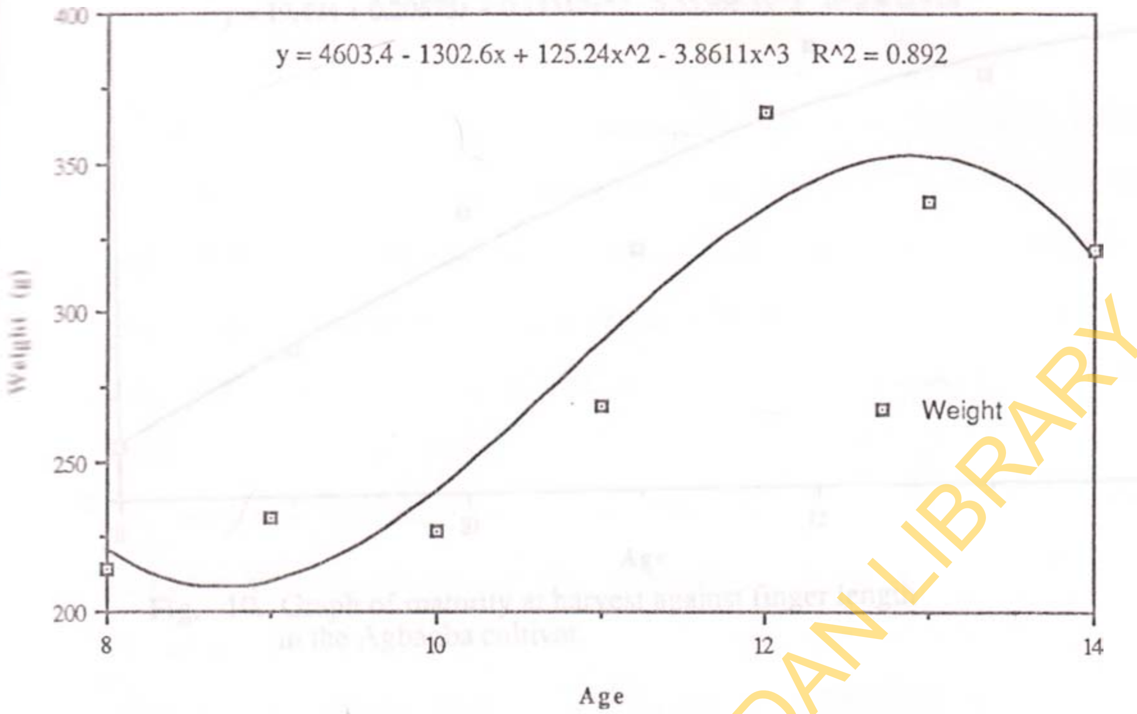


Fig. 17. Graph of maturity at harvest against finger weight in the Agbagba cultivar.

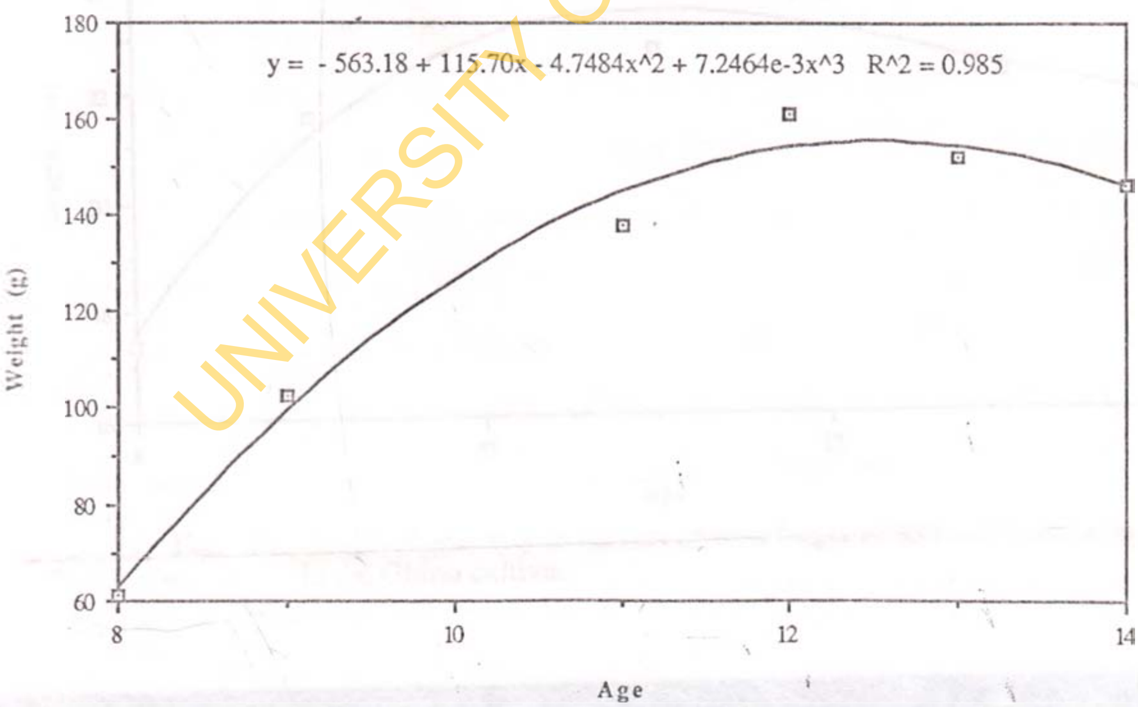


Fig. 18. Graph of maturity at harvest against finger weight in the Obino cultivar.

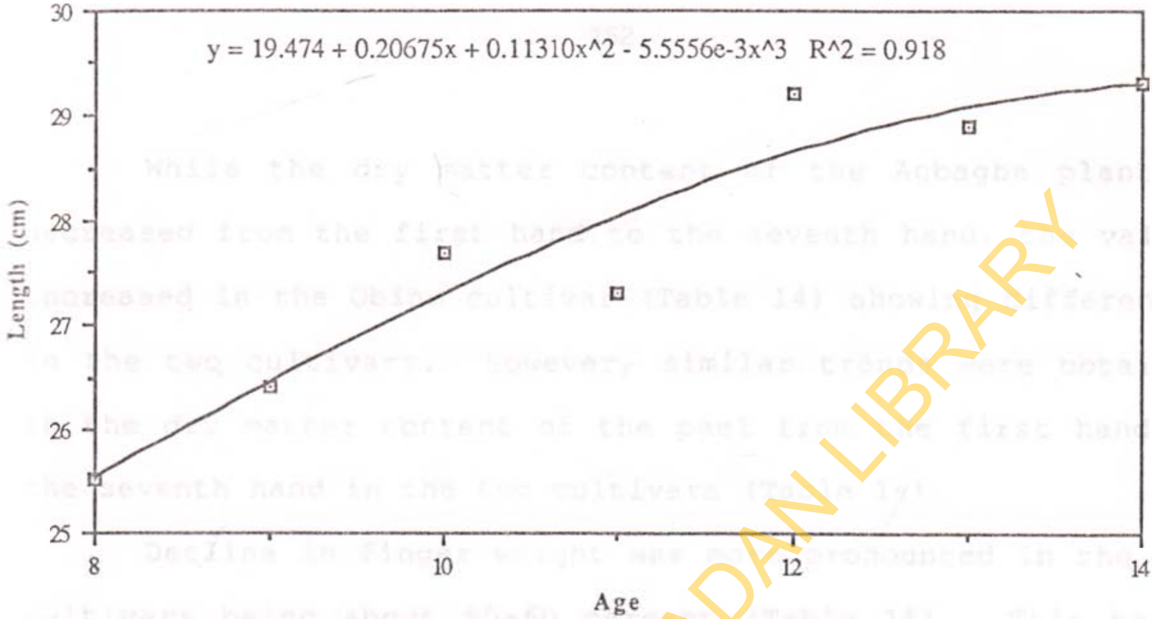


Fig. 19. Graph of maturity at harvest against finger length in the Agbagba cultivar.

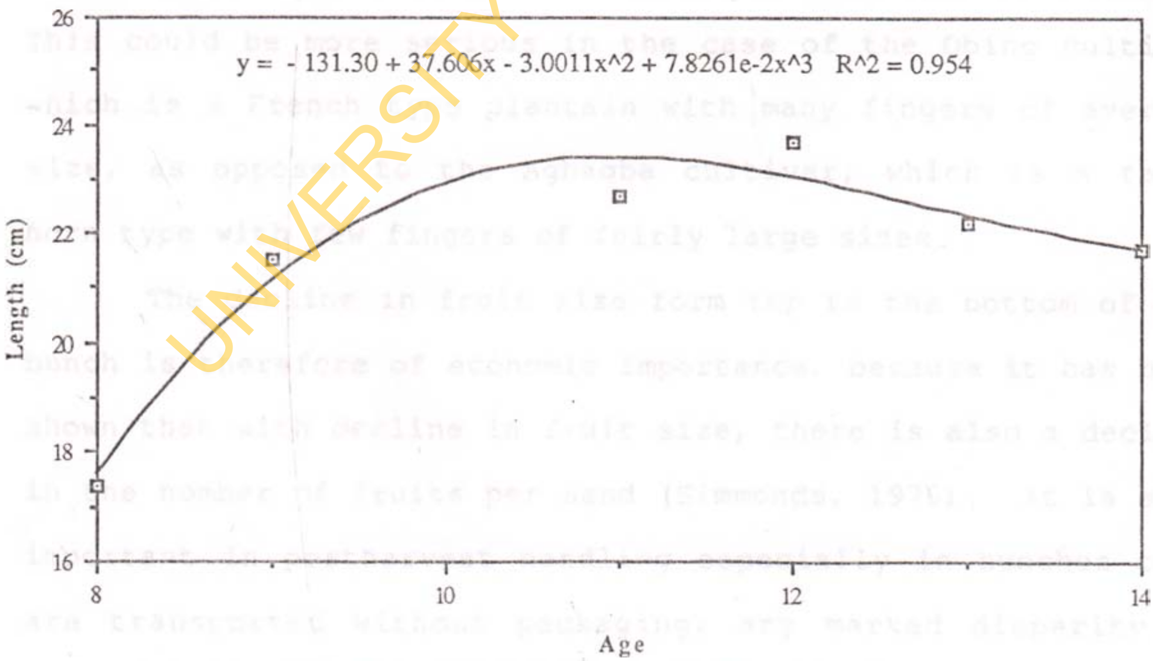


Fig. 20. Graph of maturity at harvest against finger length in the Obino cultivar.

While the dry matter content of the Agbagba plantain decreased from the first hand to the seventh hand, the values increased in the Obino cultivar (Table 14) showing differences in the two cultivars. However, similar trends were obtained in the dry matter content of the peel from the first hand to the seventh hand in the two cultivars (Table 14).

Decline in finger weight was more pronounced in the two cultivars being about 50-60 percent (Table 15). This has a great implication when considering the age at which to harvest plantain. If the plantain is grossly immature, the fruits may be too small to give a reasonable pulp content (Table 16). This could be more serious in the case of the Obino cultivar which is a French type plantain with many fingers of average size, as opposed to the Agbagba cultivar, which is a false horn type with few fingers of fairly large sizes.

The decline in fruit size form top to the bottom of the bunch is therefore of economic importance, because it has been shown that with decline in fruit size, there is also a decline in the number of fruits per hand (Simmonds, 1970). It is also important in postharvest handling especially in bunches that are transported without packaging; any marked disparity in hand size at the big end of the bunch is a disadvantage since it causes assymetry and encourages damage during transportation.

TABLE 11

Finger diameter from different hands of bunches of Agbagba and Obino cultivars harvested at 12 weeks after anthesis.

Hand number	Finger diameter (cm)	
	Agbagba	Obino
1	4.6 ± 0.1	3.8 ± 0.1
3	4.5 ± 0.1	3.4 ± 0.0
5	4.2 ± 0.2	3.4 ± 0.1
7	4.1 ± 0.2	3.3 ± 0.1

TABLE 12

Finger length from different hands of bunches of Agbagba and Obino cultivars harvested at 12 weeks after anthesis.

