Routine Post-Harvest Screening of Banana/Plantain Hybrids: Criteria and Methods

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Acknowledgements

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Introduction

Banana, cooking banana and plantain (*Musa* spp. AAA, AAB and ABB groups) are major starch staple crops of considerable importance in the developing world. They are consumed both as an energy yielding food and as a dessert. It has been estimated that plantains and other bananas provide nearly 60 million people in Africa with more than 200 calories (food energy) a day (Stover and Simmonds, 1987). In tropical America and the Caribbean, they are of great socio-economic and nutritional significance and they generate considerable export earnings and employment. Together, plantain and banana constitute the fourth most important global food commodity after rice, wheat and maize in terms of the gross value of production (CGIAR, 1992, 1993). Nearly 90% of the total banana and plantain produced worldwide (63 million tonnes) are consumed locally in the producing countries leaving only 10% for export (CGIAR, 1992, 1993).

In the last twenty years, the production of banana, cooking banana and plantain has continued to decline as a result of decreasing soil fertility, yield decline phenomena, pest (weevils, nematodes) problems and most importantly, the wide spread leaf spot disease called black Sigatoka (*Mycosphaerella fijiensis*) (IITA, 1992; Stover and Simmonds, 1987; Swennen, 1990). Black Sigatoka can be controlled, but the cost of chemical fungicides, a staggering US$800-1000 per hectare per year is prohibitive. In Guatemala, for example, some banana and plantain growers are spraying up to 50 times a year (IDRC, 1994). The massive application of chemicals in banana and plantain plantations is also drawing the ire of environmentalists and concerned consumers. Therefore the best alternative for the control of black Sigatoka is the breeding of resistant hybrids.

The *Fundación Hondureña de Investigación Agrícola* (FHIA), has been at the forefront of breeding new and promising black Sigatoka resistant banana, cooking banana and plantain hybrids with superior agronomic potential. However, not much research has been undertaken to screen and characterise their post-harvest attributes and organoleptic qualities. As a result, in 1993, a two and half year international collaborative research project involving the International Network for the Improvement of Banana and Plantain (INIBAP), the Natural Resources Institute (NRI) and FHIA, and funded by the British Overseas Development Administration (ODA) was initiated. The principal objective of the project was the establishment of major post-harvest criteria and methods/procedures for routine screening of new banana/plantain hybrids.

This manual describes the key post-harvest criteria and methods/procedures for routine selection of new *Musa* hybrids. Most of the methods and procedures described are simple, easy to use and require limited and inexpensive technology (in terms of equipment). The manual is designed to provide useful information to assist breeders and researchers in the post-harvest selection of new *Musa* hybrids. It is anticipated that the manual would also serve as a useful reference material to others involved in post-

harvest research or technology transfer.

There are many post-harvest criteria for screening new banana, cooking banana and plantain hybrids, however the major ones include:

1. Post-harvest characteristics at harvest
2. Fruit maturation
3. Green-life and shelf-life
4. Fruit ripening quality
5. Sensory quality
6. Cooking or boiling quality
7. Processing quality
8. Mechanical damage
9. Physiological disorders
10. Post-harvest diseases

The major post-harvest methods and procedures for routine screening of new *Musa* hybrids are described in the subsequent chapters.

1.   Post-Harvest Characteristics at Harvest

The post-harvest characteristics at harvest essential in the screening of new banana, cooking banana and plantain hybrids include:
1. Bunch and fruit characteristics
2. Post-harvest quality attributes

Depending on the locality or country, most producers and consumers of banana, cooking banana and plantain usually prefer large size bunches with large or small size fingers and/or long or short fingers. Therefore, assessment of bunch weight and fruit characteristics such as fruit weight, length, circumference and volume are important post-harvest selection criteria. Screening of new *Musa* hybrids for their fruit characteristics at harvest may be important in the design of packaging for the fruit which would enhance efficient handling and transportation. It is also important in the assessment of fruit maturity at harvest. Assessment of the post-harvest quality attributes (such as peel and pulp colour, pulp firmness, total soluble solids, moisture and dry matter content) are important in determining fruit maturation and it could also complement sensory evaluation studies. Screening of new banana, cooking banana and plantain hybrids for their post-harvest characteristics at harvest would provide the plant breeder useful information for future breeding work. It would also enable meaningful comparison of new *Musa* hybrids to existing cultivars.

1.1.   Assessment of post-harvest characteristics at harvest

To reduce variation and to obtain consistent data, it is essential that all measurements are limited to (or taken on) the fingers of the second hand of freshly harvested physiologically matured bunches (with green fruit). However, if there are not enough samples, fruits from the third hand may be included.

The following are the post-harvest methods and procedures for routine screening of new *Musa* hybrids for their post-harvest characteristics at harvest:

1.1.1. Bunch and fruit characteristics at harvest

Assessment of bunch and fruit characteristics at harvest include the following:

a. Bunch weight (kg)
   Bunch weight (of each cultivar/hybrid) is determined by weighing individual bunches with a balance (usually to 2 decimal places).

b. *Number of hands*

Number of hands is obtained by counting the number of hands on each bunch.

c. *Number of fingers*

Number of fingers is obtained by simply counting the number of fingers (per hand) on each bunch.

d. *Fruit weight (g)*

Fruit weight is determined by weighing individual fruit on a balance (e.g. Mettler electronic balance usually to 2 decimal places).

e. *Fruit length (cm)*

Generally, fruit length is determined by measuring the outer curve of individual fruit with a tape from the distal end to the point at the proximal end where the pulp is judged to terminate (Figure 1). However, some researchers determine the fruit length of banana fingers by measuring the inner curve of the fruit from the junction of the pulp and fruit stalk to the tip of the fruit and others also measure in a straight line from the fruit stalk to the tip (flower end); (Thompson and Burden, 1995). Which ever method is used it is important to report it.

f. *Fruit girth or circumference (cm)*

Fruit girth or circumference is determined by measuring individual fruit with a tape at the widest midpoint of each fruit (Figure 2).

g. *Fruit volume (cm³)*

Volume of fruit is obtained by direct volume displacement or by weighing fruit under water as follows:
- Weigh (with Mettler electronic balance usually to 2 decimal places) a container of water, allowing enough space for fruit submersion;
- Submerge fruit while container is still on the scale. To avoid air bubbles on the fruit surface, which cause erroneous readings, put a few drops of a wetting agent or detergent in the water to reduce surface tension. Keep fruit from touching the sides or bottom of the container by holding it under water with a weight (determine the weight on a scale before use);
- Read the weight of the container plus the water plus the submerged fruit (with the weight);
- The difference in grams between the two weights is equal to the volume of the fruit in cubic centimeters (cm^3).

h. *Fruit density (specific gravity)*

Fruit density or specific gravity is obtained by simply dividing the fruit weight in air by the fruit volume (Kushman and Pope, 1968; Kushman *et al*., 1966).

i. *Pulp and peel weight (g)*

Pulp and peel weight are determined after fingers have been hand-peeled and peel and pulp weighed separately (e.g. with Mettler electronic balance usually to 2 decimal places).

j. *Pulp to peel ratio*

Pulp and peel are separated, weighed individually and expressed as pulp to peel ratio (i.e. pulp weight divided by the peel weight).

k. *Peel and pulp thickness (cm)*

Hand peel each fruit after cutting transversely at the midpoint, and measure the peel and pulp separately with a pair of calipers as illustrated in Figure 3.

1.1.2. Post-harvest qualities at harvest

The post-harvest methods and procedures for the assessment of the post-harvest quality attributes at harvest include assessment of the following:

a. *Peel and pulp colour*

The colour of banana, cooking banana and plantain probably contributes more to the assessment of quality by the consumer than any other single factor. Therefore, peel and pulp colour of banana, cooking banana and plantain are important post-harvest selection criteria. The colour of the fruit could give an indication of state of deterioration, disease infestation and/or contamination. The market quality and consumer acceptability of banana, cooking banana and plantain are significantly influenced by the colour of the fruit. The peel colour is often the major post-harvest criterion used by researchers, growers and consumers to determine whether the fruit is ripe or unripe (Medlicott *et al*., 1992). In some countries, (e.g. Ghana, Nigeria, Honduras, etc), consumers have developed distinct correlations between colour and the overall quality of specific products. Cooking banana or plantain should be green or yellow, any thing which falls short of that (e.g. red plantain) would be difficult to sell. Hence, colour is critical as the first visual assessment of the quality of cooking banana or plantain. Consumers associate the colour of the peel with specific tastes or uses and they will usually buy cooking banana or plantain if the colour is suited to the required purpose or desire. In some West African countries, if the pulp colour of plantain or cooking banana is white, consumers feel that, the fruit is immature and if the pulp colour is orange/yellow it indicates that the fruit is mature. Therefore, assessment of peel and pulp colour is important in the post-harvest screening of new hybrids.

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Communicating a perception of colour requires an evaluation, description and a means to relay the results in a systematic way. Colour charts or colour measuring instruments are tools used for this purpose (Knee, 1980; Wainwright and Hughes, 1989, 1990).

Calibration of colour meter

Calibrate the colour meter as outlined in the users' manual prior to each measuring session. Follow the guidelines for colour measurement that are peculiar to the instrument being used.

Measuring peel and pulp colour using colour meter
The peel and pulp colour of banana, cooking banana and plantain can be measured using a Minolta chromameter (CR-100 or CR-200) with an 8 mm measuring head.
To measure peel colour: Place the measuring head on the fruit surface (peel surface) and take approximately 2-3 readings (on each fruit surface) and find the mean.
To measure pulp colour: Cut the fruit transversely at the midpoint and place the measuring head at the centre or locule and take a single reading.
Colour measurements are recorded using Hunter L*, a* and b* scale (Hunter, 1975; Francis, 1980). The "L" coordinate is a measure of lightness (white - black and ranges from no reflection L=0 to perfect diffuse reflection L=100), the "a" scale ranges from negative values for green to positive values for red and the "b" scale ranges from negative values for blue to positive values for yellow. The L*, a* and b* values must be converted to hue, value and chroma (McGuire, 1992). On some Minolta chromameters, L*, a* and b* values are converted to hue, value and chroma automatically.

b. *Pulp firmness*

The texture or firmness of the pulp of banana, cooking banana and plantain hybrids is an important post-harvest quality attribute in the assessment of the post-harvest characteristics at harvest. It could be used as a maturity/ripening index. It could also facilitate comparison of the rate of softening of the new hybrids with that of their parents. Assessment of firmness is important in the evaluation of fruit susceptibility to physical or mechanical damage or post-harvest handling (Kramer, 1964).

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The texture of banana, cooking banana and plantain is a composite attribute resulting from a combination of several factors such as water turgor and structural components of tissues and cells. Any single (or individual) physical assessment procedure can only provide a limited indication of these textural properties. Most routine texture measuring devices determine aspects such as compressibility, deformation or rupture of the sample being tested. An indication of firmness is obtained by the force necessary to cause penetration of a standard probe within a specified distance into the product. Hand-held penetrometer (Figure 4) or a stand mounted penetrometer or the penetrometer in combination with a drill press (Figure 5) are some of the tools usually used for measuring pulp firmness.

Types of penetrometer
The types of penetrometer available include:
• Effegi penetrometer;
• Magness-Taylor pressure tester
Non-destructive sonic techniques for measuring fruit firmness have been developed but they do not appear to have found wide application.

Calibration of the penetrometer
Penetrometer should be checked each day before use. The plunger should be worked in and out about ten times to ensure that it is running smoothly; otherwise initial readings can be higher than subsequent readings.
The penetrometer is essentially measuring the resistance of the fruit to a constant force. Therefore, to obtain accurate fruit firmness readings, it is essential that the

method employed in operating a penetrometer be standardised as follows:
• When using a hand-held penetrometer hold the sample firmly in one hand against a firm surface;
• When using a stand mounted penetrometer or the penetrometer in combination with a drill press (to provide a steady application force) to measure the pulp rupture force of transverse sections of pulp tissues, place the sample on a perspex or similar platform with a hole slightly larger than the probe diameter. This is to reduce the risk of damaging the probe or force gauge (Figure 5);
• The depth to which the plunger is inserted into the fruit must be constant;
• Plungers have a circle inscribed on the shaft approx. 7.9 mm from the tip. The plunger should be pushed into the fruit up to this inscribed line and not up to the plate which is there to prevent juice squirting onto the instrument and the operator;
• The speed at which the penetrometer is pushed into the pulp must be constant. It should take about two seconds to insert the plunger into the pulp up to the inscribed line on the plunger.

Even following these instructions, there can be differences in the readings obtained by different operators. Thus wherever possible one trained person should do the testing for comparative and consistent results.

Measurement of pulp firmness

Pulp firmness of banana, cooking banana or plantain is determined on cross-sections of fruit as follows:
• Cut transversely at the midpoint, 1 cm of fruit tissue (i.e. containing both the peel and pulp);
• Place the sample on a perspex or similar platform as shown in Figure 5;
• Measure the force required to penetrate the 1 cm of pulp tissue with a 6 mm diameter cylindrical probe mounted on a bench-top firmness tester fitted with a 0-10 kg Salter electronic force gauge (Figure 5);
• The value recorded is the maximum force required for the pulp to yield to the tip of the probe. Pulp firmness is usually reported in kilogram force (kgf) or Newtons (N) (1 kgf = 9.80665 N).

Temperature of the samples can affect measurements (Bourne, 1982) and should be standardised. The probe diameter of the penetrometer must be reported.

c. *Total soluble solids*

Fruits including banana, cooking banana and plantain contain many compounds which are soluble in water; e.g. sugars, acids, vitamin C, amino acids and some pectins. These soluble compounds form the soluble solids content of the fruit. In most ripe fruits including banana, cooking banana and plantain, sugar forms the main component of soluble solids. Total soluble solids (TSS) is an important post-harvest quality attribute in the screening of new banana, cooking banana and plantain hybrids. Since the amount of TSS or sugar in fruits usually increases as they mature and ripen, the soluble solids content of the fruit can be a useful index of maturity or stage of ripeness. The refractometer is the instrument used to measure the total soluble solid content of fruits.

Types of refractometer

The most common types of refractometer used to assess total soluble solids content of fruits including banana, cooking banana and plantain are the hand held refractometer. These generally have a degree brix (°B) range of 0-20 or 0-32% in 0.2 or 0.5% graduations.

There are various types of refractometer on the market including:
• Atago 0-20% or 0-32%;
• Bellingham & Stanley 0-28%;
• Erma 0-20%.

Choosing a refractometer

When choosing a refractometer it is important that:
• The scale is easy to read;
• There is good contrast between the light and dark portions of the field of view and that the demarcation lines are fine and distinct;
• The instrument can be easily and accurately calibrated and does not go out of adjustment easily;
• The instrument is robust.

Calibration of the refractometer

Refractometer readings of degrees brix (°B) or % total soluble solids (% tss) alter slightly with temperature. The instrument is calibrated to be used at 20°C and thus ideally both the instrument and the fruit juice should be at this temperature. New models of refractometer have automatic temperature controls.

To calibrate the refractometer

• Place a few drops of distilled water on the prism surface;
• Close the prism cover, ensure that no air bubbles are trapped in the water film, then point the refractometer toward a light source. A circular field is seen through the eye-piece with a vertical scale to one side marked in divisions of 0.2 or 0.5% soluble solids (ss). With liquid on the prism, the field will be divided into light and dark portions. The point at which the demarcation line between these portions crosses the vertical scale gives the °B reading or estimate of % tss. With distilled water, this reading should be 0%. The line can be adjusted on the vertical scale by screws above or below the prism box;
• Having calibrated the refractometer with distilled water, it is also important to check its accuracy at higher °B using freshly made sucrose solutions of known concentration of sucrose, e.g. 12% w/v sucrose (12 g sucrose in 88 ml distilled water).

If the demarcation line on the refractometer scale is indistinct this could be due to:
• Large air bubbles trapped in the film of juice. A large amount of juice may be required to ensure that the prism surface is well covered;
• Moisture entering the optical system of the refractometer. The refractometer should be dried at 30-40°C.

Always carefully wipe the surface of the refractometer prism clean with soft tissue paper between each reading. After use wash the prism with distilled water and dry well with soft tissue paper and store in a safe place until required.

Measurement of total soluble solids
To measure accurately the total soluble solids in fruits requires long tedious methods. However, there are two commonly used, less difficult methods to estimate soluble solids in fruit juice. One is to measure the specific gravity of the juice using a hydrometer.

The second and most popular is to measure the refractive index of the juice using a refractometer. Only the second method is described below, since it is the most popular method used to measure the total soluble solids content of banana, cooking banana and plantain.

Measuring the refractive index of pulp juice using a refractometer
The refractive index (or total soluble solid content) of banana, cooking banana or plantain pulp juice are measured as follows:
• Blend in a kitchen blender, 30 g of pulp tissue (from the transverse section of the fruit) in 90 ml distilled water for 2 min and filter (e.g. through a filter paper);
• A single drop of the filtrate is placed on the prism of a refractometer (e.g. Figure 6; Atago N-20 refractometer, Model N, McCormick Fruit Tech., brix range from 0-20% at 20°C). ;
• Point the refractometer towards a light source and read the percentage total soluble solids;
• The recorded value is multiplied by three (because the initial pulp sample was diluted three times with distilled water).

The % TSS content of fruit juice varies within fruit depending on the stage of ripeness, e.g. in banana, cooking banana and plantain, the centre or the locular area usually has higher sugar content than cortex tissue. Therefore, to obtain an accurate % TSS, significant pulp samples containing both the centre (or locular) and pulp tissues should be taken.

Limitations
Temperature of the samples can affect measurements of the total soluble solids (Bourne, 1982) and should be standardised. It is assumed that, the predominant compound in the solution or fruit juice being tested is sucrose or sugar. However, other compounds such as acids, vitamin C, amino acids and some pectins may be present.

d. *pH and total titratable acidity*
pH values give a measure of the acidity or alkalinity of a product, while titratable acidity gives a measure of the amount of acid present.

Assessment of pH and titratable acidity of banana, cooking banana and plantain are used primarily to estimate consumption quality and hidden attributes. They could be considered as indicators of fruit maturity or ripeness. Acids make an important contribution to the post-harvest quality of the fruit, as taste is mainly a balance between the sugar and acid contents, hence post-harvest assessment of acidity is important in the evaluation of the taste of the fruit.

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The pH value of the filtrate from pulp samples is determined using a pH electrode. Total titratable acidity of the filtrate from pulp samples is determined by titration of the sample with sodium hydroxide to the phenolphthalein end point and calculation of acid present as malic acid.

Preparation of reagents

To prepare phenolphthalein indicator: Dissolve 1.0 g of phenolphthalein in 50 ml ethanol and dilute to 100 ml with distilled water. Store in dropping bottles until required.
To prepare 0.1 N sodium hydroxide solution: Weigh 4 g of NaOH and dissolve in 1 litre of distilled water. Solution must always be stored in a sealed container and stored until required.

Calibration of pH meter

pH of the pulp juice may be measured with a digital hand-held (Figure 7) or bench top pH meter (Figure 8), while total titratable acidity may be ascertained manually by titration (Figure 9) or using an automatic titrator (Figure 10). Follow instructions provided by the manufacturer of the particular pH meter or titrator being used. Use pH 4 and 7 solutions to calibrate the pH meter.

Measurement of pH of pulp juice

pH of banana, cooking banana or plantain pulp juice is measured as follows:
• Weigh 30 g of banana, cooking banana or plantain pulp into a kitchen blender and add 90 ml of distilled water and blend for 2 mins and filter (e.g. through a filter paper);
• Wash the pH electrode in distilled water and place electrode in the filtrate;
• Allow a few moments for reading to stabilise. Record the pH value of the filtrate. Wash pH electrode with distilled water and store as recommended by manufacturer.

In the absence of a pH meter, use universal indicator paper. Dip the paper in the prepared filtrate and compare the colour change with the chart given on the indicator packaging. Identify the corresponding colour and note the pH.

Measurement of total titratable acidity

Total titratable acidity of banana, cooking banana or plantain is measured as follows:
• Weigh 30 g of pulp tissue into a kitchen blender and add 90 ml of distilled water and blend for 2 mins and filter.
• Transfer 25 ml of the filtrate into a 125 ml conical flask.
• Add 25 ml of distilled water and 4-5 drops of phenolphthalein indicator.
• Fill a 25 ml burette with 0.1 N sodium hydroxide (NaOH) and adjust to the zero mark after eliminating the bubbles.
• Titrate with 0.1 N sodium hydroxide until the indicator just changes pink/red (Figure 9).
• Record the titre volume of NaOH added. The results are expressed (e.g. as milliequivalent per 100 g sample) in terms of the predominant acid present. In banana, cooking banana and plantain malic acid is the predominant acid (Josylin, 1970).

When using an automatic titrator, titrate pulp samples to the phenolphthalein end point of pH 8.1 with 0.1 N NaOH.

Limitations

The phenolphthalein method of titratable acidity method is dependent on a colour change from colourless to pink/red. This pink/red colour can be difficult to see with highly coloured products. In the determination of total titratable acidity of banana, cooking banana and plantain, the predominant acid present is malic acid, hence it is assumed that, malic acid is the only acid present.

e. *Peel and pulp moisture and dry matter content*

Peel and pulp moisture and dry matter content (%) are important post-harvest quality criteria in the screening of new banana, cooking banana and plantain hybrids, since they provide a measure of the water content. They also provide plant breeders with information in determining whether increased yield is due to higher water content or due to genuine increase in harvested weight. Assessment of dry matter content is essential because, the high rate of respiration accompanied by water loss that occurs in plantain and banana during ripening, particularly at the climacteric stage causes a net reduction in the proportion of the fruit dry matter. In addition, because the male parents mostly banana (diploid) used to obtain some of the plantain hybrids have low dry matter content, it is important to assess the dry matter content to find out if this trait has been passed on to the plantain hybrids. Evaluation of the dry matter content could provide useful information on the differences in the moisture content between the plantain hybrids and their parents.

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The loss of weight by plant materials dried at 100°C is attributed to evaporation of hygroscopical water. If the drying is prolonged chemically, bound water will evaporate too. But the latter losses are small in comparison with the first (Kushman *et al*., 1966).

Measurement of moisture and dry matter content

The moisture and dry matter contents of banana, cooking banana and plantain are measured as follows:

• Label and weigh empty container (e.g. foil dish) on a Mettler balance (± 0.0001) and record the weight (A).
• Put approximately 30-50 g of chopped fresh peel or pulp samples into the container and record the weight (B).
• Place samples in a draft air oven at 100°C over night (24 hours).
• Transfer samples from the oven into a desiccator and cool at room temperature.
• Weigh samples again after drying (C).
• Percentage moisture and dry matter content of the sample are calculated as follows:

Wet weight of sample	(D) = B - A
Weight of dry sample	(E) = C - A
Moisture content	(%) = $\dfrac{D - E}{D} \times 100$
Dry matter content	(%) = 100 - (% moisture content)

2.   Fruit Maturation

Fruit maturation is an important post-harvest criterion essential in the screening of new banana, cooking banana and plantain hybrids because, the stage of maturation at which any fruit is harvested greatly influences the green-life or the ability of that fruit to be stored for long periods and its final eating quality. Every fruit will develop its full characteristic flavour, taste and colour during storage if it is picked during an optimum period. Fruits harvested at an early stage of maturity are more susceptible to shriveling and mechanical damage and are of poor quality upon ripening, despite having a long storage life.   On the other hand, harvesting at an advanced stage of maturity is unsuitable for fruits intended for long distance shipment due to their shorter storage life (Harman, 1981; Kader, 1994). Therefore, it is important to carry out harvesting at the right maturity stage to suit the purpose. Maturity at harvest is an important factor affecting quality perception and the rate of change of quality during post-harvest handling. By knowing the stage of maturation of a new *Musa* hybrid, it would be possible to schedule harvesting, handling and marketing operations efficiently. Therefore, it is important to identify key indicators or indices of maturation for new banana, cooking banana and plantain hybrids that would ensure the best eating quality to the consumer and provide the needed flexibility in marketing.

2.1. Characteristics of the maturity index

For maturity measurements to be carried out by producers, handlers and quality control personnel, they must be simple, readily performed in the field (and/or laboratory) or inspection point and should require relatively inexpensive equipment.   The index should preferably be objective rather than subjective and ideally the index should be non-destructive.

2.2. Requirements for maturity indices

Many features of fruits have been used in attempting to provide adequate estimates of maturity.   The maturity index must consistently meet two requirements for all producers, districts and years (or seasons).

It should ensure:

• Minimum acceptable eating quality.

• A long storage life.

2.3. Common criteria or indices for assessment of fruit maturity

There are no universally recognised objective criteria for determining when to harvest banana, cooking banana and plantain. However on most plantations and farms, the common criteria or indices used in the assessment of maturity or time to harvest include any of the following:

• By experience and judged largely by the visual appearance of the hanging bunch and particularly by the angularity of individual fingers (Palmer, 1971).

• Fruits are harvested when the fingers of the first hand on the bunch show signs of ripening or yellowing or when the finger tips turn black (Dadzie, 1994b, c).

• On most banana plantations, fruits destined for distant markets are harvested at a stage known as 'three quarters full', when the fingers are still clearly angular. For local markets fruits are often harvested when fingers are full or rounded.

• Usually coloured ribbons are used to provide information regarding bunch age.

• Fruit diameter (or caliper grade of fruit) and fruit length may be used as criterion to determine when to harvest.

2.4. Age control

Proper age control or assessment of bunch age of banana, cooking banana and plantain is important in deciding time of harvest. Inadequate age control at harvest, is one of the factors predisposing banana consignments to show a proportion of 'ship ripe' fruit at their eventual destination. Lack of age control may also result in the harvesting of under-filled or immature bunches. Age control is important in the proper assessment of green-life as well as scheduling harvesting and marketing operations efficiently. Hence, proper age control and identification of key indices of maturity for new banana, cooking banana and plantain hybrids that would ensure maximum shelf-life, best eating quality to the consumer and at the same time will not risk an abnormal ripening are essential.

2.5. Identification of key indicators of maturation

The use of a single indicator of maturity may be applicable to one cultivar/hybrid, but may not be applicable to other cultivars/hybrids, therefore, the use of a combination of several indicators, are essential in the determination of the time of harvest. The maturity indices must measure fruit characteristics and post-harvest quality attributes which change consistently as the fruit develops, so that harvesting the fruit at particular indices enable final eating quality to be predicted. While it is advantageous if the maturity index is non-destructive, so that every fruit can be evaluated, it is important that the indices can be measured in a rapid, simple and inexpensive way.

The need for suitable indicators of maturity for new banana, cooking banana and plantain hybrids would ensure that fruits reach an appropriate stage of development before harvest. In addition to the current criteria for assessing fruit maturity (mentioned above), various indices of maturity must be identified for each new *Musa* hybrid.

2.6. Assessment of fruit maturation

Both field and laboratory methods and procedures must be used in the identification of key indicators of fruit maturation.

Field methods and procedures

Field methods and procedures essential in the assessment of key indicators of maturation of banana, cooking banana and plantain include:

2.6.1. Tagging of plants at flower emergence

This involves tagging of plants in the field immediately after flower emergence (note date of flowering) or use of colour ribbons to give an indication of date of flowering. Calculating number of days from anthesis to harvest provides one of the best indicators of maturity of banana, cooking banana or plantain. Some variations in development will be noted among cultivars/hybrids as well as variations in field conditions, nevertheless in banana, cooking banana or plantain this is a very reliable method of estimating bunch age.

2.6.2. Visual observation of bunch and fruit development

After tagging of plants at flower emergence, regular visual observation (or inspection) of bunch and fruit development in the field are extremely important in the identification of external indicators of maturation of banana, cooking banana or plantain. Make note of any changes observed in bunch and fruit development in the field.

The most significant visual changes in the morphological characteristics of the fruit during maturation occur in the size, shape, length and volume (circumference) of the fruit as bunches advance in age. Generally, in most *Musa* cultivars/hybrids, during the early stages of development, individual fingers are angular, however as growth progresses, the fingers loose angularity and become more rounded and full in shape (as fruit advance in age). The final degree of roundness is cultivar dependent. In some banana, cooking banana and plantain hybrids during maturation, vertical lines appear on the fruit surface. These lines are more pronounced in immature fruit but become less pronounced as fruits progress in maturity (Figure 11). In some cooking banana hybrids, visible short, small brown distinct lines appear on the fruit surface at a latter stage of development and these lines become more pronounced as fruits advance in age. In some *Musa* hybrids, the stylar ends become dry and loosely attached to the fruit at harvest, while in others, the dry stylar detaches from the fruit at maturity. These visible changes in the morphology of the fruit during maturation, are important maturity indices essential in the overall assessment of the time to harvest. It is important to mention that, although some of the visual morphological changes that occur in the fruit during maturation may be cultivar/hybrid dependent or unique to a particular cultivar or hybrid, in general, most of these visual changes may be manifested in most banana, cooking banana and plantain hybrids. Figure 11 is an example of the typical changes in the morphological characteristics during fruit maturation.

Laboratory methods and procedures

Harvest bunches of different ages on the same day (see Figure 11) and carefully transport fruits to the laboratory for analysis. To reduce variation and to obtain consistent data, it is essential that all measurements be limited to (or taken on) the fingers of the second hand of the bunch. However, if there are not enough samples, fruits from the third hand may be included.