Hand number	Finger length (cm)	
	Agbagba	Obino
1	28.6 ± 2.5	23.7 ± 0.3
3	27.2 ± 3.0	22.8 ± 0.6
5	24.8 ± 3.2	20.2 ± 0.4
7	21.5 ± 2.5	18.3 ± 0.3

TABLE 13

Pulp to peel from different hands of bunches of Agbagba and Obino cultivars harvested at 12 weeks after anthesis.

Hand number	Pulp to peel ratio	
	Agbagba	Obino
1	1.32 ± 0.19	1.28 ± 0.22
3	1.52 ± 0.20	1.18 ± 0.07
5	1.37 ± 0.14	1.11 ± 0.05
7	1.16 ± 0.15	1.00 ± 0.03

TABLE 14

Dry matter content of the pulp and peel from different hands of bunches of Agbagba and Obino cultivars harvested 12 weeks after anthesis.

Hand number	Dry matter content (%)			
	Agbagba		Obino	
	Pulp	Peel	Pulp	Peel
1	40.1 ± 2.0	11.8 ± 0.5	39.6 ± 0.7	13.8 ± 1.6
3	37.1 ± 1.2	11.6 ± 0.7	39.6 ± 0.7	12.6 ± 1.2
5	38.1 ± 2.7	12.3 ± 0.2	40.1 ± 0.5	13.5 ± 1.8
7	38.5 ± 1.3	11.6 ± 7.0	41.0 ± 0.8	12.1 ± 1.6

TABLE 15

Finger weight from different hands of bunches of Agbagba and Obino cultivars harvested at 12 weeks after anthesis.

Hand number	Finger weight (g)	
	Agbagba	Obino
1	308 ± 46	165 ± 11
3	286 ± 60	140 ± 10
5	245 ± 53	108 ± 8
7	195 ± 51	88 ± 10

TABLE 16

Pulp content from the first hand of Agbagba and Obino cultivars harvested between 8 to 14 weeks after anthesis.

Maturity at harvest (weeks after anthesis)	Pulp content (as percentage of fruit weight)	
	Agbagba	Obino
8	51	37
9	53	46
10	55	-
11	58	50
12	58	53
13	61	55
14	50	54

4.4 CONCLUSION

The results agreed with observations by previous workers (Hedge and Srinivas, 1989) that harvesting at immaturity increases loss through lower fruit weight while late harvesting increases loss through peel splitting. Peel splitting and ripening on the tree was observed in the Agbagba cultivars harvested from 12 weeks after anthesis. This was not observed in the Obino cultivar even at 14 weeks. This suggests that for food preparations where green plantain is most suited, this cultivar will be more ideal.

Pulp to peel ratio, finger diameter, finger weight, and dry matter content in the two cultivars, could all be used as objective means of measuring maturity at harvest in plantain. The measurement of finger diameter could be messy as a result of latex fluid secreted by green plantain. Pulp to peel ratio and dry matter content could be measured in a fairly equipped laboratory with an oven and sensitive weighing balance. Measurement of finger weight and finger length in addition to giving high correlations with maturity at harvest, are very easy to perform, they are also non-destructive and require minor instrument in the case of finger weight and only a tape measure in the case of finger length, they are therefore easier to apply. Simple and rapid measurements of finger weight or finger length of representative samples of plantain would be a useful objective tool to assess and predict their maturity, so that harvesting can be controlled according to finger weight, finger length and bunch age. Also, finger length measurement could be easily carried out in the field. Kader (1983a) reported that numerous objective maturity indices are available for fruits and vegetables, but very few are actually used in practice because they are in most cases destructive and difficult to do in the field or orchard. However, further work is required find out if these criteria are season - specific.

Decline in fruit size within the bunch is of economic importance in terms of pulp content obtained especially in the Obino cultivar. It is also important in plantain handling since it determines the shape of the bunch. The near cylinderical shape of the Obino bunch is an advantage in handling, especially when the bunches are transported without packaging, as it makes stowage easier.

CHAPTER 5

EFFECT OF AGE AT HARVEST ON ORGANOLEPTIC QUALITIES OF PROCESSED PLANTAIN

5.1 INTRODUCTION

Harvested plantains consist of not only mature plantains, but sometimes grossly immature ones, which are sold in the market especially during the rainy seasons as a result of damage by wind. In some other cases, plantains are cut before they are fully mature to prevent pilferage (Chapter 3).

In the previous chapter, the optimum age for harvesting plantain was investigated. Even though most of the maturity indices used such as finger weight, finger diameter were also factors of quality, there are many important quality indices which were not used in determining optimum harvesting stage. In Nigeria, experience show that some plantain have poor eating quality despite good appearance. Showing that the eating quality cannot be accurately determined by the appearance factor alone. According to Kader (1983b) consumers see quality fruits as ones that look good, are firm, and offer good flavour and nutrient value. Although they buy on the basis of appearance and feel, their satisfaction is dependent upon good eating quality. However, no reports are available concerning studies on organoleptic qualities of processed products from plantain based on different maturities at the time of harvesting. From common knowledge, it is known that immature plantain is not as tasty as mature ones.

The purpose of this study was to provide data on the sensory qualities of plantain chips and 'dodo' derived from frying green and ripe plantains respectively, using plantain of the Agbagba cultivar harvested between 8 to 12 weeks after anthesis. Plantain chips is one of the major snacks in Nigeria and 'dodo' is a favourite food prepared from ripe plantain.

5.2 MATERIALS AND METHODS

5.2.1 Cooking procedures

Green plantain fruits of the Agbagba cultivar between 8 to 12 weeks after anthesis were processed into chips. The fruits were peeled into separate containers by hand. They were cut into sizes of about 0.03cm (1/8th inch) thickness. The slices were then fried in vegetable oil. Small samples of about 50g of sliced plantain in about 0.75 L of vegetable oil were fried at a time to minimise temperature drop during the frying process. Frying was carried out at a temperature of about 175°C. The plantain slices were fried to similar colour using slightly different frying duration. A similar approach was used by Timothy et al. (1989) in determining the effect of maturity on flavour of peanuts. Since colour was not one of the quality attributes assessed, it is important that the colour of the samples be as uniform as is practicable. The vegetable oil was topped continuously during the frying process to prevent the oil from charring. The slices were continuously stirred to ensure adequate temperature distribution and to prevent the slices from sticking together. Each treatment was fried separately using fresh oil since oil has a tendency to pick up the flavour of the produce being fried in it, and this might affect the sensory perception of flavour in the different batches.

The chips were allowed to cool before being packaged in polyethylene bags which were heat sealed and labelled with the sample codes made of three digit random numbers.

In the second experiment, ripe plantain fruits between 8 -12 weeks after anthesis were processed into 'dodo'. The fruits were peeled by hand and slices of about 1.5cm thickness were cut perpendicular to the main axis of fruit (Olorunda and Aworh, 1984). The slices were then fried in vegetable oil using a frying pan. Sensory tests were carried out on the coded samples immediately after processing.

5.2.2 Sensory Evaluation

All sensory evaluation tests were conducted using tasting booths in a specially constructed panel room which provided a suitable distraction - free environment. Sensory evaluation tests were carried out on the samples using 10 panelists. The coded samples with questionnaires (appendix

III) were presented to panelists to test for flavour and crispiness in the case of plantain chips, and flavour and texture in the case of `dodo'. Texture was assessed organoleptically as hardness in the case of plantain chip and as softness in the case of 'dodo'. Each panelist evaluated the samples independently. The test was replicated by changing the code at each session.

In the two tests, treatments were compared using the multiple comparison difference test (Larmond, 1977) against a given reference 'R' which is the plantain harvested at 12 weeks after anthesis. Plantain at 12 weeks was chosen as a reference since optimum fruit diameter, length and weight were obtained at this age and harvesting of the Agbagba after this age is undesirable as a result of peel splitting and ripening on the plant (Chapter 3).

The ratings obtained were assigned numerical scores on a nine point scale with 'no difference' equaling 5, "extremely better than R' equaling 9. and "extremely inferior to R" equaling 1 (Larmond, 1977). Treatment means were further subjected to Tukey's test to evaluate the differences between the samples.

5.3 RESULTS AND DISCUSSION

5.3.1 Effect of age at harvest on flavour and crispiness of plantain chips

The flavour and crispiness of plantain chips were significantly affected by the age of the plantain at the time of harvesting at P = 0.05 and P = 0.01 respectively, (Table 17).

The amount of difference in the samples are presented in Table 18. Chips made from fruit harvested at 8 weeks after anthesis were rated inferior in flavour and crispiness to chips made from the reference samples (12 weeks after anthesis) (Table 18). A similar result was obtained by Sanders *et al*. (1989) in their work on peanuts and Tanteeratarm *et al*. (1989) in their work on soy bean seeds. The inferior flavour at immaturity (8 weeks) could be due to the fact that substances that give the characteristic flavour of plantain have not yet fully developed at this

TABLE 17

Analysis of variance table on the sensory evaluation of flavour and cripiness of plantain chips from green plantain harvested between 8 to 12 weeks after anthesis.

Source of variation	df	F- ratio Flavour	F- ratio Crispiness
Samples	3	3.46*	17.53**
Judges	19	1.45	2.68
Error	57		
Total	79		

* Denotes significance at probability level of P = 0.05.

** Denote significance at probability level of P = 0.01.

TABLE 18

Effect of age at harvest on flavour and crispiness of plantain chips.

Age at harvest (weeks after anthesis)	Sensory attributes of plantain chips	
	Flavour	Crispiness
8	3.35c	2.80c
9	4.50b	4.90b
10	4.60b	5.25a
11	5.05a	5.35a

Any two means not followed by the same letter in a column are significantly different (P=0.05) by Tukey's test. Higher values indicate greater preference.

TABLE 19

Analysis of variance table on the sensory evaluation of flavour and texture of 'dodo' from ripe plantain harvested between 8 to 12 weeks after anthesis.

Source of variation	df	F-ratio Flavour	F-ratio Texture
Sample	3	9.69**	1.23
Judges	19	0.96	0.09
Error	57		
Total	79		

** Denotes significance at probability level of P=0.01.

TABLE 20

Effect of age at harvest on flavour and texture of `dodo'.

Age at harvest (weeks after anthesis)	Sensory attributes of 'dodo'	
	Flavour	Texture
8	2.3d	4.8
9	3.1c	4.9
10	3.6b	5.0
11	4.2a	5.0
		NS

Any two means not followed by the same letter in a column are significantly different at (P=0.05) by Tukey's test.
Higher values indicate greater preference.
NS Denotes not significant.

age. According to Marriott (1980), physical changes during maturation relate to the eating quality of the harvested banana when processed in the unripe stage. No reports are available on the flavour profile analysis of plantain. Even the banana, which has been highly researched, has limited information on flavour. Result also showed that the flavour and cripiness of the plantain chips got significantly (P=0.05) better as the plantain became more mature in age (Table 18).

5.3.2 Effect of age at harvest on the flavour and texture of 'dodo'

The fact that plantain harvested as early as 8 week after anthesis could be processed into 'dodo' showed that plantain of the Agbagba cv. harvested at this stage of maturity would ripen to an edible condition. Similar observation has been made in the banana (Barnell, 1941, as quoted by Simmonds, 1970).

The flavour of 'dodo' processed from plantain at different times after harvest were found to differ Significantly (P=0.01) (Table 19), while the age at which the plantain was harvested had no significant effect on the texture of `dodo' (Table 19). Ripening must have taken place in both the mature and immature plantains with the concurrent starch- sugar conversion and tissue softening giving a soft texture in both cases. Therefore there was no significant different in the texture of 'dodo' prepared from mature and immature plantain (Table 20), whereas the sensory perception of flavour of `dodo' prepared from immature plantains scored significantly (P=0.05) lower marks than those prepared from more matured ones (Table 20). Similar results have been obtained by previous workers; Sanders _et al_. (1989) found that immature peanuts had less roast flavour potential than mature ones. Tanteeratarm _et al_. (1989) found that the quality of crude oil from mature soybean seeds was superior to those of immature ones. The reason for the inferior flavour or quality experienced with immature plantain could be due to the fact that the substances giving the characteristic plantain flavour have not been fully developed at this stage.

5.4 CONCLUSION

Maturity at the time of harvesting has been shown to have a major effect on plantain sensory qualities with respect to ripe and unripe fruit. Even though it is desirable to harvest plantain at an 'early' stage for long-distant transportation, plantain of the Agbagba cultivar should not be harvested earlier than 10 weeks for optimum organoleptic qualities such as crispiness and flavour in plantain chips and 'dodo' respectively. This is also important from the standpoint of fruit yield (Table 16 in Chapter 4) since to the processor fruit yield hence product yield is of a great economic importance.

Further work is required to look into the crucial components of flavour and how they may be affected by maturity at harvest and other postharvest handling practices.

CHAPTER SIX

EFECTS OF AGE AT HARVEST, VIBRATION AND PACKAGING ON MECHANICAL DAMAGE

6.1 INTRODUCTION

Improper handling practices, lack of suitable packaging materials and poor transport and distribution systems contribute to post harvest losses in plantain (Chapter 3). At harvest and during transport, the peel of plantain is very susceptible to mechanical injury, the full extent of which are not apparent until the fruit has turned yellow. These losses are difficult to quantify because there are no standard methods of quantification.

A major thrust in this study was in devising a means of measuring mechanical injury in plantain in terms of qualitative and quantitative losses. The methodology developed was to measure the effect of mechanical damage either directly by measuring the area of skin bruising (bruise area) or the weight of pulp trimmed off as a result of pulp bruising (trimming losses). A similar approach had been used for apples by Holt and Schoorl (1981, 1983). Indirectly, mechanical damage was measured by the number of days it took the green-damaged plantains to attain the full yellow çolour, and percentage weight loss since bruising is likely to encourage moisture loss.

In chapter 4, plantain at different ages at the time of harvesting were screened in order to come up with a harvest maturity indicator and the best age to harvest plantain in terms of optimum fruit size. It would therefore be worthwhile to look into the effect of age at harvest and packaging on mechanical damage encountered during transportation and handling. This information on optimum handling conditions for plantain distribution would go a long way in improving the postharvest quality of fresh plantain during physical distribution.

6.2 MATERIALS AND METHODS

The plantains used for this study were Obino cultivar. harvested at 9, 11, 12, 13, 14 weeks and Agbagba cultivar harvested at 8, 9, 10, 11, 12, 13, 14 weeks after anthesis. The bunches were carefully harvested to minimise or avoid bruises and were transported from the field to the laboratory, a distance of less than 1km in a truck. In the laboratory the fruits were dehanded with a knife and separated into fingers by hand. The fruits used for the study were sorted out to ensure uniformity and absence of blemishes as much as was practicable. All the plantains used for the experiment were at the stage 1 green of ripeness on the banana ripening chart (United fruits, 1964).

Packaging materials used were control (no packaging), polyethylene and wooden box. Wooden containers of 7.5 x 20 x 32cm and 6 x 15 x 25cm (inside dimensions) were used for the Agbagba cultivar and the Obino cultivar respectively. The wood was typical of material generally used for packaging containers. The plantain packaged in polyethylene bags with no perforations and tied at the necks were placed in the wooden containers for the vibration test and then subsequently stored in the polyethylene bags until they were fully ripe. The polyethylene bag was used primarily to reduce the frictional force between the wooden container and the fruit thereby simulating a smooth surface and to create a modified atmosphere environment for the fruits during storage.

Three fairly uniform-sized plantain fingers were used at a time in a packaging container. The containers were fitted to the shaker and held in place with bars and nuts during the test. The vibration treatment experienced during transportation was simulated using a shaker (Eberbach, Ann Arbor Michigan) with the speed adjusted to 192 revolutions per minute for 1 hour. Preliminary investigations showed that the damage on plantain during 1 hour vibration time was similar to what obtains in practice. On the above premise, the test condition could be assumed to be a reasonable representation of what would happen in transit. Similar approach was used by Olorunda and Tung (1985).

The experiment was a 7 x 2 x 3 factorial treatment combination in a completely randomized design, using plantain at 8-14 weeks after anthesis 2 vibration treatments and 3 packaging methods for the Agbagba cultivar. and 5 x 2 x 3 factorial treatment combinations using plantain at 9, 11, 12, 13, 14 weeks after anthesis, 2 vibration treatments and 3 packaging methods for the Obino cultivar.

Mechanical damage was evaluated directly by measuring the bruise area and trimming loss and indirectly by measuring the percentage weight loss and ripening days. The plantains were stored after the treatment in the laboratory at a temperature of about 27±1°C. The determinations were made on the individual fingers when the plantain attain the full yellow colour, that is stage 6 on the banana ripening chart (United fruit, 1964). Some of the plantain of the Agbagba cultivar packaged in polyethlene bags developed mouldiness during storage and were subsequently discarded, also the experimental material (plantain harvested at various ages) makes it difficult to use an equal number of replications for all treatments, the unequal replication was taken into consideration in the data analysis. The data were analysed using a statistical analysis system (SAS,1985) package for the analysis of variance and F-test. If the F-test proved significant, Duncan's multiple range test was applied to determine significant differences among treatment means.

6.2.1 Measurement of bruise area (cm^2)

The green plantains were stored at a temperature of about 27±1°C until fully yellow. The yellow plantain was wrapped round a tightly held transparent paper on which the outlines of the bruises were traced out with a pen and then labeled appropriately. The outlines were then cut off from the paper with a razor blade and the area measured using a portable area meter (model L1-3000 AL1-COR).

6.2.2 Measurement of ripening days at 20°C

The basis for this measurement is that mechanical damage decreases the pre-climateric period in plantains (Littman, 1972b). It is therefore expected that the more the effect of the damage on the plantain, the faster it would ripen.

The day of carrying out the treatment was taken as day 1 and the date was recorded for each treatment; the date the plantain attained the full yellow colour was also recorded. The difference between the two dates is the period it took green-damaged plantain to attain full yellow colour and it was recorded as ripening days.

6.2.3 Measurement of percentage weight loss

Mechanical damage was indirectly measured as percentage weight loss because it has been found to accelerate the rate of water loss from a produce (McGlasson, 1970; Littman 1972b; Sitkei, 1986; Jen, 1989). Each lot of plantain was weighed prior to packaging and vibration test and following storage to determine the percentage weight loss. A similar approach was used by Gosselin and Mondy (1989) for potatoes.

6.2.4 Measurement of trimming loss

After weighing the fingers for the determination of weight loss at the ripe stage, the fingers were then peeled and the weight of the pulp recorded. The fingers were examined for under-peel injury which are brownish necrotic tissues (George, 1981) on the pulp. If none was present, trimming loss was recorded as zero, when underpeel injury is present, it was trimmed off and weighed and the trimming loss expressed as a percentage of the pulp weight.

6.4 RESULTS AND DISCUSSION

The fruits used for the simulated transit studies were examined following storage at about 27±1°C, on the days they attained the full yellow colour that is, stage 6 of the banana ripening guide (United Fruits, 1964). Preliminary tests showed that mechanically-induced damage which was not too apparent immediately after the test became more pronounced on ripening. Holt et al. (1983) attributed this to the fact that discolouration of the bruised tissue due to enzyme reaction may take some time, even though bruising occurs immediately. The results are therefore based on measurement taken when the plantain attained full yellow colour.

Signs of mechanical damage such as peel bruising could be seen in almost all treatments, with the severity varying according to the respective treatments. The effects of treatments on mechanical damage, manifested as peel bruising, trimming losses, ripening days and percentage weight loss are presented in Tables 21 and 22.

TABLE 21

Analysis of variance table of the simulated transit tests on the effect of mechanical damage and packaging method on age at harvest in the Agbagba cultivar.

Treatment	df	F-ratio			
		Nature of mechanical damage			
		ripening days	percentage weight loss	Bruise area (cm^2)	Trimming loss (%)
Vibration	1	205.0**	2.2**	46.2*	28.2**
Packaging	2	383.0**	69.4**	36.5**	18.6**
Age	6	309.0**	8.2**	1.1	28.9**
Vib. x pack	2	85.0**	2.0	45.0**	11.4**
Pack x Age	12	69.0**	2.5**	1.2	21.0**
Vib x Age	6	47.0**	1.1	1.1	1.1
VibxPackxAge	12	77.0**	1.3	1.9	1.8

* Denotes significance at P=0.05

** Denotes significance at P=0.01

TABLE 22

Analysis of variance table of the simulated transit tests on the effect of mechanical damage and packaging method on age at harvest in the Obino cultivar.

Treatment	df	F-ratio: Nature of mechanical damage			
		ripening days	percentage weight loss	Bruise area (cm^2)	Trimming loss (%)
Vibration	1	266.0**	41.3**	33.8*	9.8**
Packaging	2	97.0**	73.5**	10.1**	6.7**
Age	4	90.0**	2.6**	4.9**	9.6**
Vib. x pack	2	42.0**	11.5**	15.0**	7.2**
Pack x Age	8	14.0**	2.9**	0.9	6.8**
Vib x Age	4	78.0**	0.5	2.3**	9.1**
VibxPackxAge	8	67.0**	0.1	0.3	10.0**

* Denotes significance at P=0.05

** Denotes significance at P= 0.01

Results showed that ripening days and trimming losses were significantly (P=0.01) affected by age at harvest in the Agbagba cultivar (Table 21). In the Obino cultivar., bruise area, trimming losses, ripening days and percentage weight loss were all significantly (P= 0.01) affected by age at harvest (Table 22).

The results showed that measurement of bruise area was important in aesthetic quality of the plantain cultivars, as it was possible to measure and quantify the unpleasant brownish colouration developed on the peel as a result of mechanical damage through this method.

Measurement of days it took the green plantains to be fully ripened was an important indicator of storage life. An added advantage of this method was the fact that no measuring instrument was required.

Measurement of trimming losses was important in quantitative loss. However, the method is destructive, further work is therefore required to look into non-destructive means of measuring under-peel bruising in plantain as this is an important aspect of plantain quality.

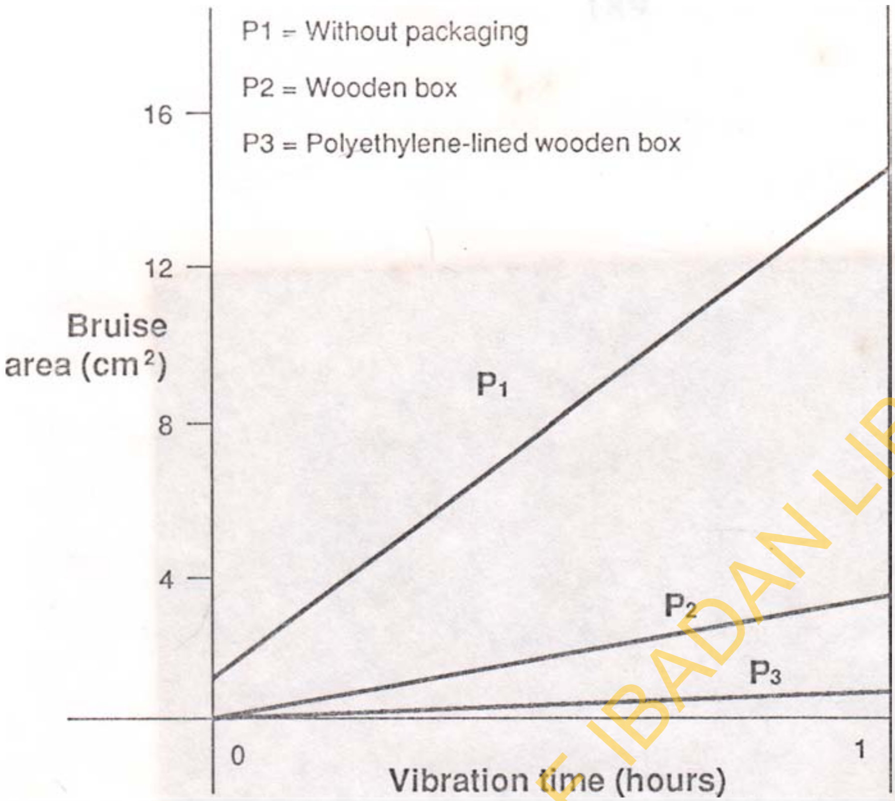
Even though mechanical damage resulted in higher percentage weight losses in the treatments, the hypothesis that percentage weight loss was used as an indirect measurement of quantitative loss since mechanical damage accelerates the rate of water loss from a produce could not be proved conclusively. This is because it was not possible to determine from the experiment the losses actually due to mechanical damage and the losses attributable to normal respiratory process in the plantain as a result of carbohydrate metabolism. Therefore this measurement was more important in aesthetic quality as a result of shrivelling especially in immature plantains.