Laboratory methods and procedures essential in the assessment of key indicators of maturation of banana, cooking banana and plantain hybrids include:

2.6.3. Changes in fruit characteristics during maturation

During maturation, fruits exhibit increases in fruit characteristics such as fruit weight, girth relative to length and in pulp to peel ratio. These changes occur simultaneously with other visual changes in the fruit, such as, size, shape, volume, angularity, skin colour and nature of the stylar end. Generally, changes in fruit characteristics such as fruit weight, length, circumference and cross-sectional area during maturation are hybrid dependent. Therefore, in the assessment of fruit maturation, the following fruit characteristics must be assessed in the post-harvest screening of new banana, cooking banana and plantain hybrids:

a. *Fruit diameter, length, weight, volume and density*
   Fruit maturity is usually related to the diameter or grade of the fingers, hence an estimate of the bunch's maturity can be made. In commercial practice, finger diameter or harvest grade is determined by measuring the middle finger in the outer whorl of the second hand (at the thickest part of the finger) on each bunch with a pair of calipers (Figure 12). The grade is expressed in three ways depending on the country:
   (a) total thirty-seconds of an inch (e.g. grade 42 which is 110/32 inch);
   (b) the number of thirty-seconds of an inch above thirty-two (e.g. grade 10 which is 110/32 inch);
   (c) millimetres (e.g. grade 42 is 33 mm using 0.794 for each thirty-second of an inch). In Central and South America grade is expressed as the number of thirty-seconds of an inch above 1 in, whereas millimetres are used in the Caribbean and Africa (Stover and Simmonds, 1987). This parameter may vary between seasons.
   In the banana industry, fruit or finger length is also used to asses the maturity of the bunch before harvest and it is determined by measuring the middle finger on the outer whorl of the second hand with specially designed tape (Figure 13).
   During maturation, changes also occur in the weight, volume and density of banana, cooking banana and plantain. Therefore, it is essential to evaluate these fruit characteristics in conjunction with other visual changes in the fruit.
   The post-harvest methods and procedures for the assessment of fruit weight, length, volume and density have been described in the preceding chapter.

b. *Pulp to peel ratio*
   Changes in pulp to peel ratio of banana, cooking banana and plantain during maturation is one of the significant and consistent indicators of maturity. There is both a linear relationship and a strong correlation between pulp to peel ratio and bunch age (Dadzie, 1993, 1994b, c).

The post-harvest methods and procedures for the assessment of pulp to peel ratio have been described in the preceding chapter.

c. *Fruit cross-sectional area*

Generally, in some banana, cooking banana and plantain cultivars/hybrids, the cross-sectional area or dimensions of the fruit (i.e. the fingers near the top of the bunch) change during maturation. Figure 14 is an example of the typical changes that occur in the angles, shape and size of the cross-sectional area during fruit maturation.

ASSESSMENT OF FRUIT CROSS-SECTIONAL AREA

The cross-sectional area of the fruit is ascertained as follows:
• Cut fruit transversely at the mid-point and trace the cut surface onto a piece of paper with a soft, sharp pencil.
• Allow the paper to dry and re-trace sections onto a clean sheet of paper.
• Cut out the sections (with a pair of scissors) and weigh on a Mettler balance (± 0.0001).
• Similarly, cut and weigh a 100 x 100 mm paper. The weight of the 100 x 100 mm paper gives the weight per square millimeters (mm^2).
• The weight of traced section per fruit divided by the weight per square mm gives the cross-sectional area for that particular fruit in square millimeters (mm^2).

d. *Locular architecture*

In some hybrids, changes also occur in the locular architecture of the fruit as maturity progressed. The locular structure as well as the degenerating seeds in the fruit become more pronounced as fruits advance in age (Figure 14).
Changes in the locular architecture may be assessed by cutting fruits transversely at the mid-point and noting any changes in the locular architecture.

2.6.4. Changes in post-harvest qualities during maturation

Changes also occur in the post-harvest qualities of banana, cooking banana and plantain during maturation, hence it is important to assess these qualities to enable identification of key indices of maturity. The major post-harvest qualities that must be assessed include:

a. *Peel and pulp colour*

During maturation of banana, cooking banana and plantain hybrids, changes occur in the peel and pulp colour that are essential in the overall assessment of fruit maturity. In most *Musa* hybrids, the peel colour changes from deep green to light green (or yellow/green) as fruits advance in maturity. In most banana (and some cooking banana) hybrids, the pulp colour of pre-climacteric fruits changes from white to cream or pale yellow tint during the latter stages of development on the plant. In most plantain hybrids, the pulp colour is usually pale yellow in immature fruit, but changes to orange/yellow as fruit advance in age. These changes in peel and pulp colour may signify the onset of physiological maturity and could be used in the estimation of fruit of maturity in new *Musa* hybrids.
The post-harvest methods and procedures for the assessment of peel and pulp colour have been described in the preceding chapter.

b. *Pulp firmness*

Generally, pulp firmness of most banana, cooking banana and plantain hybrids do not change significantly during the early stage of maturation, but as growth progresses changes in pulp firmness may occur. It is therefore important to ascertain pulp firmness during fruit maturation.

The methods and procedures for the measurement of pulp firmness have been described in Chapter 1.

c. *Pulp pH and total titratable acidity*

Changes in pulp pH and total titratable acidity during maturation are hybrid dependent. Some *Musa* hybrids are characterised by a decrease in pulp pH and increase in titratable acidity as fruits advance in age, while in some hybrids, there are no significant changes in pulp pH and titratable acidity during fruit maturation. Thus, pulp pH and titratable acidity could be used as an indicator of maturity in some banana, cooking banana and plantain hybrids.

The post-harvest methods and procedures for the assessment of pulp pH and total titratable acidity have been described in Chapter 1.

d. *Peel and pulp moisture and dry matter content*

Peel and pulp moisture and dry matter content of banana, cooking banana and plantain are important post-harvest quality attributes in the assessment of fruit maturation. During maturation of banana, cooking banana and plantain, changes occur in peel and pulp moisture and dry matter content, however these changes are hybrid/cultivar dependent.

Post-harvest methods and procedures for the assessment of peel and pulp moisture and dry matter content of banana, cooking banana and plantain have been described in the preceding chapter.

3.   Green-Life

Cooking banana, plantain and particularly banana are usually harvested at matured green stage and stored. During storage, they remain firm and green without any significant changes in skin colour, texture or composition for an extended period of time (depending on the temperature, humidity and age at harvest), before the commencement of ripening. This well defined period after harvest, during which fruits remain green and firm, is referred to as the pre-climacteric life or green-life (Blake and Peacock, 1971; Peacock, 1966; Peacock and Blake, 1970). Once the green-life of the fruit has ended and ripening has been initiated, it is irreversible and any fruit in this condition would be over ripe during the marketing process.

Successful introduction of new banana, cooking banana and plantain hybrids will not only be determined by their disease resistance durability and agronomic suitability alone. Their green-life potential would play a significant role in the overall acceptability (of the new hybrids). The selection of hybrids which have long green-life or remain green for a long time after harvest, or ripen slowly, would facilitate marketing of the fruit and reduce post-harvest losses. Therefore new *Musa* hybrids should be screened for their green-life potential.

Below are the post-harvest methods and procedures for the assessment of green-life of banana, cooking banana and plantain.

3.1.   Assessment of green-life

Assessment of green-life involves the following methods and procedures:

• Tag plants in the field immediately after flower emergence (note date of flowering) and calculate the number of days from anthesis to harvest to obtain accurate estimate of bunch age.

• Harvest bunches of different ages (or maturities), dehand, pack in replicated boxes (lined with perforated polyethylene film) and store at two separate temperatures of 14±1°C and 27±1°C. Relative humidity should be well controlled (e.g. 90-95%), to prevent severe water loss or dehydration of fruits which could trigger ethylene production and hence premature ripening (George and Marriott, 1983).

• Prior to storage, take representative samples of fruit and assess initial peel and pulp colour, pulp firmness and total soluble solids (as described in chapter 1).

• Green-life may be assessed as follows:

(a) Visually inspect the peel colour of fruits at each storage temperature at least twice daily;

(b) Take representative samples of fruit from each storage temperature (at regular intervals) and measure respiration rates, ethylene production, (as described below), pulp firmness and total soluble solids (as described in chapter 1);

(c) Any box containing fruits detected to commence ripening should be removed from storage (since the ethylene produced by a fruit would trigger ripening in the rest of the fruits);

(d) Once ripening commences the green-life ends. Green-life is calculated as the period (in days) between harvest and commencement of ripening.

Green-life of banana, cooking banana and plantain is usually related to bunch age (Dadzie, 1993, 1994b, c).

3.2. Methods of measuring respiration rates and ethylene production

Various methods of estimating respiration rates and ethylene production of plant organs including banana, cooking banana and plantain have been reported but none is entirely satisfactory. The methods are either based on direct measurements of carbon dioxide (CO_2) or oxygen (O_2) and ethylene (C_2H_4) or on indirect monitoring pressure or volume variations from CO_2 (and C_2H_4) production and O_2 uptake. The following are the two main methods of estimating CO_2 (or O_2 uptake) and C_2H_4 production:

3.2.1. Flow through system

The flow through system involves incubation of the plant organ or fruit in a sealed container through which is passed a known flow of gas. The exit stream is passed through a column containing CO_2 absorber, such as sodium hydroxide (NaOH) or potassium hydroxide (KOH), which absorbs the respired CO_2. The amount of CO_2 production during a specific duration is determined by subsequent titrimetric or gravimetric analysis of the absorbed material. Alternatively, CO_2 (or O_2) and C_2H_4 concentration differences between the inlet and outlet of the container can be determined using a gas chromatograph (thermal conductivity detector, (TCD) for CO_2 and O_2 detection or an infra red gas analyser (IRGA) for CO_2 detection; while flame ionization detector (FID) for C_2H_4 detection) (Kader, 1987; Solomos, 1987).

The respiration rate (and ethylene production) is calculated on the basis of fruit weight, flow rate and change in CO_2 or O_2 concentration (or C_2H_4 concentration)

Respiration rate (ml or cm^3 O_2 (or CO_2) kg^{-1} hr^{-1}) or rate of ethylene production (μl C_2H_4 kg^{-1} hr^{-1}) is calculated as:

$$\frac{\Delta O_2 \text{ or } \Delta CO_2 \text{ or } \Delta C_2H_4}{100} \quad \times \quad \frac{\text{flow rate (ml/h)}}{\text{fruit weight (kg)}}$$

Where : ΔO_2 = change in O_2 concentration (%)

      ΔCO_2 = change in CO_2 concentration (%)

      ΔC_2H_4 = change in C_2H_4 concentration (μl^{-1}).

Limitation

The flow-through system is especially suited for the measurement of CO_2 and C_2H_4 flux since these gases can be scrubbed (using KOH and $KMnO_4$ respectively) from the incoming gas flow so that only the amounts produced by the fruit are present in the effluent stream of air. It is also extremely difficult to measure O_2 accurately using this approach, since it is necessary to measure accurately the difference between the inlet and outlet streams, following a relatively small amount of O_2 uptake by the fruit (Ben-Yehoshua and Cameron, 1988).

3.2.2. Closed system

In this method, fruit are sealed in a container and the accumulation of CO_2 and C_2H_4 and/or depletion of O_2 in the atmosphere of the sealed container are measured (using a gas chromatograph, TCD for CO_2 and O_2; or IRGA for CO_2 detection; while FID for C_2H_4 detection) after a specific duration usually one hour.

Limitation

The principal limitation of the closed system is that it is a non equilibrium system, and the depletion of O_2 and the accumulation of CO_2 or C_2H_4 may affect the tissue and its respiration rate (Kader, 1987). These problems can be overcome by keeping the incubation period to the minimum possible (usually one hour).

The rates of O_2 uptake, CO_2 and C_2H_4 production are calculated as follows:

a. Rate of O_2 uptake (cm^3 kg^{-1} h^{-1}) :

$$\frac{[O_2]\ initial - [O_2]\ final}{100} \times (V_{jar} - V_{fruits}) \times \frac{1000}{P_{fruits}} \times \frac{60}{T}$$

b. Rate of CO_2 production (cm^3 kg^{-1} h^{-1}) :

$$\frac{[CO_2]\ final - [CO_2]\ initial}{100} \times (V_{jar} - V_{fruits}) \times \frac{1000}{P_{fruits}} \times \frac{60}{T}$$

c. Rate of C_2H_4 production (μl kg^{-1} h^{-1}) :

$$\frac{[C_2H_4]\ final - [C_2H_4]\ initial}{1000} \times (V_{jar} - V_{fruits}) \times \frac{1000}{P_{fruits}} \times \frac{60}{T}$$

Where : [O_2] initial   = Initial oxygen concentration (%)

[O_2] final   = Final oxygen concentration (%) (0,01 % = 100 ppm)

[CO_2] initial = Initial carbon dioxide concentration (%)

[CO_2] final   = Final carbon dioxide concentration (%)

[C_2H_4] initial = Initial ethylene concentration (μl^{-1}) ([0,01 μl^{-1}] = ppm)

[C_2H_4] final   = Final ethylene concentration (μl^{-1})

$V_{conteneur}$ = Container or jar volume (cm^3)

V_{fruits} = Fruit volume (cm^3)

P_{fruits} = Fruit weight (kg)

T = Time (hour).

3.3.   Shelf-Life

Shelf-life is simply the time period that a fruit can be expected to maintain a predetermined level of quality under specified storage conditions. In other words, the period (in days) between initiation or commencement of ripening (i.e. end of green-life) and end of saleable life or edible life (of the fruit) on the shelf. It is essential that new banana, cooking banana and plantain are screened for their shelf-life potential, since it would provide useful information about the storage and marketing potential of the new hybrids. By knowing the shelf-life, it would also enable proper and adequate storage, handling and marketing techniques to be devised.

3.3.1. Assessment of shelf-life

Shelf-life determination requires specification of quality criteria and storage conditions. Shelf-life begins immediately the green-life of the fruit ends. Fruits stored at the two temperatures $14\pm1°C$ and $27\pm1°C$ (as described in the preceding chapter) must be transferred to ambient temperature immediately the green-life ends and the shelf-life monitored.

Shelf-life is assessed by regular visual inspection of fruits. Shelf-life is calculated as the period (in days) between commencement of ripening and end of saleable life (i.e. saleable quality) or edible life (of fruit) on the shelf.

4.   Fruit Ripening Quality

During ripening, most fruits undergo many physical and chemical changes after harvest that determine the quality of the fruit purchased by the consumer. Fruit ripening quality is an important post-harvest selection criterion, hence new banana, cooking banana and plantain hybrids be screened for their ripening quality. The ripening quality of new *Musa* hybrids should be consistent with the parents from which they were developed.