Although all the parameters measured were different attributes of plantain quality, none of them could be measured immediately after the test, the plantain needed to be stored and ripened first.

6.4.1 Effect of age at harvest and mechanical damage on bruise area

Bruise area was measured as a direct indication of mechanical damage. Peel bruising was not significantly affected by age in the Agbagba cultivar (Table 21). There was also no significant interaction between packaging method and age as well as vibration and age when bruise area was measured as a direct indication of mechanical injury in the Agbagba cultivar (Table 21). Fig.21 therefore, shows the relationship between packaging methods averaged over all the ages and vibration time against bruise area, in the Agbagba cultivar.

Peel bruising in the two cultivars was significantly ($p = 0.05$) affected by vibration experienced during transportation (Table 21 and 22) in agreement with previous workers that vibration experienced during transportation leads to bruising (Mohsenin, 1978; Sitkei, 1986). Peel bruising increased from plantains packaged in polyethylene bags, through wooden boxes to those without packaging in the Agbagba cultivar during vibration (Fig. 21). The reduction in symptoms of bruising on bananas wrapped in polyethylene films could be due partly to the fact that the polyethylene, being typical of a smooth surface greatly reduced the coefficient of friction between the plantain and the wooden



21: Plot of peel bruising against vibration time in the Agbagba packaged with different methods

Plate 5: Bruising increasing from plantains packaged in polyethylene bags, through those in wooden boxes to plantains without packaging (Left to Right).

box. Furthermore, the high humidity around the fingers could prevent damaged areas from drying out and becoming severely necrotic (Silvis et al. 1976). Also, Siriphanich and Kader (1985) found that phenolic production and polyphenoloxidase activity were greatly reduced in the presence of high carbon dioxide concentration.

That maturity at harvest had no significant effect on peel bruising in the Agbagba cultivar could be explained by the fact that dopamine concentration in the banana peel remains fairly constant from the first month after fruit emergence until the initiation of ripening (Palmer, 1971). As enzymes purified from plantain have similar properties as the banana enzyme (Marriott and Lancaster, 1983), and dopamine has been implicated in peel bruising, it is not surprising that peel bruising was not significantly affected by maturity at harvest in the Agbagba cultivar.

Wills and Lee (1989) found that plantains are of high quality when harvested at optimum maturity, but are often subjected to poor handling practice during the transfer from farm to market which result in a loss of quality.

6.4.2 <u>Effect of age at harvest and mechanical damage on trimming losses</u>

Loss of fruit flesh by trimming is a direct cost of mechanical damage (Mohsenin, 1978). The vibration time, packaging method and the age of plantain at the time of harvesting have a significant (P=0.01) effect on trimming losses in the Agbagba cultivar (Table 21) and the Obino cultivar (Table 22).

Packaging in polyethylene gave minimal trimming losses (figs. 22 and 23), probably because bruising was minimal in this treatment.

Trimming losses were significantly (P=0.05) higher at immaturity (8 and 9 weeks) in the Agbagba and Obino cultivars respectively than at the more mature ages, probably because the peel was more tender and could prevent less damage to the pulp. Lowest trimming loss was obtained at 12 weeks in the Obino cultivar (fig.23), bruising was also lowest at this age.

Results generally showed that the incidence of peel bruising (bruise area) is more pronounced in the mechanical damage of plantain than that of pulp bruising resulting in

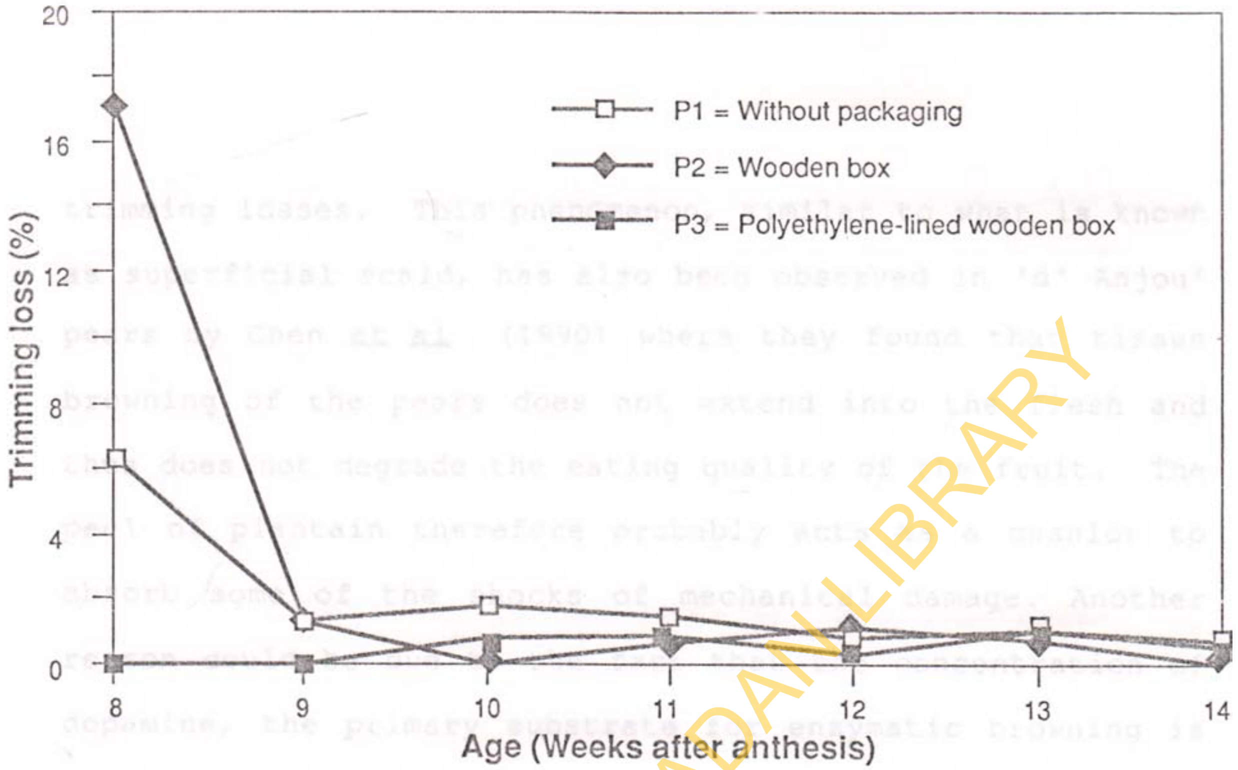


Fig. 22 : Quantity of pulp tissue trimmed off against age at harvest in the Agbagba cv. packaged with different methods

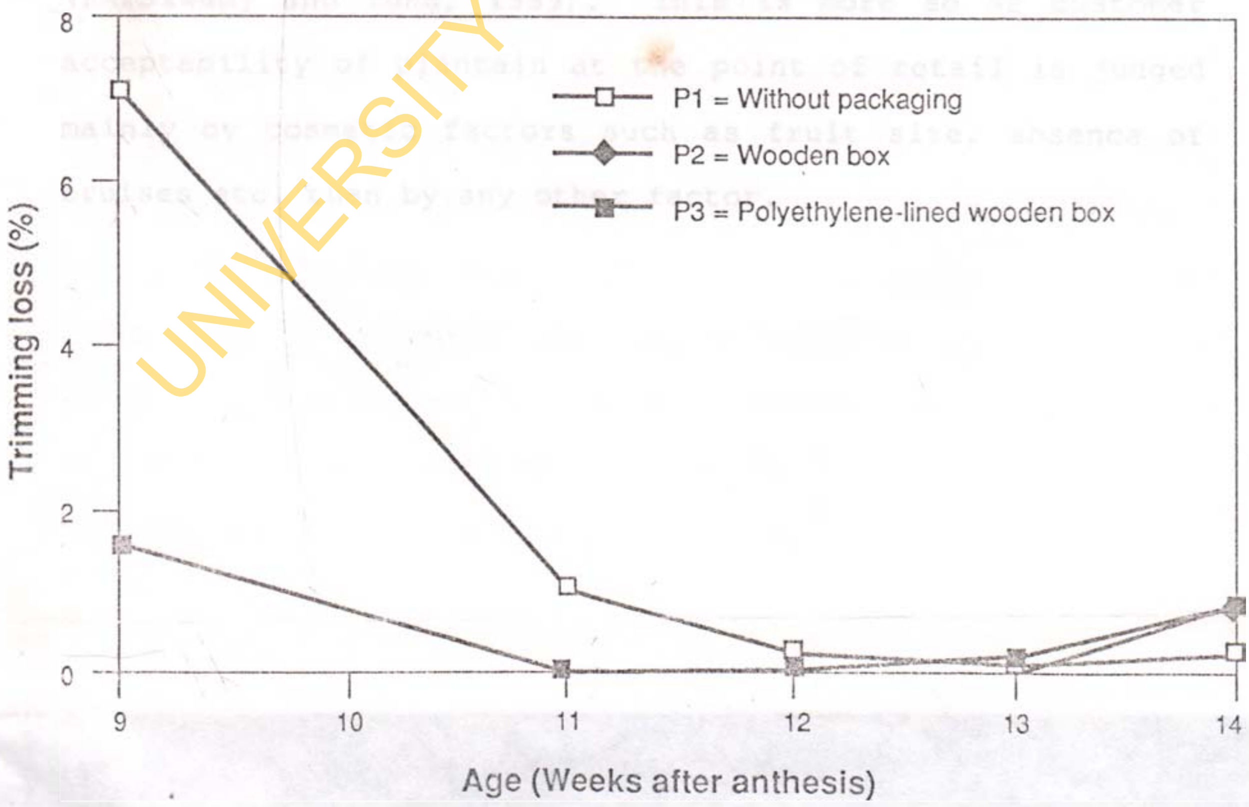


Fig.23 : Quantity of pulp tissue trimmed off against age at harvest in the Obino cv. packaged with different methods

trimming losses. This phenomenon, similar to what is known as superficial scald, has also been observed in 'd' Anjou' pears by Chen et al. (1990) where they found that tissue browning of the pears does not extend into the flesh and thus does not degrade the eating quality of the fruit. The peel of plantain therefore probably acts as a cushion to absorb some of the shocks of mechanical damage. Another reason could be due to the fact that the concentration of dopamine, the primary substrate for enzymatic browning is higher in the peel than in the pulp (Griffiths, 1959). However, peel bruising is no less important as peel colour is one of the parameters used in judging banana quality (Ramaswamy and Tung, 1989). This is more so as customer acceptability of plantain at the point of retail is judged mainly by cosmetic factors such as fruit size, absence of bruises etc. than by any other factor.

6.4.3 Effect of age at harvest, mechanical damage and packaging method on percentage weight loss

Tables 21 and 22 showed that percentage weight loss was significantly affected by vibration, packaging and age at harvest in the Agbagba and Obino cultivars respectively. The analysis of variance table however showed that only the interaction between age and packaging was significant (P= 0.05) when percentage weight loss was measured as an indirect indication of mechanical damage in the Agbagba cultivar (Table 22). Therefore, the means of percentage weight loss for all the ages (8-14 weeks) and the three packaging methods were averaged over the two vibration levels and presented in Table 23.

Tables 23 and 24 showed that there was no significant difference in percentage weight loss at all the ages when the plantain of the Agbagba and Obino cultivars were packaged in polyethylene bags. This is probably because packaging in polyethylene bags eliminates the excessive weight loss normally experienced in fruits and vegetables as a result of immaturity as reported by Wills et al. (1982). The implication of this is that when plantains are harvested

TABLE 23

Effect of age at harvest and packaging method on percentage weight loss in the Agbagba Cultivar[z].

Age at harvest (weeks after anthesis)	Packaging method		
	Weight loss (%)		
	None	wooden box	polyethylene
8	13.6ab	14.9ab	2.01
9	17.4a	20.4a	1.1
10	6.3a	8.7b	1.1
11	9.6b	7.4b	1.0
12	3.4b	5.4b	0.7
13	11.8ab	9.3b	1.2
14	14.1ab	13.3ab	1.6
			NS

[z]Means with a common underline in the same horizontal row do not differ significantly at P=0.05.
Means in the same column bearing different subscripts differ significantly at P=0.05.
NS denotes not significant

TABLE 24

Effect of age at harvest and packaging method on percentage weight loss in the Obino Cultivar[z].

Age at harvest (weeks after anthesis)	Packaging method Weight loss (%)		
	None	wooden box	polyethylene
9	17.7a	22.7a	1.9
11	13.9b	23.4a	1.5
12	13.6b	9.9a	1.9
13	14.0b	10.1b	2.5
14	12.0b	16.8ab	1.9
			NS

[z]Means with a common underline in the same horizontal row do not differ significantly at P=0.05
Means in the same column bearing different subscripts differ significantly at P=0.05.
NS denotes not significant

before full maturity, for transportation to long distances, packaging in polythyelene bags would be an advantage in minimising weight loss due to immaturity. Lowest percentage weight loss was recorded at 12 weeks after anthesis in all the packaging methods in the Agbagba cultivar (Table 23). This is probably because bruising was lowest at this age. Also because plantain at this age is at optimum maturity, ripening days was correspondingly short.

Plantain of the Agbagba and Obino cultivars packaged in polyethylene bags had significantly (P=0.05) lower weight loss than those packaged in wooden boxes or left unpackaged for all the ages (Tables 23 and 24).

No significant difference was found in weight loss between plantains packaged in wooden boxes or left unpackaged for all the ages in the two cultivars (Tables 23 and 24) showing that wooden box is probably not effective in the prevention of weight losses in the two cultivars.

In plantain packaged in wooden boxes during vibration time, percentage weight loss was significantly (P=0.05) higher in immature (8 - 9 weeks) and overmature fruits (14 weeks) than those between 12 and 13 weeks in the two cultivars (Table 23 and 24). Also, the plantains packaged in wooden boxes recorded higher weight losses at these maturities than those packaged in polyethylene bags or those without packaging. Thus immaturity and over maturity result in postharvest losses in quality as a result of percentage weight loss, leading to excessive shrivelling. The result agreed with the observation of Wills et al. (1982) that excessive shrinkage (or weight loss) is due among other things, to immaturity of produce and packing produce together in dry wooden boxes.

6.4.4 Effect of age at harvest, mechanical damage and packaging method on the number of days to full ripeness

In the Agbagba plantains subjected to vibration without packaging, ripening days decreased gradually from 8 weeks after anthesis (16 days) to 12 weeks (6 days) (fig.24) and there was no significant difference in the ripening days from 12 weeks to 14 weeks after anthesis. No significant difference in ripening days was found in plantains left

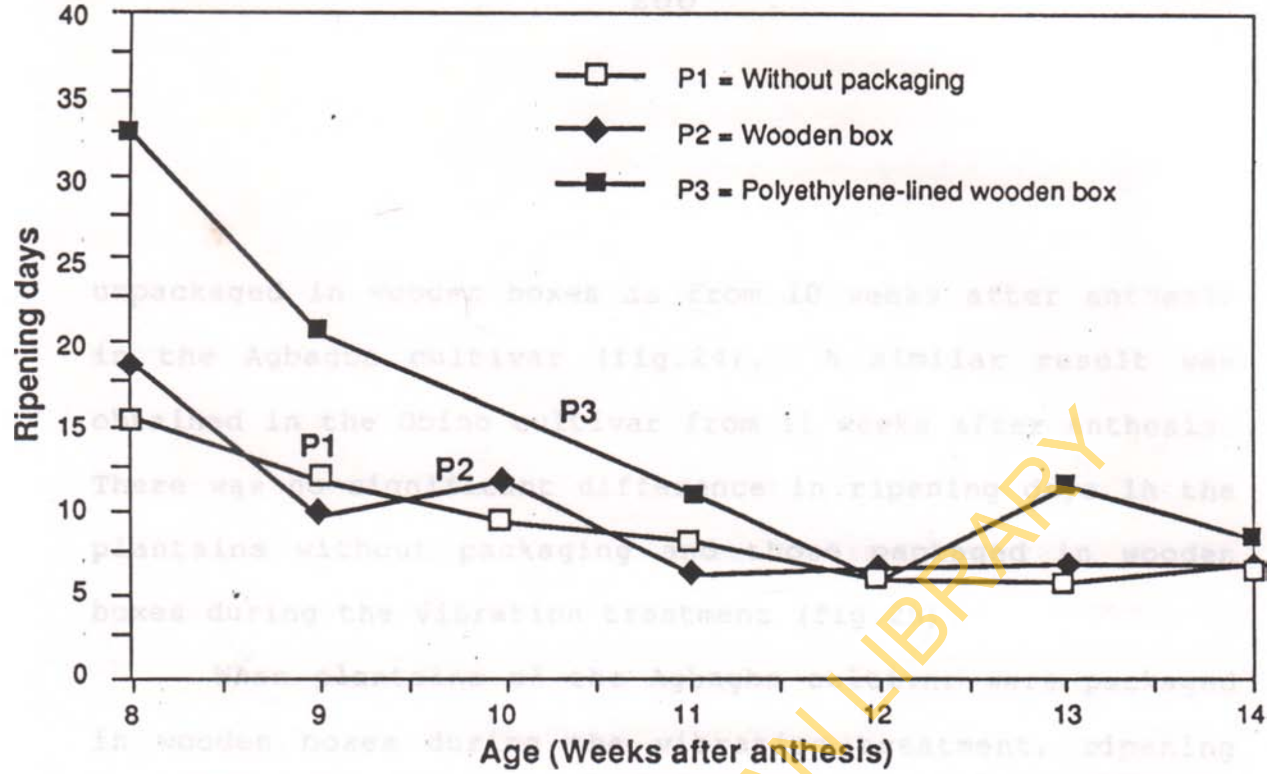


Fig. 24: Number of days it took green - damaged Agbagba plantains, packaged with different methods and harvested between 8 - 14 weeks after anthesis to be fully ripe.

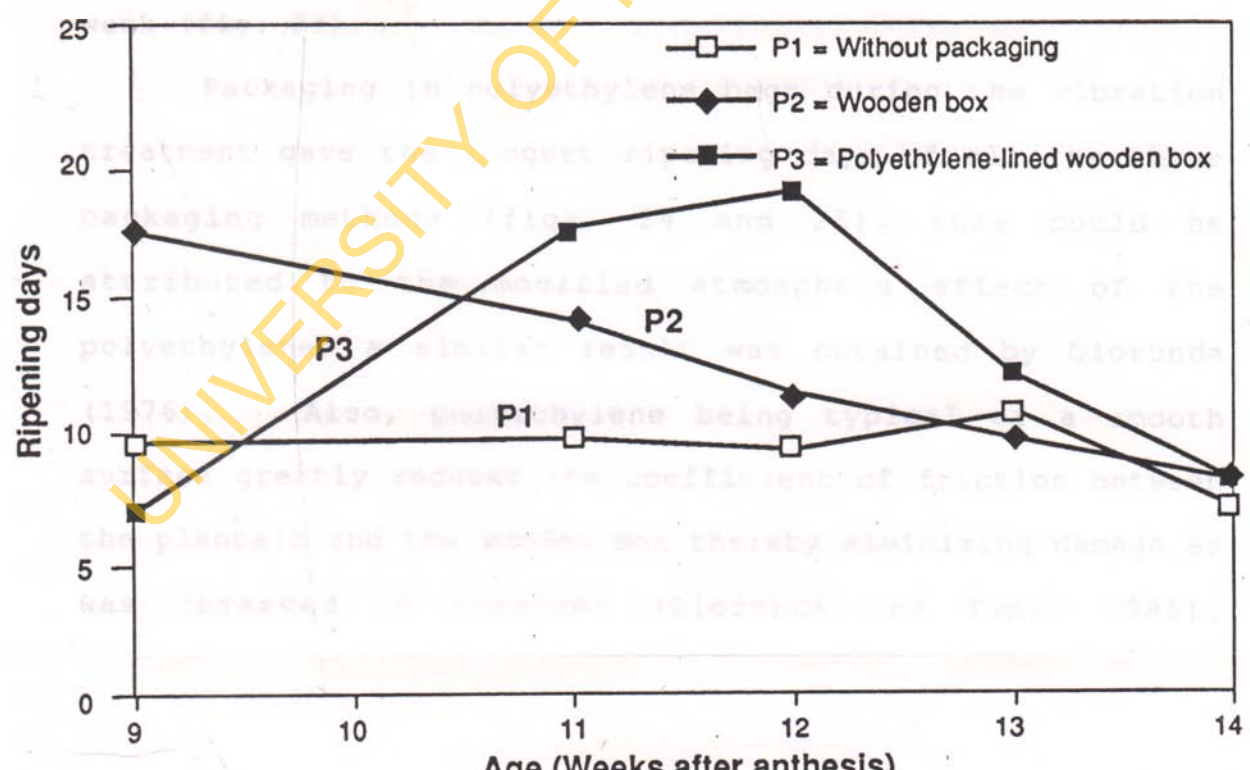


Fig. 25 : Number of days it took green - damaged Obino plantains, packaged with different methods and harvested between 9 - 14 weeks after anthesis to be fully ripe.

unpackaged in wooden boxes as from 10 weeks after anthesis in the Agbagba cultivar (fig.24). A similar result was obtained in the Obino cultivar from 11 weeks after anthesis. There was no significant difference in ripening days in the plantains without packaging and those packaged in wooden boxes during the vibration treatment (fig.25).

When plantains of the Agbagba cultivar were packaged in wooden boxes during the vibration treatment, ripening days decreased significantly (P=0.05) with increasing age at harvest from 8 weeks to 11 weeks and remained fairly constant as the age at harvesting increased from 11 to 14 week (fig. 24).

Packaging in polyethylene bags during the vibration treatment gave the longest ripening days of all the three packaging methods (figs. 24 and 25), this could be attributed to the modified atmosphere effect of the polyethylene; a similar result was obtained by Olorunda (1976). Also, polyethylene being typical of a smooth surface greatly reduced the coefficient of friction between the plantain and the wooden box thereby minimizing damage as was observed in tomatoes (Olorunda and Tung, 1985).

However, because of the moisture retained in the polyethylene bags some of the plantain of the Agbagba cultivar developed slight surface mould growth. Such treatments were discarded prior to analysis. A similar observation was made by Fuchs and Temkin-Gorodeiski (1971) in their work on bananas.