Traditionally, the stage of ripening of banana, cooking banana and plantain have been closely linked with the changes in peel colour (Lœsecke, 1950; Palmer, 1971) and the matching of the peel colour against a set of standard colour plates is a common method used to assess the ripeness of the fruit. Sometimes, high temperatures and low relative humidities could cause fruits to retain their green peel colour even though ripening has already commenced internally creating a situation whereby the peel colour does not reflect the internal changes. Therefore, the use of a combination of external and internal indicators of ripeness are essential in the assessment of the stages of ripeness of new *Musa* hybrids. Simple and reliable post-harvest methods and procedures for assessing ripening quality or the stage of ripeness would assist in scheduling harvesting, transportation and marketing operations efficiently.

4.1.   Changes that may occur during ripening

Fruit ripening is the result of a complex of changes, many of them probably occurring independently of each other (Brady, 1987). The following are the list of some major changes that occur in most banana, cooking banana and plantain during ripening:

• Peel and pulp colour changes.

• Conversion of starch into sugar.

• Changes in pulp to peel ratio (and ease of peeling).

• Changes in pulp firmness or pulp softening.

• Changes in total soluble solids content.

• Changes in pulp pH and total titratable acidity.

• Changes in peel and pulp moisture and dry matter content.

• Changes in respiration rate and ethylene production.

4.2. Assessment of changes that occur during ripening

In assessing changes that occur during ripening of banana, cooking banana and plantain:

- Harvest physiologically matured bunches and take the fingers of the second hand of the bunch. However, if there are not enough samples, fruits from the third hand may be included.
- Ripen fruits naturally at ambient temperature or by exposure to ethylene (1 ml/litre) for 24-48 hours.
- Ventilate and allow fruits to ripen at a temperature of 18°C and relative humidity of 90-95%.

The following changes that occur during ripening of banana, cooking banana and plantain are assessed as follows:

4.2.1. Peel and pulp colour changes

The disappearance or loss of peel green colour and the corresponding increase in yellowing of the peel during ripening are the obvious manifestations in banana, cooking banana and plantain. The loss of green colour is due to degradation of the chlorophyll structure. External changes in peel colour during ripening often reflects changes in pulp colour (Deullin, 1963; Wainwright and Hughes, 1989, 1990).

Classify fruits according to peel colour by visually matching the peel colour of fruits against a colour chart (e.g. Figure 15). Also the use of colour measuring devices (methods and procedures described in Chapter 1) could give a good indication of the changes that occur (in the peel and pulp) during ripening or the stage of ripeness of the fruit. Peel and pulp colour charts may be developed for each hybrid to help standardise the stages of ripeness.

4.2.2. Conversion of starch into sugar

The most striking post-harvest chemical change which occurs during the post-harvest ripening of banana, cooking banana and plantain is the hydrolysis of starch and the accumulation of sugar (i.e. sucrose, glucose and fructose; Lœsecke, 1950, Palmer, 1971) which are responsible for the sweetening of the fruit (as it ripens). In dessert banana (e.g. Cavendish) the breakdown of starch and the synthesis of sugar is usually completed at full ripeness (peel colour stage 6-7), while in plantain this breakdown is slower and less complete and continues in over-ripe and senescent fruits (Marriott *et al*., 1981).

Different methods and procedures for assessing starch (or sugar) content during ripening of fruits (including banana, cooking banana and plantain) have been described by various researchers (AOAC, 1990; Josylin 1970; Kayisu *et al*., 1981), however most of these methods are complex, time consuming and require trained personnel and expensive technology. Hence, an easy, rapid and inexpensive method of estimating the starch content of the fruit could serve as a useful indicator of ripeness. The starch iodine test is a simple, rapid and inexpensive method of visually assessing the conversion of starch to sugar during fruit ripening.

Starch iodine test

The starch iodine test was originally designed to help assess maturity in apples (especially, Granny Smith apples; Reid *et al*., 1982; Saltveit and Hale, 1982). This technique has been adopted to assist in the assessment of the conversion of starch into sugar during ripening of banana, cooking banana and plantain (Blankenship *et al*., 1993; Dadzie, 1993, 1994b, c; Garcia and Lajolo, 1988; Kader *et al*., 1994).

PRINCIPLE

The basis of the starch iodine test is that, starch accumulated by the fruit during growth and maturation is converted to sugar as the fruit ripens. The process of starch degradation or the relative degree of hydrolysis or starch conversion to sugar can be visually assessed by staining cross-sections of fruit with iodine-potassium iodide. This shows the loss of starch commences in the locules next to the degenerate ovules and spread throughout the locule as ripening progresses in a pattern characteristic of the cultivar/hybrid (Blankenship *et al*., 1993; Dadzie, 1993, 1994b, c; Kader *et al*., 1994). The test is most useful when index values (e.g. scale of 1-8 corresponding to peel colour stage (Figure 15); Lœsecke, 1950) are assigned to the changing starch pattern.

Preparation of reagent

Dissolve 10 g potassium iodide (dissolve first in small amount of hot water, because the potassium iodide takes longer time to dissolve in cold water) and 2.5 g iodine in 1 litre of distilled water. The solution should be stored in a sealed glass container in a dark place (as it will deteriorate in the light) until required.

Assessment of ripening changes using the starch iodine test

The following are the methods and procedures in the assessment of ripening changes in banana, cooking banana and plantain using the starch iodine test:
• Cut transversely from the mid-point of the fruit approximately 2-3 cm thick and separate the peel from the pulp;
• One side of the cut surface of the pulp should be stained for 5 seconds in potassium iodide/iodine solution (Figure 16);
• The starch present in the pulp would react with iodine causing a dark blue colour change. Immature banana, cooking banana and plantain have a high starch content and hence have a high degree of blue colouration. Where the starch in the pulp has changed to sugar (during ripening), no iodine reaction occurs and the area stays a pale tan colour;
• Assessment of the starch pattern of each fruit is done by comparing the stained cut surface with an accompanying photograph (e.g. Figure 17);
• Scale of 1-8 corresponding to peel colour stage should be assigned to the changing starch pattern (Figure 17).

The first visual signs of failure to stain for starch during ripening occur in the locules next to the degenerate seeds where starch degradation usually commences (and spreads out during ripening). The intensity of staining depends largely on the stage of ripeness, the amount of starch in the pulp and cultivar/hybrid (Figure 17). For instance, in ripe (peel colour stage 7) dessert bananas the major part of the locule fails to stain for starch, whereas in plantain and cooking bananas the failure to stain may only be commencing at the yellow peel stage. Hence the differences in

the timing of these changes and in the relative sizes of locular tissues may account in part for the differences between *Musa* spp. in their starch contents at equivalent physiological ages (peel colours). The use of the starch index pattern to distinguish between the various stages of ripeness provide a rapid and simple method of assessing pulp starch conversion to sugar.

Limitation
The differences between colours in the range of high starch content are not very distinct.

4.2.3. Changes in pulp to peel ratio

Pulp to peel ratio is a good and consistent index of ripening of banana, cooking banana and plantain. Pulp to peel ratio increases in response to ripeness (i.e. peel colour score). Changes in pulp to peel ratios during ripening of banana, cooking banana and plantain indicate differential changes in moisture content of the peel and pulp. The increase in pulp to peel ratio during ripening is related to sugar concentration in the two tissues. During ripening, there is a rapid increase in the sugar concentration in the pulp compared to the peel thus contributing to a differential change in osmotic pressure. The peel looses water both by transpiration to the atmosphere and also to the pulp by osmosis, (Stover and Simmonds, 1987) thereby contributing to an increase in the fresh weight of the pulp as the fruit ripens. This results in an increase in the pulp to peel ratio during ripening.

Post-harvest methods and procedures for the assessment of peel to pulp ratio during ripening of banana, cooking banana and plantain have been described in Chapter 1.

4.2.4. Changes in pulp firmness

Under normal storage conditions, banana, cooking banana and plantain, undergo significant textural transformations as they pass through the ripening process. The crisp, hard and green fruit turns into a yellow fruit with tender and soft internal pulp at the optimal ripening stage, and becomes mushy as it advances towards senescence. The loss of firmness during ripening leads to lower quality and higher incidence of mechanical damage during handling and transportation. Loss of pulp firmness during ripening varies with cultivar/hybrid. Pulp firmness is often inversely related to ripening, implying that, as ripening progressed, pulp firmness declined (Smith *et al*., 1989). Generally, the triploid cultivars are usually firmer than the tetraploid hybrids (Dadzie, 1994c). Loss of firmness or softening during ripening has been associated with two or three processes. The first is the breakdown of starch to form sugar. The second is the breakdown of the cell walls or reduction in the middle lamella cohesion due to solubilisation of pectic substances (Palmer, 1971; Smith *et al*., 1989). The third is the movement of water from the peel to the pulp during ripening due to the process of osmosis.

Post-harvest methods and procedures for the assessment of pulp firmness during ripening of banana, cooking banana and plantain have been described in Chapter 1.

4.2.5. Changes in total soluble solids content

During ripening of banana, cooking banana and plantain, the total soluble solids content increases. However, the magnitude of increase is dependent on cultivar/hybrid. In most ripe fruits, including banana, cooking banana and plantains, sugar forms the main component of soluble solids. Since the amount of sugar in fruits usually increases as the fruit matures and ripens, the soluble solids content of the fruit can be a useful index of stage of ripeness. Soluble solids content vary between cultivar and between stage of ripeness. For instance, in some hybrids soluble solids contents increase to a peak and then decline (the drop in total soluble solids may be due to the conversion of sugar in the pulp to alcohol). While in some hybrids, total soluble solids continue to increase with ripening.

Methods and procedures for the assessment of total soluble solids content during ripening of banana, cooking banana and plantain have been described in Chapter 1.

4.2.6. Changes in pulp pH and total titratable acidity

Pulp pH and total titratable acidity are important post-harvest quality attributes in the assessment of fruit ripening quality. In most banana, cooking banana and plantain cultivars/hybrids, there is a rapid decline in pulp pH in response to increasing ripeness. However the magnitude of decline is cultivar dependent. Generally, when fruits are harvested at matured green stage, the pulp pH is high but as ripening progresses pH drops. Thus the pulp pH could be used as an index of ripening.

Usually organic acids decline during ripening as they are respired or converted to sugar (Wills *et al*., 1989). Organic acids are important in giving a desired sugar-to-acid balance which results in pleasing fruit taste during ripening. Acidity measured as titratable acidity in the pulp tissues of most banana, cooking banana and plantain cultivars/hybrids shows large increases during ripening or as ripening progresses. Therefore, total titratable acidity could be used as an index of ripening.

Post-harvest methods and procedures for the assessment of pulp pH and total titratable acidity during ripening of banana, cooking banana and plantain have been described in Chapter 1.

4.2.7. Changes in peel and pulp moisture and dry matter content

Peel and pulp moisture and dry matter content are important post-harvest parameters in the evaluation of the ripening quality of new banana, cooking banana and plantain hybrids. During ripening, the moisture content of the peel decreases whereas that of the pulp increases, this is because the peel looses water both to the atmosphere and to the pulp. In most cultivars/hybrids, the dry matter content of the peel and pulp during ripening does not change significantly.

Methods and procedures for the assessment of peel and pulp moisture and dry matter content during ripening of banana, cooking banana and plantain have been described in Chapter 1.

4.2.8. Changes in respiration rate and ethylene production

During ripening of banana, cooking banana and plantain, there is a tremendous increase in the amount of ethylene produced. This increase is usually accompanied by an increase in respiration rate of the fruit (a phenomenon which is called the climacteric). The rate of respiration and ethylene production usually depends on storage temperature, age of fruit and cultivar/hybrid (Kader, 1987).

Post-harvest methods and procedures for the estimation of respiration rate and ethylene production of banana, cooking banana and plantain during ripening have been described in Chapter 3.

5.   Sensory Quality

Although instruments can be used to objectively measure various aspects of post-harvest quality of banana, cooking banana and plantain, these measurements would be of little value if they are not related to human evaluations. Furthermore, instruments will only analyse components within their capabilities, whereas sensory analyses rely upon evaluation through the use of our senses to give a total impression of aroma, taste, temperature, auditory and tactile component. Therefore, objective physiological measurements must be complemented with subjective studies of fruit palatability for which taste panels must be used. Results of sensory, chemical and objective tests can easily be correlated to identify the relationship among the chemical and physical properties of a cultivar/hybrid and its sensory qualities.

Sensory evaluation studies are very important in the screening of new *Musa* hybrids since they give an indication of the potential for consumer acceptability of the new hybrids. They also provide valuable information to plant breeders for future breeding work.

5.1.   Sample preparation and presentation

Sensory testing does not require elaborate facilities but some basic requirements must be met if tests are to be conducted efficiently and results are to be reliable (Watts *et al*., 1989). Ideally, sensory evaluation tests should be performed as follows:

• In special facilities housing a number of individual booths or portable booths which can be constructed easily.

• The booths should:

(a) be partitioned from one another to eliminate interaction between panelists and to facilitate concentration;

(b) provide an atmosphere conducive to making sound judgements;

(c) be clean, adequately lighted (in some cases it is desirable to have lights that mask colour differences between samples) and ventilated, free from chemical odours or cigar smoking, audio and visual distractions, equipped with a sink for rinsing and expectoration, with ready access to the food preparation area.

• Samples should be presented to panelists in a form and at a temperature at which they are consumed normally.

• Samples should be coded in a fashion that will not bias a panelist (e.g., three-digit codes extracted from a random number table are sufficient).

• Panelist should be instructed to drink water or rinse mouth with water in between samples.

• No communication should be allowed between panelists during sensory evaluation.

• Tests should be conducted at the same time each day, preferably not to interfere with normal break times or close to a normal mealtime.

For more details on panel environment and sample preparations, refer to Watts *et al*., (1989); Piggott, (1988); O'Mahony, (1986); Lawless (1991); Larmond (1987).

5.2.   Design of questionnaire

Design of a proper questionnaire for a sensory test is critical.

The questionnaire should:

• Adequately address the objectives of the test.

• Be readily understandable, using unequivocal and clear language.

• Not be too long, so as to tax the panelists.

• Present the samples to the panelists in the same order in which they are presented physically.

• Be designed to generate valid, accurate data from the sensory tests.

Always explain the questionnaire to the panelists prior to the sensory test.

5.3.   Selection of panelists

In the selection of panelists, it important that, a large random sample of people representative of the target population of potential users, are selected to obtain information on consumers' attitudes or preferences. It is important that, panelists are untrained nor chosen for their sensory acuity, but should be users of the product.