Ripening days at one hour vibration time was significantly (P=0.05) higher in treatments packaged in polyethylene bags than in those left without packaging or those packaged in wooden boxes in the Agbagba cultivar at all the ages except at 12 weeks (fig.24). In the Obino cultivar, there was no significant difference in the ripening days in all the packaging methods from 12 weeks after anthesis. The implication of this is that when plantain is to be transported from the farm gate to not too distant areas, the most economical means of transporting the plantain could be utilised when it is harvested at 12 weeks in the Agbagba cultivar or from 11 to 13 weeks in the Obino cultivar. However, for longer distances, plantain, must be harvested at earlier ages to prevent ripening in-transit. The plantain should be cut at a more mature age e.g. at 11 weeks instead of 9 weeks after anthesis and then packaged in polyethylene-lined wooden boxes during transportation. In the Obino cultivar packaged in polyethylene, ripening days was significantly (P=0.05) lower in immature plantain (9 weeks) and overmature plantain (14 weeks) than those harvested from 11 weeks to 13 weeks after anthesis (fig. 25). This may be due to the fact that at these stages (immaturity and over maturity) the plantains are highly susceptible to mechanical damage, the effect of which could not be effectively removed by packaging in polyethylene.

6.5 CONCLUSION

Plantains packaged in polyethylene bags and placed in wooden boxes during the simulated transit studies gave the best quality on ripening, than those packaged in wooden boxes, or those left unpackaged.

Lowest bruising and percentage weight loss were obtained in 12 week fruits of the Agbagba cultivar. In the Obino cultivar, lowest bruising was also obtained at 12 weeks and there was not much difference in the susceptibility to bruising, trimming losses and percentage weight loss in the plantain harvested between 11 - 14 weeks. Plantain of the two cultivars harvested 'early' (8-9 weeks) are much more apt to bruising and shrivelling during transportation and also under-peel bruising, hence, trimming losses were more pronounced at these stages than at later stages.

Under-peel bruising in the plantain cultivars was found not to be directly proportional to bruising on the peel, care must therefore be taken not to over-emphasize appearance quality as is somewhat done in developed countries as reported by Kader (1983b). A fruit that has some bruises on the peel may have none on the pulp.

The methodology developed in measuring qualitative and quantitative losses in plantain showed that the measurement of bruise area on the peel was important in aesthetic quality, measurement of percentage weight loss of the fruit was more important in aesthetic quality; as a result of shrivelling, especially in immature plantains than in quantitative losses. Measurement of trimming losses on the pulp, even though destructive was very important in determining quantitative losses. Measurement of days it took the green plantain to be fully ripened was an indication of the storage-life, it also had an added advantage of not requiring instrumentation. All the parameters are therefore different attributes of quality, however none could be measured until the plantains were ripe, since the parameters manifest better after storage. These methods, with some modifications to suit the commodity, could also be used for other horticultural produce.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

This study was undertaken to evaluate the social and technical factors in the postharvest handling system of plantain in Nigeria, which results in losses in quality ad quantity, and to prescribe alternative solutions to plantain handling. To establish the causes of these losses, primary data on postharvest handling practices of plantain was obtained from the operators of the system. The survey revealed that absence of standardized maturity index, the use of inefficient and very often inappropriate packaging containers, leading to both mechanical and physiological damage to the produce during handling and transportation are some of the major technical causes of postharvest losses and poor quality plantain in the marketing system. In the light of the above, two cultivars of plantain; Agbagba, a Falsehorn type and Obino l'ewai, a French type, were examined for physical characteristics that could be used for harvest maturity index. Also methodology for measuring qualitative as well as quantitative losses was developed.

In addition, the optimum handling conditions for distribution and for the processing outlets were established for these two cultivars.

1. The work showed that measurement of pulp to peel ratio, fruit weight, fruit diameter, fruit length in the two cultivars, as well as dry matter content of the pulp and peel in the Obino cultivar only, could be used to determine harvest maturity in plantain because they gave highly significant positive correlations with maturity at harvest. Apart from this, measurement of fruit weight and fruit length have a greater advantage in that they are simple and non-destructive, the latter could also be easily carried out in the field or orchard.

2. The work showed that it is undesirable to harvest plantain of the Agbagba cultivar anytime later than 12 weeks after flowering, as this often lead to splitting

of the peel and ripening of the fruit on the plant. This phenomenon was however not observed in plantain of the Obino cultivar, even when harvested at 14 weeks, showing that the Obino cultivar is late - maturing compared to the Agbagba cultivar.

3. In this work, a new methodology for measuring qualitative and quantitative losses in plantain was developed, where measurement of bruise area on the peel and percentage weight loss of the fruit were associated with the assessment of aesthetic quality. Measurement of trimming losses on the pulp was a good indication of the quantitative losses, while measurement of the number of days to full ripeness was an indication of the storage life in the two cultivars.

4. The study showed that immature plantain fruits inn the two cultivars are more susceptible to shriveling and under-peel bruising leading to trimming losses, than mature fruits during transportation. Lining the

packaging containers with polyethylene reduced the damage significantly.

5. The work showed that bruising on the peel does not necessarily lead to corresponding bruising on the pulp, which is generally discarded as trimming losses during processing. In down - grading, undue emphasis should therefore not be placed on this parameter as it is the case with banana in the international trade.

6. Textural quality and flavour are affected by the stage of maturity of the plantain at the time of harvest, in that chips and 'dodo' prepared from immature plantain scored significantly lower points in terms of texture and flavour than mature ones. Even though it might be adviseable to harvest plantain at an immature stage in order to extend their green-life as is always the, it is clear from this work that this would be at the expense of quality. Care must therefore be taken not to unduly compromise the eating quality as this ultimately, is the most important factor to the consumer.

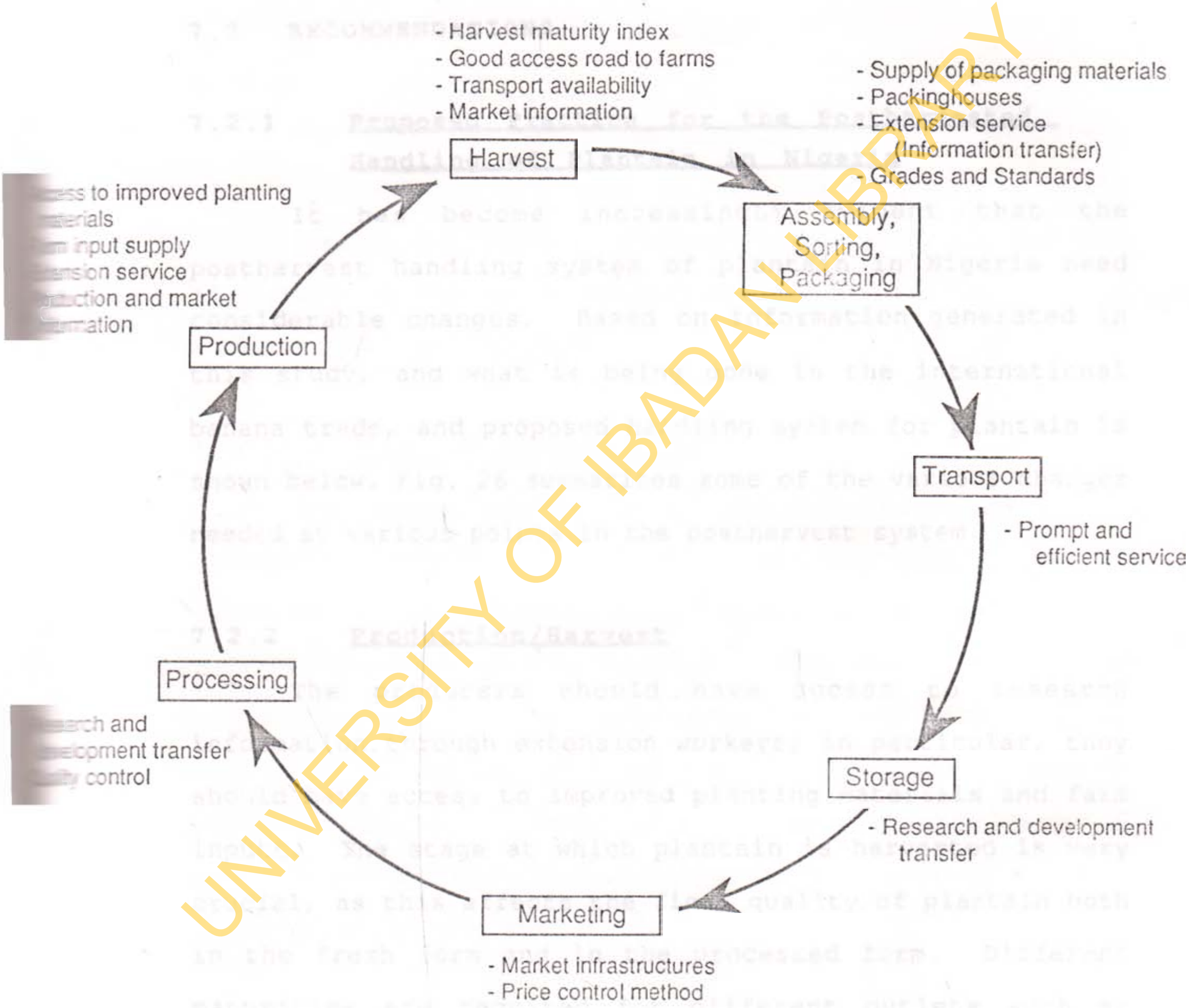


Fig.26 : Facilitating services to overcome physical and economical losses at distinct points in the Commodity System.

7.2 RECOMMENDATIONS

7.2.1 Proposed Practice for the Postharvested Handling of Plantain in Nigeria

It has become increasingLY evident that the postharvest handling system of plantain in Nigeria need considerable changes. Based on information generated in this study, and what is being done in the international banana trade, and proposed handling system for plantain is shown below. Fig. 26 summarises some of the various changes needed at various points in the postharvest system.

7.2.2 Production/Harvest

The producers should have access to research information through extension workers; in particular, they should have access to improved planting materials and farm inputs. The stage at which plantain is harvested is very crucial, as this affects the final quality of plantain both in the fresh form and in the processed form. Different maturities are required for different outlets such as storage, processing, transportation. This thesis has made available relevant information which have hitherto been non-existent.

The treatment which the produce receives immediately after harvest is a major factor contributing to its deterioration in quality. Plantain should be collected from the field in suitable containers and not allowed to be exposed to direct sunlight.

7.2.3 Lack of information

The human element in postharvest handling is of tremendous importance. This thesis has shown how the decision of the various participants in the postharvest system affect plantain quality. The participants and intermediaries in the postharvest system have limited knowledge or no appreciation for the need for or how to maintain quality. Therefore effective extension services are required for information dissemination to the participants of the system.

7.2.4 Supply of packaging materials etc.

It is important that the tools which would enable the participants to use recommended technology for a given situation be available to them. Tools such as packaging materials, special knives for cutting plantain etc. could be manufactured locally and purchased by the cooperatives for common usage.

7.2.5 Grades and standards

Mandatory minimum quality standards for plantain must be established and legislated. Grades and standards are developed to identify the degrees of quality in the various commodities which aid in establishing their usability and value (Kader, 1983b). Information contained in this thesis and the methodology developed for measuring plantain quality would be of tremendous use in this area. It is also believed that the establishment of grades and standards would motivate the producers and other participants in the system to better handling practices, hence better quality plantain. In order to meet the demand of a constant high and reliable quality in terms of size, colour of plantain etc. the operation of an efficient packinghouse is required as illustrated on Fig. 27.

The produce is received at a centrally-located collection centre in the area of plantain production. This would involve an organization, preferably a cooperative. The plantain should be placed on tables and dehanded (separation of the hands from the stalks) with a special knife that is not pointed at the edge. The fingers are then separated by hand. The plantain should then be washed to remove dirts and latex stains, fungicidal could be incorporated into the water for those to be stored or those intended for long transportation period to distant markets e.g. export markets. In small-scale operations, fungicides treatment can be carried out by dipping using a thoroughly homogenized suspension of fungicide or by spraying with a knapsack.

Selection for quality and size in small-scale operations is best done by usually human eye and by hand

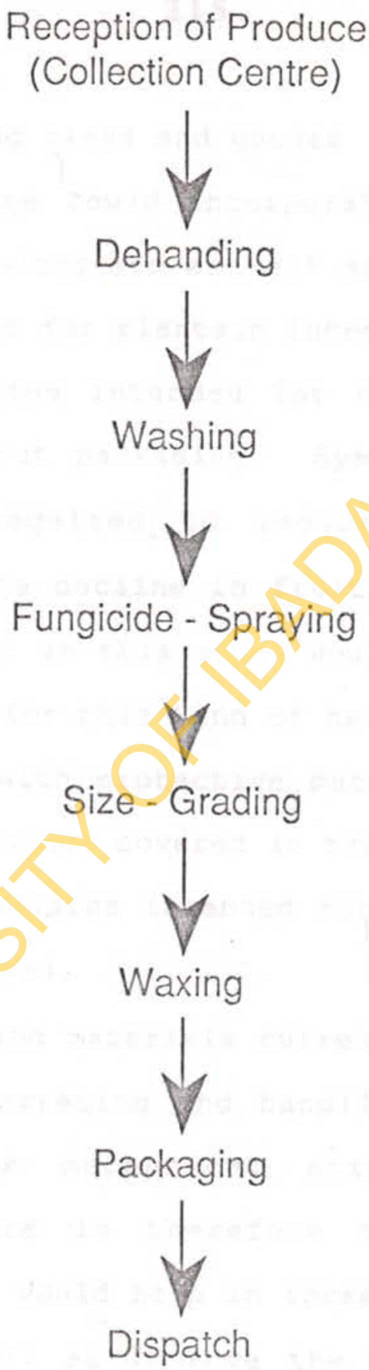


Fig. 27 : Proposed packinghouse operation for Plantain

assisted by sizing rings and guages.

Waxing stage could incorporate the use of chemicals such as Tal - prolong etc as well as controlled or modified atmosphere storage for plantain intended for storage.

The plantains intended for nearer markets could be transported without packaging. Systematic stacking within the lorry is required to reduce the transit damage, Measurement of the decline in fruit size within the bunch, as was carried out in this study would give an indication of cultivars suited for this kind of handling. Also, the lorry should be lined with protective materials such as plantain leaves and the produce covered in transit to protect it from the weather. Plantains intended for distant markets should however, be packaged.

The packaging materials currently in use are more for convenience in marketing and handling than for protection since they lack mechanical strength and structural integrity. There is therefore the need for improved containers, which would help in increasing the efficiency in the system as well as improve the quality of the produce reaching the consumer. However, improved containers are very often expensive and the operators need to use this expensive container several times before it could pay its way, which would further raise the cost of plantain. However, if this is done in a returnable fashion, the cost could be lessened. For instance, according to Sayers (1984), the traditional containers of timber and jute used in Australia, have, during the last 20 years been largely replaced by improved containers. The same principle has been adopted in the Southeast Asian countries, within an organization framework requiring different approaches namely; the captive systems, the restricted pool systems and the unrestricted pool systems.

In captive systems, containers are kept wholly within set limits. This may be a well-defined location such as produce market or an organization such as a retail chain. The high level of control possible under these circumstances minimizes the risk of their improper use. However, effectiveness is reduced if produce must be transferred from other containers at the system interface.

With restricted and unrestricted pools, the containers are able to pass between the various parties of the

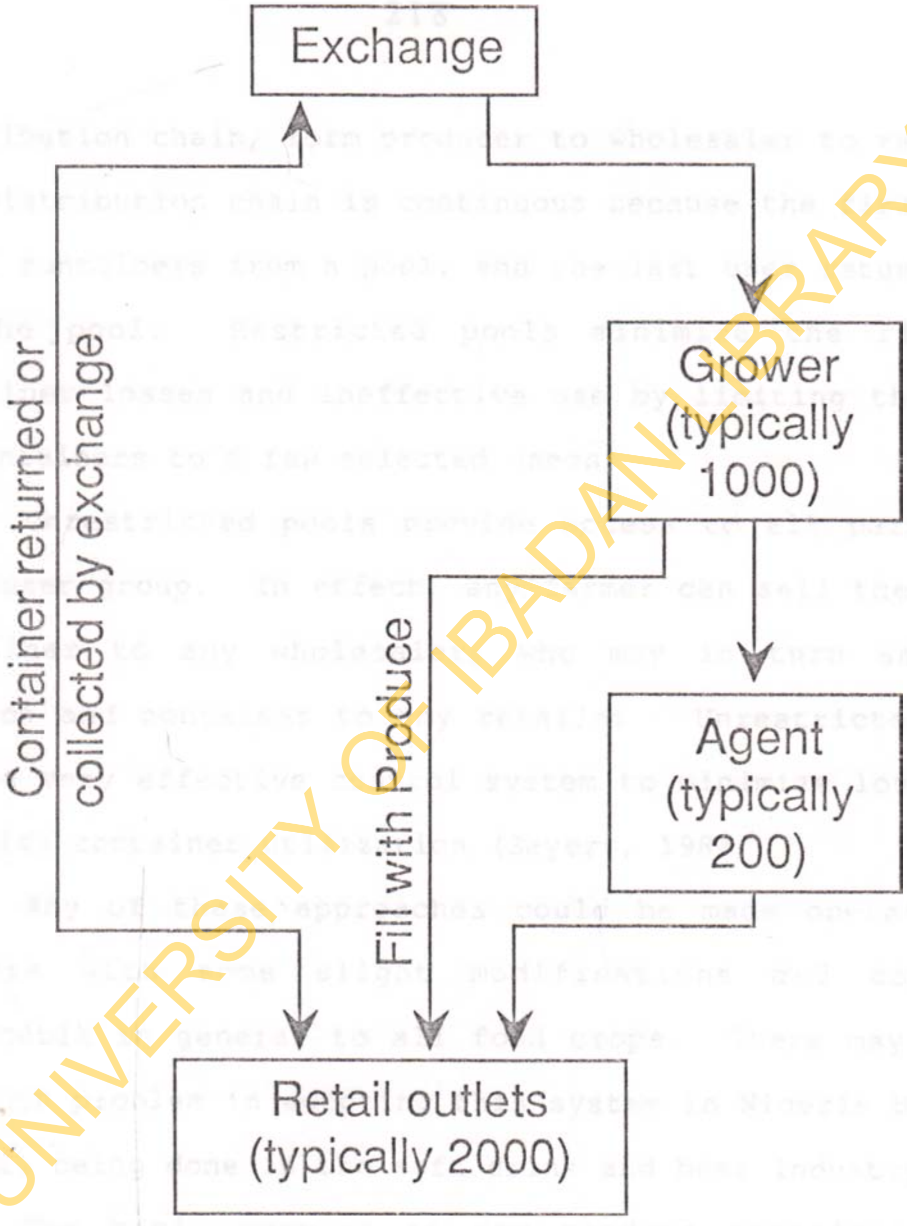


Fig. 28: Unrestricted pool charging set fee per use.

Source (Wills and Lee, 1989)

distribution chain, form producer to wholesaler to retailer. The distribution chain is continuous because the first party draws containers from a pool, and the last user returns them to the pool. Restricted pools minimize the risks of container losses and ineffective use by limiting the issue of containers to a few selected users.

Unrestricted pools provide access to all parties in each user group. In effect, any farmer can sell the filled container to any wholesaler, who may in turn sell the produce and container to any retailer. Unrestricted pools need a very effective control system to minimize losses and optimize container utilization (Sayers, 1984).

Any of these approaches could be made operative in Nigeria with some slight modifications and could be applicable in general to all food crops. There may not be too much problem in adopting this system in Nigeria based on what is being done in the soft drink and beer Industry now.

The basic purpose of any produce container is to facilitate delivery of the product in sound condition to the buyer. Returnable containers can offer opportunities for both improving product quality and reducing packaging costs, the container must therefore protect the produce from mechanical damage and facilitate temperature management and other treatments which may be necessary. The use of wooden containers lined with polyethylene is worth examining, thus taking advantage of the smooth - surface, which would minimize friction between the produce and the walls of the container and at the same time create a modified atmosphere for the extension of storage life.

The economic viability of using returnable containers is largely dependent on achieving a service life well in excess of that obtained by traditional containers (Appendix V). However, this is a social problem rather than technical, and it depends on limiting losses which could result from pilferage, carelessness or damage. Also, users of returnable containers must accept some financial responsibility for those units in their possession.

7.2.6 Transport

Transport vehicles suited for proper transport of horticultural produce are required. Majority of the traders have small holdings and cannot acquire their own transport.

Marketing organizations and cooperatives could acquire transport vehicles which could be loaned out to traders. Road conditions in Nigeria are slowly improving, but much work is required to educate the drivers on improved handling practices.

7.2.7 **Storage**

Several work has been done on preservation of plantain in the fresh form by the use of chemicals such as TAL - prolong (Olorunda and Aworh, 1984) or controlled or modified atmosphere (Scott and Gandanegara, 1974; Olorunda, 1976; Ndubizu, 1976). However, these technologies even though available, are not utilised, because of the unit value of plantain, they may not be economically feasible as at now.

Processing into more stable products such as plantain flour or chips should be encouraged. Storage in the fresh form could be carried out in the form of cooperative storage in centrally-located packing houses, this is further discussed later.

7.2.8 Marketing

Because of the present level of traditional plantain production, which is characterised by scattered, small-scale holdings, marketing cooperatives should be encouraged among producers and traders. The advantages of such cooperatives include; provision of a central collection centre for plantain, where packinghouse operations could be carried out to benefit from improved handling technologies such as sorting, grading and storage prior to distribution through the marketing channels. The cooperatives should purchase equipment needed for improved handling such as packaging materials etc. in large quantity. This arrangement would also facilitate transportation to the markets and provide common selling unit for the members thus, coordinating the marketing programme with equitable profit distribution.

The wholesale and retail markets are in desperate need in terms of facilities and sanitation.

7.2.9 Processing

Research into various forms of plantain processing to obtain shelf-stable products of uniform quality is highly desirable. Processing plants should be located in production areas to minimize the problems and costs of transporting fresh produce which is bulky and fragile.

No technology has yet been developed which can completely stop food deterioration either in the fresh or processed form. Consequently, once food enters the postharvest state, it begins a process of continuos deterioration, and the success of the food distribution depends greatly on the effectiveness of the marketing system and the methods used to reduce the speed of the deterioration processes.

Finally, information contained in this thesis should be useful in the production of produce data handbook for plantains, especially in the area of handling. Further work is required on the cost of improved handling system in relation to produce price and to come out with suggestions to make the system cost-effective.

CHAPTER EIGTH

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APPENDIX I

QUESTIONNAIRE FOR THE POST-HARVEST HANDLING OF PLANTAIN

Date of interview.............

Questionnaire Serial No.......

1. Village .... LGA .... State ....
2. Sex: Male [ ] Female [ ] Name: ....
3. Occupation ....

PRODUCTION INFORMATION

4. Do you plant plantain? Yes [ ] No [ ]
5. Where? Homestead [ ] on the farm [ ]

   Others (specify) ....
6. What is the hectarage of your plantain farm?.........
7. Do you plant other things on your plantain plot?

   Yes [ ] No [ ]
8. If yes, what? (i).............. (ii) ....

   (iii)......... (iv) ....

   (v) ....
9. What variety(ies) of sucker do you plant?

Traditional [ ] Any [ ] Improved [ ] Don't know [ ]

10. Do you think the plantain fingers are bigger in the past two years? ....

YEAR	DRY SEASON		RAINY SEASON	
1987	1	2	1	2
1988	1	2	1	2

1 = Yes 2 = No

11. Do you use traditional method of farming i.e. hoes, cutlasses, etc.? Yes [ ] No [ ]

12 What other method of farming apart from (ii) above do you use? Fertilizer [ ] Pesticides [ ]

13. What principle governs the time you harvest your plantain?

No other food available [ ] Financial need [ ]

When you feel like [ ] When it is mature [ ]

Others (specify) ....