In the screening of new *Musa* hybrids for their sensory quality, panelists can usually be drawn from the personnel of the institution or organisation where the research is being conducted. The majority of the people within an organisation are potential panelists. They will usually be interested in participation if they feel that their contribution is important. People from outside the institution or organisation willing to devote the time can also be recruited. For more details on panel selection, refer to Watts *et al*., (1989); Piggott, (1988); O'Mahony, (1986); Lawless (1991).

5.4.   Types of sensory tests

There are two major classifications of sensory tests: consumer-oriented (or affective) and product-oriented (or analytical) tests (Institute of Food Technologists, 1981).

5.4.1. Consumer-oriented or affective tests

Consumer-oriented or affective test are used to evaluate preference (e.g. paired preference test) or degree of liking (e.g. hedonic scaling) and/or acceptance and/or opinions of products. Generally, a large number of respondents are required for such evaluations. A minimum of 24 panelists may be used, however 50-100 panelists are usually considered adequate. Unlike analytical tests, these panelists are untrained, but are selected at random, representative of a target population. Panelists are selected in accordance with a number of criteria, which may include: previous use of the product, age, sex, economic or social level, geographic area etc.

5.4.2. Product-oriented or analytical tests

Product-oriented or analytical tests are used for laboratory evaluations of products in terms of differences or similarities and for identification and quantification of sensory characteristics. There are two major types of analytical tests; discriminative and descriptive. Both employ experience and/or trained panelists. Potential panelists are screened for selected personal traits, interest and ability to discriminate differences and generate reproducible results. Training further familiarises the panelists with test procedures and increases their ability to recognise, identify and recall sensory characteristics. In effect panelists are trained to function as human analytical instruments.

• Discriminative tests consist of difference and sensitivity tests:
    (a) Difference tests (e.g. paired-comparison, Duo-trio, triangle, ranking test etc.) measures simply whether samples are different. It answers the question: are there any perceived differences between the samples;
    (b) Sensitivity test measures the ability of individuals to detect sensory characteristics.

• Descriptive tests (e.g. scoring, rating) answer the question: what are the perceived sensory characteristics and their relative intensities. It measures qualitative and/or quantitative characteristics.

For more details about the types of sensory tests that could be used, refer to Watts *et al*., (1989); Piggott, (1988); O'Mahony, (1986); Lawless (1991); Stone and Sidel, (1985).

5.5.   Key aspects of sensory evaluation

Prior to any sensory study of banana, cooking banana and plantain, it is essential to assess objectively, some key post-harvest characteristics (e.g. peel and pulp colour, pulp firmness, total soluble solids content, pH and titratable acidity, etc.) relevant to the sensory test. The data obtained could be related to the sensory qualities being ascertained and would also help explain some of the differences in consumer preference and acceptability (Dadzie, 1993, 1994b, c).

The three key aspects of sensory evaluation essential in the post-harvest screening of new *Musa* hybrids are as follows (in any sensory study of this nature it is very important to always have control samples):

5.5.1. Consumers criteria for selection at the time of purchase

At the time of purchase of banana, cooking banana or plantain, consumers criteria for selection are based largely on visual impression or appearance, colour, shape and size.

To ascertain consumers criteria for selection:

Untrained panelists (comprising both men and women) should be presented (in a blind test) with coded samples (e.g. fingers or hands) of banana, cooking banana or plantain hybrids and standard cultivars.;

• Panelist should be given a questionnaire (or taste panel test sheet) in which they should be asked to assume that they had gone to the supermarket (or market) where there are many different banana, cooking banana or plantain cultivars on display.;

• Panelist should be asked to rank the coded samples for each sensory attribute (i.e. appearance, colour, shape and size of samples) in order of preference (Appendix 1 is an example of taste panel test sheet or questionnaire, which may be modified to suit the objective of test).

In the screening of new plantain hybrids for their sensory qualities, it is also important to assess the pulp colour of the new hybrids against standard cultivars. Most consumers of plantains prefer plantains with orange/yellow pulp colour. If the pulp colour is white consumers feel that, the fruit is immature and may not be accepted (by consumers). Hence new plantain or cooking banana hybrids should be screened for their pulp colour. Panelists should be presented in a blind test with different pulp samples (i.e. remove the peel and put pulp samples in polyethylene bag). Panelists should be asked to rank the samples in order of preference based on pulp colour (Appendix 2 is an example of taste panel test sheet or questionnaire, which may be modified to suit the objective of test).

5.5.2. Consumer acceptability

Assessment of consumer acceptability of banana or prepared dishes of plantain or cooking banana are essential in the post-harvest screening of new *Musa* hybrids.

To ascertain consumer acceptability:

To ascertain consumer acceptability of banana or prepared dishes of plantain (Dadzie and Wainwright, 1995) or cooking banana:

• Studies should be conducted in which panelists comprising both men and women be used for the sensory evaluation of (unripe and ripe) banana samples or prepared dishes of plantain or cooking banana (e.g. fried unripe chips, fried unripe, fried ripe samples, etc).

• The criteria for testing may include, texture, taste, flavour, sweetness, crispness, colour and overall acceptability (Appendix 3 is an example of taste panel test sheet or questionnaire, which may be modified to suit the objective of test).

5.5.3. Comparative evaluation

In anticipation of general introduction of new banana, cooking banana and plantain hybrids as substitutes to the existing cultivars, comparative sensory studies should be conducted to determine:

• Whether untrained randomly selected persons could distinguish between the existing cultivars and new banana, cooking banana and plantain hybrids.

• What ways are the new hybrids different in eating qualities, if any.

• The preferences of those who are able to distinguish cultivars.

This study would provide a comparative data on how individual hybrids performed against the standard cultivars and/or other hybrids.

6.   Cooking or Boiling Quality

Plantain and cooking banana are nearly always cooked before use and may be boiled, fried, baked/roasted or dried either intact or after grating or pounding. This diversity of culinary processes depends largely on the texture and composition of the fruit. The texture and appearance of the pulp of plantain or cooking banana after cooking are particularly important to the consumer. Consumers of boiled green plantain or cooking banana, usually prefer that the pulp remains firm and 'crunchy' after cooking rather than too soft and water soaked. Hence, the texture of the cooked pulp is often important in determining a good cooking plantain or cooking banana cultivar. It is therefore essential to screen new *Musa* hybrids for their cooking qualities or suitability to cooking.

6.1.   Cooking quality parameters

The follow parameters are essential in the assessment of cooking quality or suitability to cooking of banana, cooking banana and plantain hybrids:
> (1) Ease of peeling;
> (2) Pulp firmness (before and after boiling);
> (3) Pulp water absorption;
> (4) Duration of cooking (or boiling).

6.2.   Assessment of cooking or boiling quality

The cooking quality or suitability (or response) to cooking of banana, cooking banana and plantain could be assessed using the following post-harvest methods and procedures:

6.2.1. Ease of peeling

Consumers of green boiled plantain or cooking banana often prefer cultivars/hybrids that are easy to peel, hence the ease or difficulty to peel should be ascertained. At matured green stage, ease of peeling of cooking banana or plantain largely depends on peel thickness and the degree of adhesiveness of the peel to the pulp. When fruits ripen they are generally easy to peel, hence ease of peeling should be assessed on green or unripe fruits and not on ripe fruits.

The ease or difficulty to peel is assessed subjectively on matured green plantain or cooking banana by peeling each fruit and scoring (the ease or difficulty to peel) on a scale of 1-5. It is important that new hybrids are evaluated against standard cultivars.

After assessing ease of peeling, pulp to peel ratio and pulp thickness are then assessed. The pulp to peel ratio and pulp thickness are important post-harvest quality indices essential in the evaluation of the cooking quality of matured green plantain and cooking banana. This is because consumers of boiled green plantain or cooking bananas often prefer thicker and bigger pulp (i.e. higher pulp than peel). Thus, by assessing the pulp to peel ratio and pulp thickness of the new hybrids, one gets a good indication of the proportion of the pulp to the peel as well as the thickness of the pulp.

Methods and procedures for the assessment of pulp to peel ratio and pulp thickness of cooking banana and plantain have been described in Chapter 1.

6.2.2. Pulp firmness and water absorption

During cooking or boiling, banana, cooking banana and plantain absorb some quantity of water which ultimately results in softening of the pulp. The amount of water absorbed often depends to some extent on the duration of cooking, the cultivar and other factors. Usually good cooking qualities of a cultivar/hybrid may be related to its low water absorption potential, high initial pulp firmness, high percentage pulp dry matter and low moisture content. Hence these parameters should be ascertained.

Assessment of cooking quality or suitability to cooking involves controlled boiling or cooking of pulp samples as follows:

• Harvest physiologically matured green bunches and take the fingers of the second hand of the bunch. However, if there are not enough samples, fruits from the third hand may be included.

• Measure the initial pulp firmness, pulp dry matter content and moisture content of a representative sample (by the methods described in Chapter 1) prior to assessment of cooking quality.

• Cut pulp into 1 cm thick pieces.

• Take 5-10 pieces of the cut pulp samples at a time and weigh on a balance (e.g. Mettler electronic balance to 4 decimal places).

• Put 5-10 pulp samples at a time in a 600 ml pyrex beaker containing 300 ml of boiling distilled water plus 1 gram of salt.

• Allow samples to boil at time intervals of e.g. 5, 10, 15, 20, 25 and 30 mins (use a stop watch to monitor time).

• After boiling for 5, 10, 15, 20, 25 or 30 mins, quickly empty samples into a kitchen sieve (to drain the boiling water)

• Allow samples to cool for 10 mins at ambient temperature, re-weigh samples (as described above) and measure the pulp firmness (as described earlier).

• The cooking quality or suitability (or response) to cooking is determined from the percentage water absorption which is calculated as the difference in weight of pulp before and after cooking or boiling expressed as a percentage of the initial weight.

• Changes in pulp firmness or water absorption may be determined by plotting the pulp firmness or percentage water absorption against the cooking time (i.e. 0, 5, 10, 15, 20, 25 and 30 mins).

Pulp dry matter and moisture content should be related to the pulp firmness and water absorption, since it may assist in distinguishing a good cooking cultivar/hybrid from a bad one.

6.2.3. Duration of cooking

After cooking pulp samples for 5, 10, 15, 20, 25 and 30 mins, the suitable cooking time is determined as the time at which the pulp sample is well cooked, firm and not water soaked. The shorter the cooking time the better. Usually cultivars/hybrids with higher initial pulp firmness, high pulp dry matter content and low moisture content require longer cooking time (Dadzie, 1993, 1994b, c).

7.   Processing Quality

The bulk of the banana, cooking banana and plantain are eaten either as raw, in the ripe state, or as a cooked vegetable, and only a very small proportion are processed in order to obtain a storable product. Generally, preserved products do not contribute significantly to the diet of the millions of people who eat banana, cooking banana and plantain, however in some countries or areas, the processed or preserved products are important in periods when food is scarce. Processing is recognised as a way of preserving the fruit. Yet the proportion of fruits processed and the suitability of the various *Musa* groups to processing is relatively unknown. New *Musa* hybrids should therefore be screened for their processing quality or suitability for processing.

There are many different products that can be made from banana, cooking banana and plantain and only the common and more widespread ones will be described in this chapter. The following are some of the products:

7.1. Flour

Flour can be made from green unripe banana, cooking banana or plantain. Fruits should be hand-peeled and sliced or chopped into pieces about 5-10 mm thick. The slices may be dried in the sun by spreading out the slices on mats, on bamboo frame-work, on cement floors, or on a roof or sheets of corrugated iron or simply on a swept-bare ground. Various designs of solar dryers can be used, or they may be dried in ovens, over fires, in a cabinet dryer or tunnel dryer. After drying, the chopped pieces have a moisture content of about 5-10%. The dried pieces are ground and usually sieved to produce the flour. Flour may be packed in moisture proof bags. The dried slices may be stored and only converted to flour when needed since the flour tends to lose its flavour rapidly or may absorb moisture (hygroscopic) and become mouldy.

7.2. Powder

Powder may be prepared from fully ripe banana, cooking banana or plantain. Fruits should be washed, hand-peeled and chopped fairly coarsely. The material is converted into a paste by passing through a mill to reduce the particle to a colloidal size (below about 10 μm). A 1-2% Sodium metabisulphite solution is added at this stage to improve the colour of the final product or to prevent discolouration. The material is then dried. Drying can be achieved, either in a spray dryer (at 30-32°C and less than 30% RH under vacuum) or a drum dryer (product temperature should not exceed 94°C). After drum drying it might be necessary to further dry the product in a cabinet dryer. The final moisture content of the powder should be about 2% and should be stored in moisture proof bags (Thompson, 1995).

7.3.   Canned slices

Several methods for canning banana slices in syrup have been described (Lawler, 1967; Smit and Burger, 1957). Best quality slices are obtainable from fruit at an early stage of ripeness. The slices are processed in a syrup of 25° Brix with pH of about 4.2 and in some processes calcium chloride (0.2%) or calcium lactate (0.5%) are added as firming agent (Marriot and Lancaster, 1983).

Canning plantain slices in syrup is considered to be unsatisfactory (Sanchez-Nieva and Hernandez, 1967). However, ripe slices may be cooked in 40° Brix syrup until the concentration of the syrup reach 54-60° Brix and cinnamon and lemon juice is added to improve the colour. The product may be packed in boilable plastic pouches and quick-frozen at -23°C. It is served by boiling the pouches in water for 15 mins.

7.4.   Chips (Crisps)

Various methods of preparing banana or plantain chips have been described in the literature (Bai and Roa, 1969; Berg *et al*., 1971; Jain *et al*., 1962). Typically, unripe banana or plantain may be thinly sliced vertically or transversely (1.2-0.8 mm thick). The slices are immersed in a sodium or potassium metabisulphate solution (to improve the colour of the final product or to prevent discolouration) and fried in hydrogenated oil at 180-200°C.   The fried slices are dusted with salt and antioxidant (e.g. butylatedhydroxytoluene to delay rancidity); (Marriot and Lancaster, 1983).

Alternatively slices may be dried before frying and the antioxidant and salt are added with the oil.   Fried chips should have moisture content of about 1.5-2%.   The temperature at which the chips are fried and the frying time affects their oil content, appearance, texture and flavour (Thompson, 1995).   The chips must be packed in moisture proof bags to prevent them absorbing moisture and losing their crispness.

7.5.   Jam and Jelly

The various methods of preparing jam and jelly have been described in the literature. In one method for the preparation of jelly, fully ripe or over-ripe fruits are used.

Fruits are hand-peeled and cut into 2 cm pieces or slices. The slices are boiled for 1 h in 60° Brix sugar syrup at the rate of 1 lb of banana to 1 pint of syrup (454 g to 0.568l). This is then strained and the clear solution is boiled until it sets. The pH should be adjusted to 3.5. Pectin may be added to improve the set (Thompson, 1995).