14. How do you know when your plantain is ready for harvesting? (Please describe) (i) ....

....

....

15. Do you have finger breakages when you harvest?

Yes [ ] No [ ]

16. What do you do with your harvested plantain?

Household use [ ] Sell some [ ] Sell all [ ]

Others [ ] (specify) ....

....

17. Do you store your harvested plantain? Yes [ ] No [ ]

18. If yes, how? ....

....

If No, Why? ....

19. If a storage structure is designed will you be willing to use it? Yes [ ] No [ ]

20. How much are you prepared to spend for a good storage structure? ....

21. Give reasons ....

....

22. How do you sell your produce?

Collectively with other farmers [ ] Individually [ ]

23. Can your farm be reached by road? Yes [ ] No [ ]

24. If yes, what is the condition of road leading to

your farm? Untarred but good [ ]
Tarred [ ] Untarred [ ]Very rough [ ]
Other[ ] (specify)...............

25. How do you convey your produce to the market?
Head loading [ ] Lorry [ ] Taxi [ ] Bicycle [ ]
Others [ ] (specify) ....

26. The distances you travel from your farm to the market are usually: Less than 1 km [ ] One to two km [ ]
Two to five km [ ] More than 5 km [ ] Others[ ]
(specify) ....

27. What is the major constraint you encounter in selling your produce? Transportation availability [ ]
Transportation cost [ ] Distance to the nearest market [ ] Others [ ] (specify) ....

28. How much money do you usually make from the sale of your products? (Per coach or per bunch. Please indicate).

29. Compared with other crops you grow, how can you rank the profit you make from plantain?
More profit [ ] Less profit [ ] Same profit [ ]
No profit [ ]

30. Do you package your plantain? Yes [ ] No [ ]

With what? ....

31. Why? For protection [ ] To facilitate handling [ ]

Others [ ] (specify) ....

32. How are your plantains packed? Fingers [ ] Clusters [ ]

Hands [ ] Bunches [ ]

33. Do you think your packaging material achieves the aim in (32) above? Yes [ ] No [ ]

34. If yes, How? ....

....

35. If no, Why? ....

....

36. At what level do you package? Farm-gate [ ] Village [ ]

Collection centre [ ] Others [ ]

(specify) ....

37. Do you sort out your plantain for quality standard before packaging? Yes [ ] No [ ]

38. If yes, How? Colour grades (degree of ripening)

Broken Fingers [ ] Spoilage (rottenness) [ ]

Others [ ] (specify) ....

If no, why? ....

39. How much are you prepared to spend for a good packaging material? ....

40. Why? ....

TRANSPORTATION INFORMATION

1. Name of market................. Village ....
   LGA .... State ....
2. Gender [ ] Male [ ] Female [ ]
3. Primary occupation: ....
4. Secondary occupation (if any) ....
5. Do you buy plantain or you just transport?
   I buy and transport [ ] I only transport [ ]
6. If you buy, from whom do you buy? Farmer [ ]
   Wholesaler [ ] An intermediary [ ] Others [ ]
   (specify) ....
7. Who employs your services? Farmer [ ] Wholesaler [ ]
   Retailer [ ] Private Company [ ] Self employed [ ]
8. Do you have an association? Yes [ ] No [ ]

8b. If yes, what are your activities? ....
   ....
   ....
9. What is the make of your vehicle? ....
   Lorry [ ] Pick-up van [ ] Taxi [ ]
   Others (specify) ....

10. How long does it take you to fill/load this vehicle?

....

11. Where do you buy your plantain from? ....

.................................(Name of place/market).

12. Where do you take them to? ....

(Name of place).

13. At what speed do you normally travel

(km/hr.) ....

14. How long does it takes you to reach your destination, after loading? ....

15. How can you describe the condition of the road you play?

Good [ ] Bad [ ] Very good [ ] Very bad [ ]

Others ....

MARKETING INFORMATION

Date of interview ....

Name of enumerator ....

Questionnaire Serial No ....

1. Name of market .... Frequency of market days .....

2. Village............ L.G.A........... State............

3. Sex: Male [ ] Female [ ]

4. Level of trading: Wholesaler [ ] Retailer [ ]

   Both [ ] Others (specify) ....

5. Do you belong to any Trader's association? Yes[ ]No [ ]

6. Why? ....

7. What are the activities? ....

8. Where do you buy from? Producer(farmer/village)

   village trader [ ] City trader [ ] Transpoter [ ]

   Wholesaler [ ] Any seller [ ] Others(specify) ....

9. Where do you prefer buying from? ....

10. Why? ....

11. What quantity of plantain do you usually buy at any one

    time/trip? Lorry load [ ] Pick-up load [ ] Taxi load []

    One coach [ ] Others (specify) ....

12. How much does it normally cost you?
(e.g. N/coach or others (indicate) ....

13. Distances you travel daily to the market are usually:
Less than one km [ ] One to two km [ ]
Over two but less than five km [ ] Over five km [ ]
(If distance is not known, how much do you pay for transportation? ....)

14. When you go to buy your commodities for sale, distances covered are usually:
Less than 5km [ ] 5-10km [ ] 11-50km [ ] over 50km [ ]

15. In what form does the plantain get to the market?
All green [ ] All yellow [ ] Yellow and green [ ]
Other (specify) ....

16. Whom do you sell your plantain to? Consumers [ ]
Processors [ ] Retailers [ ] Other (specify) ....

17. Do you package your plantains? Yes [ ] No [ ]

18. With what? ....

19. Why? For protection [ ] To facilitate handling [ ]
Others(specify) ....

20. How are your plantains packaged? Fingers [ ]
Clusters [ ] Hands [ ] Bunches [ ]

21. Do you think your packaging material achieves the aims in (.........) above? Yes [ ] No [ ]

22. If yes, how? ....

....

23. If no, why? ....

....

24. At what level do you package? Farm-gate [ ]
Collection centre [ ] Others (specify) ....

....

25. Do you sort out your plantation for quality standard before Packaging? [ ] Yes [ ] No

26. If yes, how? Colour grades [ ] Broken fingers [ ]
Spoilage (rottenness) [ ] Others (Specify)........

....

27. If no, why? ....

28. If a low-cost packaging material (e.g. returnable crates) is designed, will you be willing to use it ?
Yes [ ] No [ ]

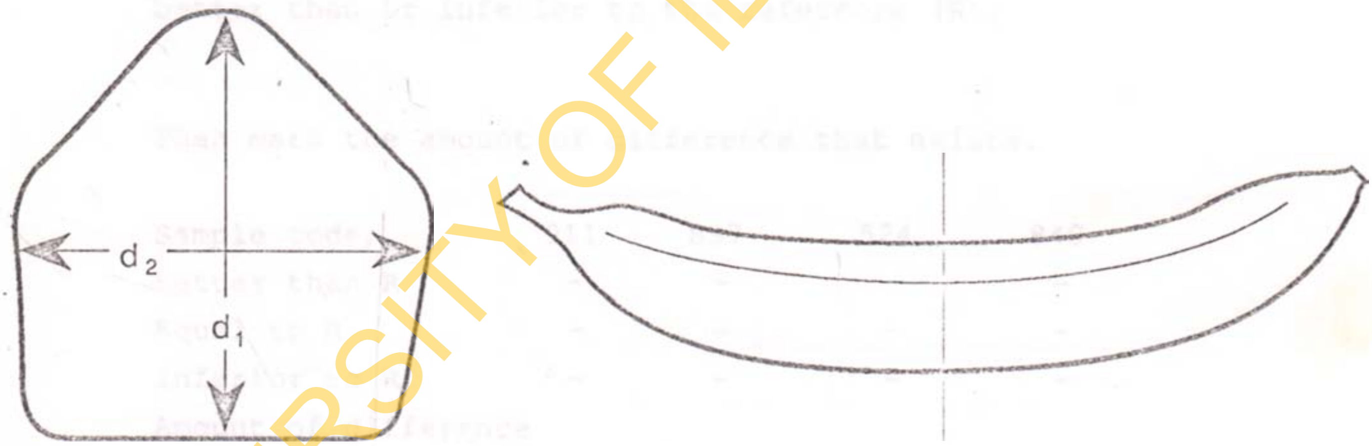
29. Why?..

....

....

APPENDIX II

measurement of finger diameter



d_1 = longer diameter

d_2 = shorter diameter

$$\text{Finger diameter} = \frac{d_1 + d_2}{2}$$

APPENDIX III

QUESTIONNAIRE FOR MULTIPLE COMPARISON TEST

You are receiving three samples of plantain chips to compare for difference in crispiness. You have been given a reference sample marked R with which you are to compare each sample. Taste each sample, determine if it is similar to, better than or inferior to the reference (R).

Then mark the amount of difference that exists.

Sample code;	911	897	524	840
Better than R	-	-	-	-
Equal to R	-	-	-	-
Inferior to R	-	-	-	-
Amount of difference				
None	-	-	-	-
Slight	-	-	-	-
Moderate	-	-	-	-
Much	-	-	-	-
Extreme	-	-	-	-

Comments:.................................

....

APPENDIX IV

AGBAGBA

Bruise area ANOVA

Source of variation	df	SS	ms	f-ratio
Treatmant	38	4788.43	126.01	5.39**
Error	88	2056.81	23.37	
Total	126	6845.24		

Ripening days ANOVA

Source of variation	df	SS	ms	f-ratio
Treatmant	38	10244.31	2.69	120.07
Error	90	202.07	2.24	
Total	128	10446.38		

Percentage weight loss ANOVA

Source of variation	df	SS	ms	f-ratio
Treatmant	39	11284.60	289.34	8.71**
Error	170	5647.99	33.22	
Total	209	16932.60		

Trimming losses ANOVA

Source of variation	df	SS	ms	f-ratio
Treatmant	38	1030.36	27.11	13.98**
Error	85	164.91	1.94	
Total	123	1195.27		

OBINO

Bruise area		ANOVA		
Source of variation	df	SS	ms	f-ratio
Treatmant	29	1558.62	53.74	5.12**
Error	74	777.12	10.50	
Total	103	2335.74		

Ripening days		ANOVA		
Source of variation	df	SS	ms	f-ratio
Treatmant	29	5919.82	204.13	55.30**
Error	72	265.75	3.69	
Total	101	6185.57		

Percentage weight loss		ANOVA		
Source of variation	df	SS	ms	f-ratio
Treatmant	29	10764.11	371.17	10.21**
Error	120	4364.03	36.36	
Total	149	15128.14		

Trimming losses		ANOVA		
Source of variation	df	SS	ms	f-ratio
Treatmant	29	737.82	25.44	7.15**
Error	70	249.13	3.55	
Total	99	986.95		

APPENDIX V

Relative costs of traditional and proposed packaging containers.

1. Existing method using previously - used polyethylene bags.

Cost of bags = ₦1.00 /bag

Transport cost = ₦3.00/bag

Cost associated with Packaging (paid to packers) = 50K/bag

Packaging cost/bag (of about 50 platains) $\doteqdot \frac{₦4.50 \times 100}{50}$

2. Proposed method using improved containers

Estimated capacity of containers = 50kg

Estimated cost of containers = ₦25.00

<u>Container replacement (CR)</u>

Container replacement = $\frac{\text{Cost of container}}{\text{kg carried during life}}$

Assuming the ratio of container required in the system to container dispatched daily is 3:1

Optimistic CR (6 years) = $\frac{3 \times ₦25.00 \times 100}{6 \text{ years} \times (x \text{ days/year}) \times 50}$

Medium CR (4 years) = $\frac{3 \times ₦25.00 \times 100}{4 \text{ years} \times (x \text{ days/year}) \times 50}$

Pessimistic CR (2 years) = $\frac{3 \times ₦25.00 \times 100}{2 \text{ years} \times (x \text{ days/year}) \times 100}$