A commercial formula for producing banana jam is as follows (Lœsecke, 1949):
    200 lbs of sugar
    10 gallons of water
    12 ounces of cream of tartar

Heat to 110°C and then add 2.5 gallons of lemon juice (lime juice or citric acid can be used to replace the lemon juice to reduce the pH of the jam to 3.5), 200 lbs of ripe banana pulp. Heat to 107°C until the correct consistency.

8.   Mechanical Damage

Mechanical damage is one of the major factors leading to post-harvest deterioration of banana, cooking banana and plantain. It can occur at any time from the point of harvest to the point of consumption.   Mechanical damage can detract from the product's appearance and increase potential for infection by diseases. It can also result in lower market quality and price.   Hence new *Musa* hybrids should be screened for susceptibility to mechanical damage.

8.1.   Sources of mechanical damage

There are three main sources of mechanical damage to banana, cooking banana and plantain and these are:

8.1.1. Impact

Impact damage can result in bruising with or without skin rupture. Impact bruises are caused from a sharp blow such as an object falling onto the fruit or fruit falling against another fruit or onto a hard surface with sufficient force to damage or even separate the cells.   Impact damage can occur throughout the entire marketing process from harvesting through to the consumer. Injury is sometimes not immediately apparent but may show later.

8.1.2. Pressure (or compression)

Pressure (or compression) damage results from excessive pressure on the fruit. There is no need for physical movement for pressure damage to occur. Pressure damage can be caused by other fruits and occurs primarily during and after packing as a result of forcing too much produce into too small a container (i.e. over-packed or where packages are stacked too high).

8.1.3. Vibrations

Vibration damage is mainly associated with transportation and results from repeated and prolonged vibration of the fruit. This damage is greatest in the top layers of fruit, particularly where there is a loose pack, since in this situation there is little to restrain fruit vibration during transportation and distribution. Vibration damage is particularly severe in loosely packed fruits.

8.2.   Factors affecting mechanical damage

The factors affecting mechanical damage include:

8.2.1. Pre-harvest factors

Pre-harvest factors which can contribute to mechanical damage in banana, cooking banana and plantain include weather, wind, spraying and fertiliser application, insect pests, birds, rodents and farm implements.

8.2.2. Harvesting factors

In the harvesting process, mechanical damage could result from poor harvesting and handling techniques. Soil adhering to fruits (when allowed to fall down during harvesting) at harvest can also cause damage by scarring fruits when the soil is removed or washed away.

8.2.3. Post-harvest factors

Post-harvest factors which can contribute to mechanical damage include:

• Over-packing and under-packing of fruits.

• Poor packaging and handling of packed fruits during loading and unloading.

• Vibration (shaking) of vehicles especially on bad roads, speed of transportation and type of suspension.

8.3.   Mechanical damage can result in the following

• Physical changes in fruit colour and flavour.

• Softening of the fruit tissue resulting from the breakdown of individual cell walls.

• Damaged fruits generally ripen earlier than non-damaged fruits. This is due to an increase in respiration rate associated with mechanical injury as well as an increase in the production of ethylene, which hastens ripening.

• Loss of fruit weight is another result of mechanical injury with obvious consequences of lower market quality and price. The weight loss is due to the breakdown of cell walls and increase in permeability of the outer cell layers to water vapour.

• Invasion by micro-organisms, resulting in a progressive decay which may affect the entire fruit.

8.4.   Assessment of mechanical damage

Assessment of fruit susceptibility to mechanical damage is an important post-harvest selection criterion because, it may provide information on the handling and storage potential of the fruit or cultivar/hybrid. It is important in the design of packaging and packaging material for the product. It is also essential in determining the textural strength of the fruit or cultivar/hybrid.

Various authors including, Banks *et al.*, (1991); Banks and Joseph, (1991); Klevin (1987); Schoorl and Holt, (1980); Saltveit, (1984); Topping and Luton, (1986) have described various methods of assessing fruit susceptibility or resistance to bruising or mechanical damage. In the screening of new *Musa* hybrids for their susceptibility or resistance to bruising or mechanical damage, the following methods and procedures may be used:

8.4.1. Impact or drop height approach

This method is based on assessing the impact of an object (from a pre-determined height) on the fruit. In this approach an object is dropped from various heights unto the fruit (test can be applied to both unripe and ripe fruits). The following are the details of the impact or drop height approach:

• Harvest physiologically mature bunches of the same cultivar/hybrid and take the fingers of the second hand of the bunch. However, if there are not enough samples, fruits from the third hand may be included.

• With a marking pen, make a circle on the fruit surface (at the middle).

• Each fruit is bruised by dropping a known weight or object (e.g. 1000 g marble or brass cylinder) from various drop heights (e.g. 15, 30, 45, 60, and 120 cm) unto each fruit.

• A tube (e.g. made of glass, plastic or metal) is used to guide the fall of the known weight so that the impact is always perpendicular to the surface of the fruit (at the marked area on the fruit surface).

• The fruit should be held firmly on a soft foam pad while being bruised to minimise additional damage to the opposite side.

• Leave bruises to develop for at least 24 hours.

• Cut fruit in half, exactly through the centre of bruise. Place the edge of a transparent ruler against the bruise at its widest point and measure the diameter (d).

• Bruise depth (r) is estimated as the distance between the deepest part of the bruise and where the fruit surface would have been before the bruise was made.

• Calculate:
   - bruise area (A) as pi x (d/2)2;
   - bruise volume (V) as A x r/2;
   - average bruise volume at each drop height;
   - impact energy (E, joules) as: E = m . g. h;
   - bruise susceptibility is quantified as the ratio of bruise volume to impact energy.

Where:
   m = the mass of the impacting weight;
   g = the gravitational constant (9.81 m.s-2);
   h = the drop height (in meters).

8.4.2. Vibration or transportation approach

This method is based on the assessment of the effect of vibration during transportation of the fruit (test can be applied to both unripe and ripe fruits). This approach enables the assessment of percentage bruised fruits based on the method of packaging during and after transportation. The following are the details:

- Carefully harvest physiologically mature green fruits of the same cultivar/hybrid.
- Make an initial visual assessment of mechanical damage or bruises on the fruit and calculate percentage bruised fruit.
- In the case of banana, dehand and pack fruits (as intact hands) in cartons lined with perforated polyethylene (as done in the banana industry) and pack cartons into a truck. In the case of cooking banana and plantain, pack fruits into a truck as follows:
    - as intact bunches,
    - as intact hands packed in jute sacks, in cartons and control (i.e. put straight into a truck without any packaging),
    - separate single fingers packed in jute sacks, in cartons and control (i.e. put straight into a truck without any packaging).
    - Transport fruits in a truck to a known distance (e.g. 50 km).
    - Unpack fruits from the truck and store for 24 hours at ambient temperature.
    - Make a final visual assessment of mechanical damage or bruises on the fruit and calculate percentage bruised fruit.

9.   Physiological Disorders

Physiological disorders simply refer to the breakdown of plant or fruit tissue that is not caused by either invasion by pathogens (disease-causing organisms) or by mechanical damage. They may develop largely in response to an adverse environment, especially temperature, or to a nutritional deficiency during growth and development (Wills *et al*., 1989). Most physiological disorders affect discrete areas of tissue. Some disorders may affect the skin of the fruit but may leave the underlying flesh intact; others affect only certain areas of the flesh or the cortical region.

The major physiological disorders that may occur in banana, cooking banana and plantain include, finger drop, splitting of the peel and chilling injury. These disorders can lower the quality and market value or lead to total loss of the fruit. It is therefore, essential to screen new *Musa* hybrids for susceptibility to these major physiological disorders. The following are some of the important physiological disorders of banana, cooking banana and plantain.

9.1. Finger Drop

Cooking banana, plantain and especially banana are often marketed as groups of fingers attached together to form a hand. If individual fingers are dislodged from the hand, they have a lower market value (and may also predispose fruits to pathogens). This effect is called finger drop. Finger drop (see. Figure 18) is a physiological disorder which occurs as a result of the softening and weakening of the pedicel which causes individual fruit of a hand to separate or dislodge very easily from the crown during ripening (Baldry *et al*., 1981, New and Marriott, 1974; Semple and Thompson, 1988). Fingerdrop is thought to be associated with rapid ripening precipitated by too high a temperature in the ripening room (New and Marriott, 1974). Tetraploid hybrids are often more susceptible to finger drop compared to the triploid cultivars (Dadzie 1993, 1994b, c; Marriott, 1980). It is essential that new *Musa* clones are screened for susceptibility to finger drop, because some cooking banana and plantain hybrids are partly derived from male parents (mostly banana) which often are susceptible to finger drop. There is therefore, the tendency that this trait may be inherited or transferred to the new hybrids. Besides, retailers and consumers do not want fruits that have the tendency for the fingers to drop easily from the crown during handling.

9.1.1 Assessment of finger drop

Various methods and procedures for assessing susceptibility to finger drop have been described by various authors including Baldry *et al*., (1981); New and Marriott, (1974).

Susceptibility to finger drop in banana, cooking banana and plantain may be assessed as follows:

• Harvest physiologically matured green bunches.

• Dehand bunches and cut into clusters.

• Pack clusters into cartons (lined with perforated polyethylene film).

• Ripen fruits by exposure to ethylene (1 ml/litre) for 24-48 hours at a temperature of 14-18°C and relative humidity of 90-95%.

• Ventilate and allow fruits to ripen at a temperature of 18°C (RH 90-95%) to colour stage 6 or 7 (Figure 15).

• Finger drop is assessed by:

    (a) subjecting each cluster to consecutive 3-5 seconds of manual shaking and record the number of fingers dislodged;

    (b) percentage finger drop per cluster is calculated as follows:

$$\frac{\text{number of fingers dislodged per cluster}}{\text{total number of fingers per cluster}} \times 100$$

9.2 Peel Splitting

Splitting of the peel or peel splitting (Figure 19) is a physiological disorder that occur in banana, cooking banana and plantain. It may occur as a result of ripening of fruits at high temperature in a saturated atmosphere, such as may develop within polyethylene packaging. It is sometimes observed in the field during bunch development when plants are starved of water. The slightest touch of the fruit with any sharp object (e.g. knife) could cause the peel to split. Fruits nearing full maturity are most susceptible to peel splitting during a dry spell which is interspersed with heavy rains. It may also occur in fruits which have been ripened prematurely (Snowdon, 1990). During ripening, the peel looses water by transpiration (to the atmosphere) and by osmosis to the pulp. This results in the increase in volume of the pulp which presumably causes the peel to split. Cultivars/hybrids which have thin peel are more susceptible to peel splitting. Peel splitting could results in loss of market quality and value (of fruits).

9.2.1. Symptoms

Symptoms of peel splitting (Figure 19) are characterised by a longitudinal split of the peel, usually beginning from the proximal end near the pedicel. The split usually divides the peel into unequal halves and ultimately exposes the pulp as the split widens.

9.2.2. Assessment of peel splitting

Susceptibility to peel splitting in banana, cooking banana and plantain may be assessed as follows:

• Harvest physiologically matured green bunches.

• Dehand bunches, cut into clusters and pack fruits into cartons (lined with perforated polyethylene film).

• Ripen fruits by exposure to ethylene (1 ml/litre) for 24-48 hours at a temperature of 14-18°C.

- Ventilate and allow fruits to ripen at a temperature of 18°C (and relative humidity of 90-95%) to colour stage 6 (Figure 15).
- Inspect fruits for peel splitting and count number of fruits that have split peel and find the percentage.

9.3.   Chilling Injury

Chilling injury is the permanent or irreversible physiological damage to plant or fruit tissues, cells or organs, which results from the exposure of chilling-sensitive plants or organs (e.g. fruits) to temperatures below some critical threshold for that species or tissue (Lyons, 1973). It is a physiological disorder that occurs in most fruits (including banana, cooking banana and plantain) of tropical (or subtropical) origin when subjected to temperatures below the critical temperature (which is generally in the region of 12 - 14°C).   In banana, cooking banana or plantain, chilling injury may occur at temperatures at, or below 12°C (depending on cultivar and other factors). Even a few hours of chilling temperatures can be sufficient to induce permanent or irreversible damage. Chilling injury can occur in either unripe or ripe fruit. It can cause a lowering of market quality and value or total loss. Chilling injury can easily be avoided in *Musa* cultivars/hybrids by simply limiting storage or handling to temperatures above the critical threshold.

To prevent chilling injury from occurring, new *Musa* hybrids should be screened for susceptibility to chilling injury.

9.3.1. Factors contributing to development of chilling injury

Several factors contribute to the development of chilling injury in banana, cooking banana or plantain. They include (Lyons, 1973; Morris, 1982; Saltveit and Morris, 1990):

- Temperature of storage.
- Duration of exposure of fruits to that chilling temperature.
- Whether exposure of fruits (i.e. cultivar/hybrid) to a chilling temperature is continuous or intermittent.
- Relative humidity, composition of the storage atmosphere and post-harvest treatment.
- Physiological age, maturity or condition of the fruit exposed.
- Relative responsiveness (or sensitivity) of the fruit (i.e. cultivar/hybrid) to chilling.
- Cultivar and growing conditions.

9.3.2. Symptoms of chilling injury

Symptoms of chilling injury (Figure 20) are not readily apparent at the injurious chilling temperature, however they become increasingly apparent after transfer of fruits to non-chilling temperatures.   There are a number of commonly occurring visual symptoms which are characteristic of chilling injury in banana, cooking banana and plantain and these include (Lyons, 1973; Morris, 1982; Saltveit and Morris, 1990; Snowdon, 1990; Wang, 1991):

- Surface lesions, such as pitting, large sunken areas and discolouration of the surface.
- Dark water-soaked areas of the peel.

• Internal discolouration (browning) of pulp.

• Breakdown of tissues.

• Failure of fruits to ripen normally: Fruits harvested at mature but unripe stage develop a dull, grey skin colour, starch is no longer converted to sugar and fruits fail to ripen in the expected pattern following removal to ripening conditions. In severe chilling, the green fruit develops extensive sub-epidermal browning or blackening and the peel may become entirely black during ripening. When chilling is less severe, green fruits usually show no visible effect, but on ripening, the colour of the peel varies from a dull yellow to greyish-yellow or grey. These symptoms arise from accumulation of oxidised phenolic substances in the epidermal or sub-epidermal areas, accompanied by some retention of chlorophyll (Palmer, 1971).

In ripe fruits, general appearance of fruit is one of dullness, the peel having an almost greyish cast, however the pulp may be unaffected. Severely chilled fruits develops extensive sub-epidermal browning and eventually turn black. There is a loss of the development of the characteristic flavour, aroma and taste, and often the development of off-flavour.

9.3.4. Assessment of chilling injury

Chilling injury in banana, cooking banana or plantain may be assessed as follows:

• Subject both unripe and ripe fruits (always have control samples as shown in Figure 20) to varying times or duration (e.g. 24, 36, 48, 72 and 84 hours) and varying temperatures at, or below 12°C.

• Transfer fruits to non-chilling temperatures (e.g. ambient temperature, 20-25°C) for 24-48 hours for observation and record symptoms development (i.e. assessment of chilling injury).

• The symptoms listed above may serve as a guide in the assessment of chilling injury.

10.   Post-Harvest Diseases

Post-harvest diseases can cause serious losses of fruits both in terms of quantity and quality. Fruits infected with disease have no market value. There are many post-harvest diseases of banana, cooking banana and plantain. However, in this chapter, only the important diseases such as crown rot, anthracnose, cigar-end rot and finger rot are discussed. It is important that new *Musa* hybrids are screened for susceptibility to these post-harvest diseases.

10.1. Crown Rot

Crown rot is one of the most important post-harvest diseases of banana/plantain. It is characteristically a disease complex caused by several fungi, sometimes in association with other micro-organisms such as bacteria (Lukezic *et al*., 1967; Meredith, 1965, 1971; Ogawa, 1971; Snowdon, 1990). Two or more of these fungi may attack the crown simultaneously or successively and cause tissue rotting. Different organisms predominate according to locality, time of year and other factors.

The most common pathogens associated with crown rot are *Colletotrichium musae* (*Gloesporium musarum*), *Fusarium roseum*, *Fusarium semitectium* and *Botryodiplodia theobromae*. Other species including *Cephalosporium* sp., *Verticillium theobromae*, *Ceratocystis paradoxa* and *Phomopsis* sp. have been associated with the crown rot complex (Lukezic *et al*., 1967; Plœtz *et al*., 1994; Snowdon, 1990). In addition more than a dozen other fungi have been found in crown rot affected tissues (Plœtz *et al*., 1994).

In its natural state, the tough skin of banana/plantain protects the fruit against fungal diseases. But when the hands are cut from the stems, the massive open wound is an ideal weak spot for crown rot fungi to enter and grow. Crown rot fungi are everywhere in the form of microscopically small spores. Fungal spores on the fruit in the field are carried along (after harvesting bunch) to the packing house. Spores follow the fruit right into delatexing baths, where they are drawn deeply into the weak spot, the wound on the crown tissue (due to dehanding). Spores also remain on the outside of the fruit and are packed.

10.1.1. Symptoms

Symptoms of crown rot (Figure 21) are characterised by (Lukezic *et al*., 1967; Meredith, 1965, 1971; Ogawa, 1971; Plœtz *et al*., 1994; Snowdon, 1990):

• Softening and blackening of tissues at the cut crown surface.

• White, grey or pink mould may form on the surface of the cut crown.

- Infected tissue turns black and the rot may advance into the finger stalk. Severely affected fingers may fall from the crown.
- When severe, fingers will drop from the crown when suspended. Crown rot severity is highly unpredictable and it is not known why some hands in a box have crown rot and others do not.

10.1.2. Assessment of crown rot

Crown rot may occur in both green and ripe fruit of banana, cooking banana and plantain and may be assessed as follows:

- Harvest physiologically matured bunches of the same cultivar/hybrid.
- Dehand bunches, cut into clusters and with the assistance of a qualified pathologist inoculate the crown of the clusters with a known quantity of inoculum. Always have control samples for comparison.
- Pack clusters into cartons (lined with perforated polyethylene film).
- Fruits should be kept at 14°C for about 14 days. Then trigger ripening by exposing fruits to ethylene (1 ml/litre) for 24-48 hours at a temperature of 18°C and relative humidity of 90-95%. Ventilate storage room and allow fruits to ripen at 18°C and relative humidity of 90-95%.
- Crown rot should be assessed with the assistance of a qualified pathologist who can properly diagnose the disease and quantify infection correctly. It is also important to isolate and identify the pathogens causing the infection.

10.1.3. Control

Control of crown rot starts in the field with the regular removal of leaf trash. Proper field sanitation can greatly reduce the number of crown rot fungi spores present. Do not keep rotting fruits or plant waste materials near the packing station. Maintain clean washing water in the delatexing baths and change the water frequently to stop it becoming heavily contaminated with spores. Dehanding should be done carefully with a sharp knife so as to avoid leaving a ragged cut. Finally, post-harvest treatment of fruits with an effective fungicide is essential.

10.2. Anthracnose

Anthracnose is one of the important post-harvest diseases of banana, cooking banana and plantain. It is caused by the fungus, *Colletotrichum musae* (Berk. & Curt) v. Arx. Anthracnose is common on wounds, but it is capable of attacking sound fruit as well. Occasionally it invades the necks of the fingers when they are damaged.

10.2.1. Symptoms

The fungi initiate two types of infection (Meredith, 1971; Plœtz *et al.*, 1994; Snowdon, 1990):

      (1) Non-latent infection;
      (2) Latent infection.

The non-latent infection occurs in small wounds, starting from harvest and continuing to develop thereafter without a dormant period.

In green fruit, anthracnose lesions are generally dark brown to black with a pale margin, lenticular in shape, slightly sunken.

Non-latent anthracnose spots that develop on ripening fruits (Figure 22) are characterised by numerous small circular and brown to dark brown spots. These spots enlarge and coalesce to form large blotches. As the disease progresses, the blotches become sunken with the centre covered with orange masses of spores. The affected finger ripens rapidly but eventually rots.

The latent infection starts early in the season when the fruit is still on the tree but the pathogen remains dormant as a subcuticular hypha until the fruit approaches maturity. When the pathogen resumes activity on ripening, the infection causes the formation of typical brown spots on ripe fruits. It can also develop into destructive finger rots of green fruits in cold storage at 12-14°C.

The spots on the fruits are at first water-soaked, usually irregular in shape and yellowish. The spots enlarge, may become lens-shape or spindle-shaped and turn dark brown to black with a water-soaked yellowish margin. The centre of the spots may burst open. Several spots may coalesce and affect large areas of the finger. Orange masses of spores develop at the centre of the spots under moist conditions. The disease, common on injured peel, is aggravated by bruises and wounds encountered during subsequent handling. Long storage and fluctuations to high storage temperatures favour anthracnose development (Meredith, 1971; Plœtz *et al.*, 1994; Snowdon, 1990).

10.2.2. Assessment of Anthracnose

Anthracnose in banana, cooking banana and plantain and may be assessed as follows:

• Harvest physiologically matured bunches of the same cultivar/hybrid.

• Dehand bunches, cut into clusters and with the assistance of a qualified pathologist inoculate fruits with known quantity of inoculum of the fungus, *Colletotrichum musae*. Always have control samples for comparison.

• Pack clusters into cartons (lined with perforated polyethylene film).

• Fruits may be ripened naturally at ambient temperature or ripening can be artificially triggered by exposure to ethylene (1 ml/litre) for 24-48 hours at a temperature of 18°C and relative humidity of 90-95%.

• Ventilate and allow fruits to ripen at a temperature of 18°C and relative humidity of 90-95%.

• Assessment of anthracnose should be undertaken with the assistance of a qualified pathologist who can properly diagnose the disease and quantify infection correctly. It is also important to isolate and identify the fungus, *Colletotrichum musae*, causing the infection.

10.2.3. Control

Preventive measures begin in the plantation. It is important to maintain strict hygiene or sanitation in the plantation and packhouse, in order to minimise the number of spores available for infection. All cultural practices that reduce scarring and injury to the fruit will prevent anthracnose. Finally, effective fungicide treatment of fruits will also help to reduce incidence.

10.3. Cigar-end Rot

Cigar-end rot of banana and plantain is an important post-harvest disease caused by the fungi, *Trachysphaera fructigena* Tabor & Bunting and *Verticillium theobromae* (Turc) Mason & Hughes.

10.3.1. Symptoms

• Cigar-end rot (Figure 23) is essentially a plantain disease (but it is also found in banana and cooking banana), the fruits being apparently most subject to attack in their more immature stages (Wardlaw, 1961).

• The number of fingers affected in the bunch varies.

• The infection which starts with localised darkening and wrinkling of the skin, originates in the perianth and spreads slowly backwards along the finger (Wardlaw, 1931). The darkened area is bordered by a black band and a narrow chlorotic region which separates infected and healthy tissues.

• In *Trachysphaera* tip rot, the surface of the lesion becomes covered with white spores which later turn pink or brown as they mature, giving the fruit finger tip the grayish ashen appearance usually associated with cigar-end rot. Internally, the pulp may undergo a dry rot and become mummified (Brun, 1970). A wet rot can occur when secondary organisms are present.

• In *Verticillium* tip rot, the tissue is characteristically dry and fibrous and the spores are grey and powdery. In both diseases the symptoms bear a resemblance to the ashy end of a burnt cigar (Plœtz *et al.*, 1994; Snowdon, 1990).

10.3.2. Assessment of cigar-end rot

Assessment of cigar-end rot should be undertaken with the assistance of a qualified pathologist who can properly inoculate, diagnose the disease and quantify infection correctly. It is also important to isolate and identify the pathogen causing the infection.

10.3.3. Control

The principal method of control is frequent manual removal and burning of dead flower parts and infected fruits. Use of fungicide to control the disease is also recommended. In the packhouse, care should be taken to cull infected fruits to avoid contaminating the washing water with spores. Cigar-end rot is effectively controlled by covering the flower (immediately after emergence) with a polyethylene bag before the hands emerge.

10.4. Finger Rot

Finger rot is caused by the fungus *Botryodiplodia theobromae* Pat. which invades wounds on the fruit skin. It penetrates the pulp and rots entire fingers and can pass to neighboring hands. Rotting fingers ripen more rapidly and can trigger premature ripening in an entire box.

10.4.1. Symptoms

Symptoms of finger rot are characterised by (Ogawa, 1971; Williams and Tandon, 1966; Plœtz *et al.*, 1994; Snowdon, 1990):

• Symptoms usually begin at the flower end of the finger or at a wound site.

• The decay spreads uniformly and causes a brownish black discolouration of the peel and a softening of the pulp.

• The affected area of the peel becomes wrinkled and encrusted with minute black bodies (pycnidia).

• The pulp is reduced to a soft (or semi-liquid state), rotten mass, and a dark gray mould grows on the peel surface when the humidity is high.

• The rate of disease development increases during fruit ripening and can spread to adjacent fingers.

• Infected clusters tend to ripen prematurely, and fully matured fruit is the most susceptible to infection.

10.4.2. Assessment of finger rot

Finger rot in banana, cooking banana and plantain may be ascertained as follows:

• Harvest physiologically matured bunches of the same cultivar/hybrid.

• Dehand bunches, cut into clusters and with the assistance of a qualified pathologist inoculate fruits with known quantity of inoculum of the fungus, *Botryodiplodia theobromae*. Always have control samples for comparison.

• Pack clusters into cartons (lined with perforated polyethylene film).

• Fruits may be ripened naturally at ambient temperature or ripening can be artificially triggered by exposure to ethylene (1 ml/litre) for 24-48 hours at a temperature of 18°C and relative humidity of 90-95%.

• Ventilate and allow fruits to ripen at a temperature of 18°C and relative humidity of 90-95%.

• Assessment of finger rot should be undertaken with the assistance of a qualified pathologist who can properly diagnose the disease and quantify infection correctly. It is also important to isolate and identify the fungus, *Botryodiplodia theobromae*, causing the infection.

Control

The disease can be held in check by minimising fruit injury, by treatment of fruits with systemic fungicide and by rapidly reducing fruit temperature after harvest.

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List of Abbreviations

CGIAR	Consultative Group on International Agricultural Research
FHIA	Fundación Hondureña de Investigación Agrícola
IDRC	International Development Research Centre
IITA	International Institute of Tropical Agriculture
INIBAP	International Network for the Improvement of Banana and Plantain
NRI	Natural Resources Institute
ODA	Overseas Development Administration

Appendix 1
Consumer's criteria for selection of plantains
at the time of purchase

Name _____ Sex _____ Date _____

The purpose of this study is to ascertain consumer's criteria for selection of plantains at the time of purchase. Assuming you go to the market to purchase plantains and you observed that there are about five (or more) different plantain cultivars on display, what criteria do you use to decide which one to purchase? Please use the following criteria to help you answer the questions below.

Instructions
1. Please look at the coded plantain samples on display.
2. Please make your own individual judgement after a moderate amount of consideration.

Please answer the following questions as best as you can

Put the coded samples in order of preference (5 = most preferred, 1 = least preferred) according to:

A. COLOUR OF FINGERS

Rank Order	Sample n°	Reasons for preferences
5_____	_____	_____
4_____	_____	_____
3_____	_____	_____
2_____	_____	_____
1_____	_____	_____

B. SHAPE OF FINGERS

Rank Order	Sample n°	Reasons for preferences
5_____	_____	_____
4_____	_____	_____
3_____	_____	_____
2_____	_____	_____
1_____	_____	_____

C. SIZE OF FINGERS

Rank Order	Sample n°	Reasons for preferences
5_____	_____	_____
4_____	_____	_____
3_____	_____	_____
2_____	_____	_____
1_____	_____	_____

D. APPEARANCE OF FINGERS

Rank Order	Sample n°	Reasons for preferences
5_____	_____	_____
4_____	_____	_____
3_____	_____	_____
2_____	_____	_____
1_____	_____	_____

Any further comments?

_____
_____
_____
_____ Thank you for your participation.

Appendix 2

Name _____ Sex _____ Date _____

Instructions

1.Please look at the coded plantain pulps on display.
2.Please make your own individual judgement after a moderate amount of consideration.

Please answer the following questions as best as you can

Put the coded samples in order of preference (5 = most preferred, 1 = least preferred) according to:

A. COLOUR OF PULP

Rank Order	Sample n°	Reasons for preferences
5_____	_____	_____
4_____	_____	_____
3_____	_____	_____
2_____	_____	_____
1_____	_____	_____

B. SIZE OF PULP

Rank Order	Sample n°	Reasons for preferences
5_____	_____	_____
4_____	_____	_____
3_____	_____	_____
2_____	_____	_____
1_____	_____	_____

Any further comments?

_____
_____
_____
_____
_____
_____
_____
_____ Thank you for your participation.

Appendix 3

Name _____ Sex _____ Date _____

Instructions

1.You are receiving coded samples of plantain chips.

2.Please make your own individual judgements after a moderate amount of consideration.

3.You are requested to take a sip of water and pause briefly before tasting each sample, and to re-taste as little as possible.

Please answer the following questions as best as you can

Please evaluate the samples for the sensory quality parameters listed below, using the appropriate scale.

Scale	Texture	Taste	Colour	Crispness	Overall acceptability
5	very hard	excellent	excellent	very crispy	excellent
4	hard	very acceptable	like very much	crispy	very good
3	soft	good	good	slightly crispy	good
2	very soft	fair	fair	soft	fair
1	too soft	poor	poor	very soft	poor

sample number	Texture	Taste	Colour	Crispness	Overall acceptability
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____

Which (one) sample do you like most?_____

Reasons for preference

_____
_____
_____

Any further comments?

_____
_____
_____
_____
_____ Thank you for your participation.
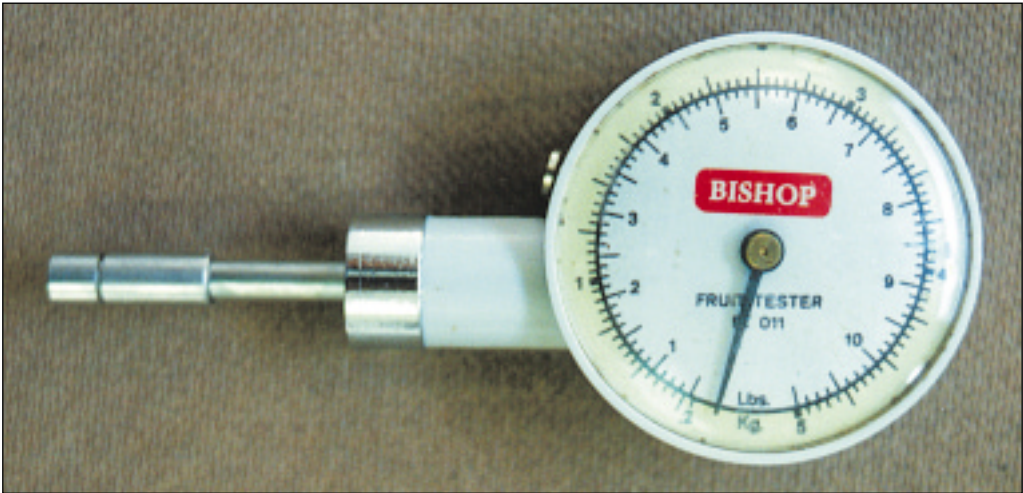
Figure 1: Measuring fruit length with a tape.

Figure 2: Measuring fruit circumference with a tape.

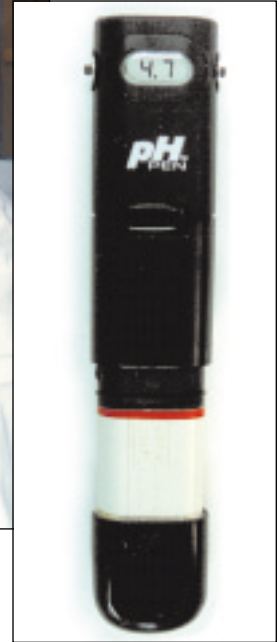*Figure 3: Measuring peel and pulp thickness with a caliper.*

Figure 4:
Hand-held penetrometer fitted with 6 mm probe
for measuring pulp firmness.

Figure 5:
Using bench-top firmness tester fitted
with a 6 mm probe to measure pulp firmness.

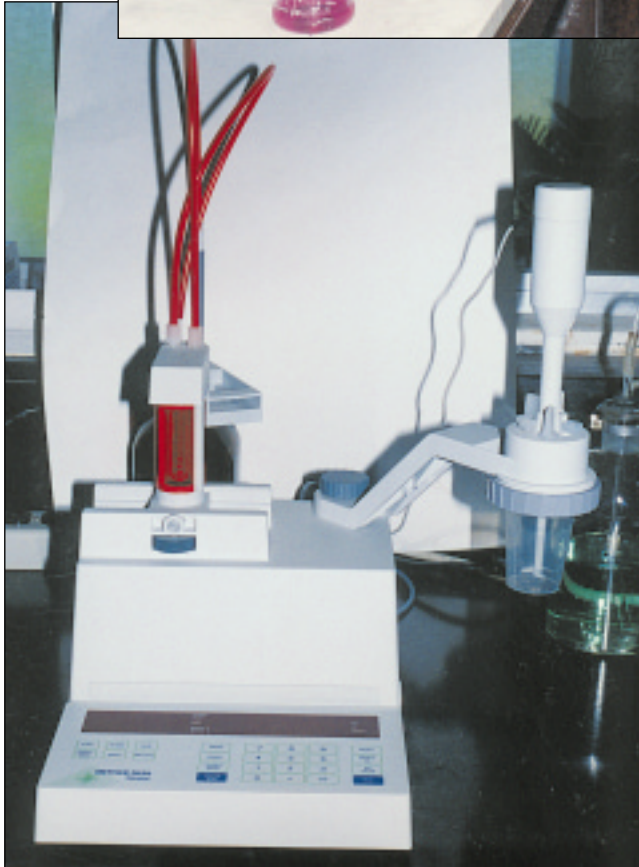*Figure 6: Measuring total soluble solids content with a hand-held refractometer.*

Figure 7: Digital hand-held pH meter for measuring pH of juice extracted from the pulp.

Figure 8. Bench-top pH meter for measuring pH of juice extracted from the pulp.

Figure 9:
Manually measuring
total titratable acidity
of juice extracted
from the pulp.

Figure 10:
Automatic titrator
for measuring total titratable
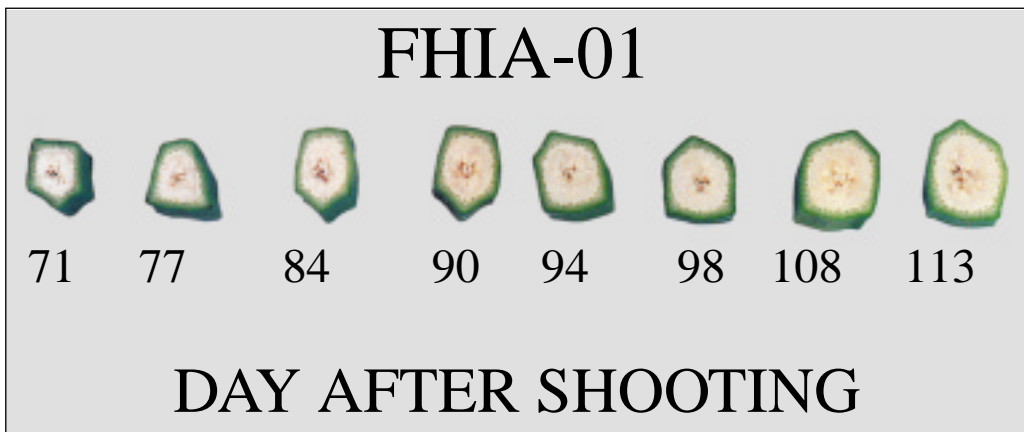*acidity of juice extracted*
from the pulp.

Figure 11: An example of the typical changes in the morphological characteristics during fruit maturation.
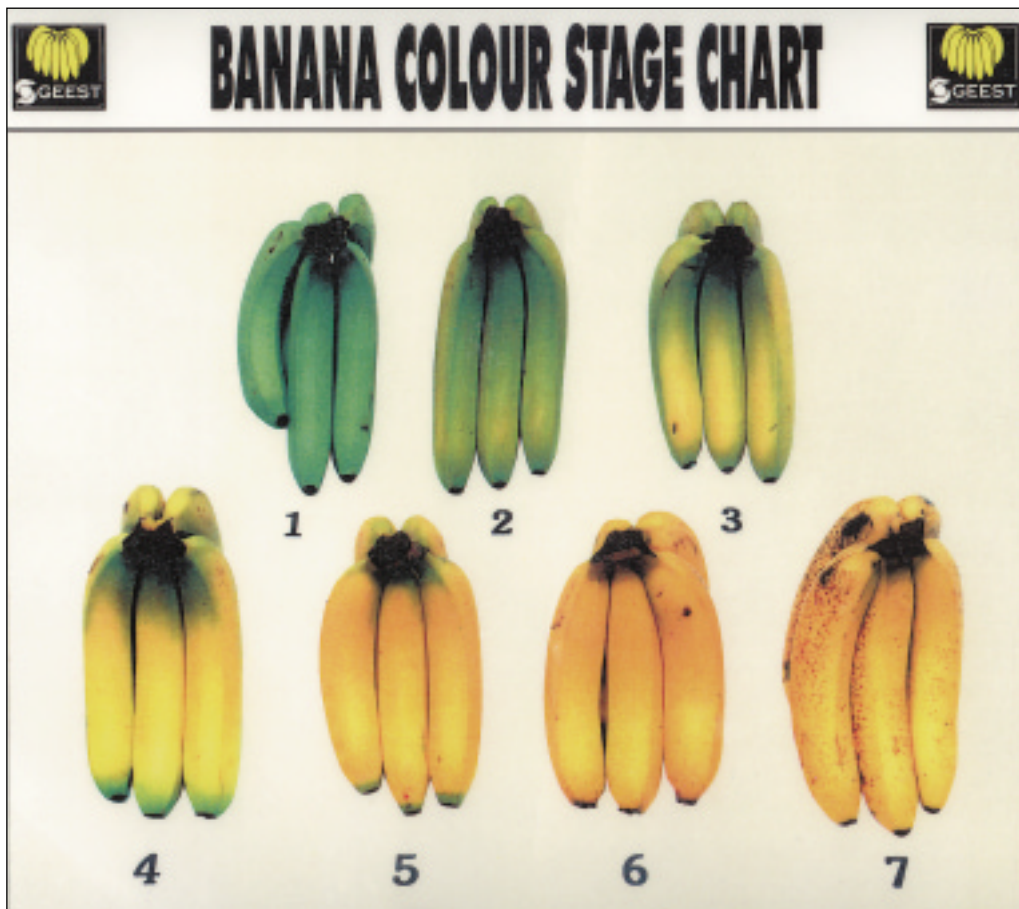

Figure 12: Assessing finger diameter or grade in commercial practice.

Figure 13:
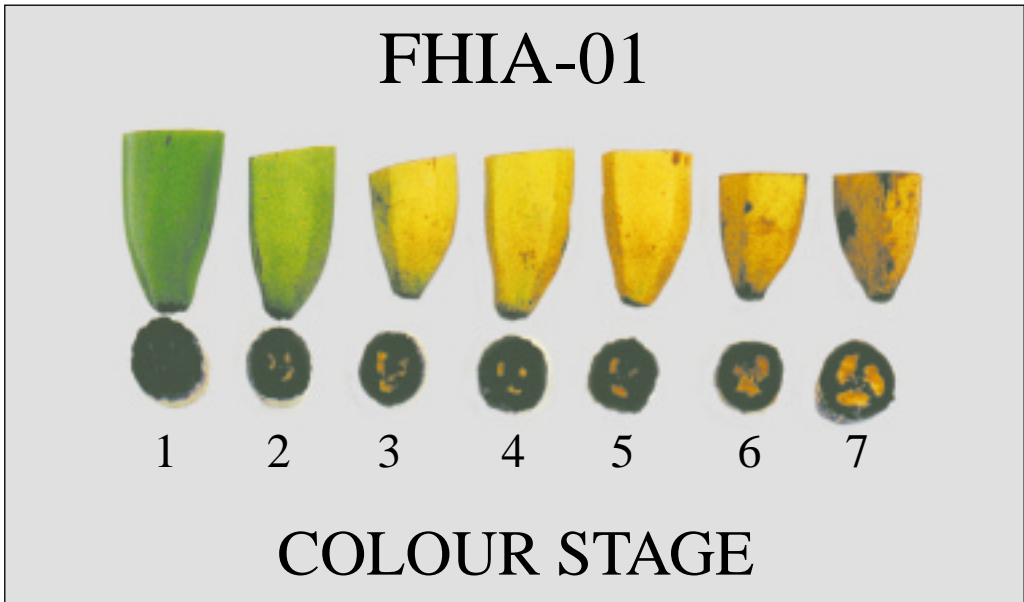*Measuring*
finger length
with specially
designed tape.

FHIA-01

71   77   84   90   94   98   108   113

DAY AFTER SHOOTING

Figure 14: An example of the typical changes in the angles,
shape and size of the cross-sectional area during fruit maturation.

Figure 15.
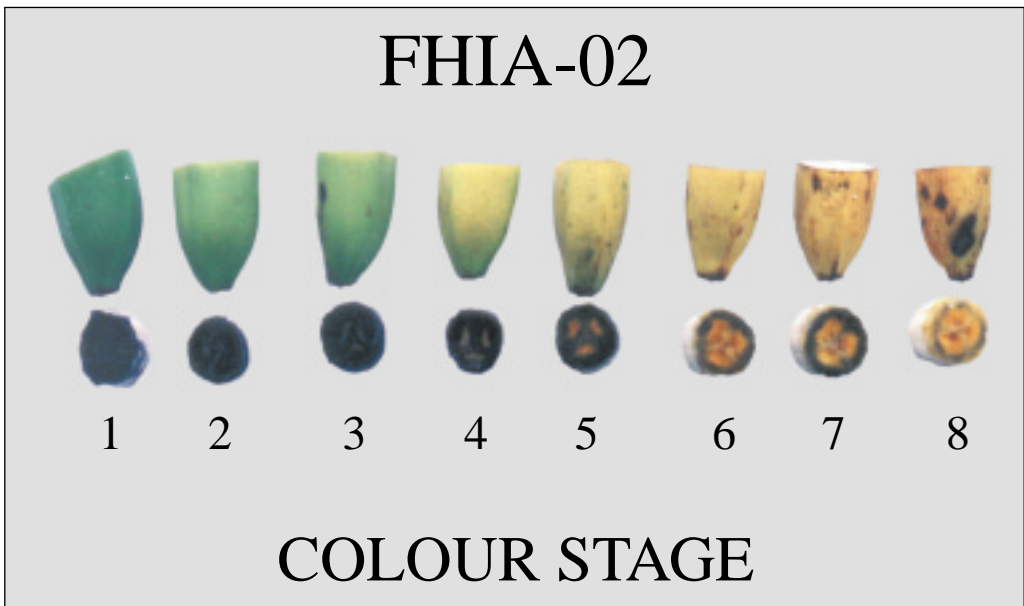

Figure 16: One side of cut surface of pulp samples being stained in potassium iodide/iodine solution.

FHIA-01

COLOUR STAGE

Figure 17:
Chart depicting changes in starch pattern
corresponding to peel colour during ripening.

FHIA-02

COLOUR STAGE

Figure 18: Finger drop, i.e. individual fingers become detached or dislodged from the crown.

Figure 19: Peel splitting in banana.

Figure 20: Chilling injury in banana
(fruits on the right are control).

Figure 21:
Crown rot in banana
(crown showing white fungal growth).

Figure 22:
Anthracnose in banana.

Figure 23:
Cigar-end rot in banana.