Banana Postharvest Ripening Manual

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GENERAL

1. Taxonomy

Musa spp., Musaceae

2. Botany

Musa species originated in a region stretching from Southeast Asia to northern Australia and are now widely distributed throughout the tropics and subtropics. There are two types of edible fruit in the genus *Musa* that are distinguished on the basis of how they are consumed. Dessert bananas are usually consumed raw as fresh fruit, while plantains are starchy bananas that are usually cooked prior to consumption. Modern edible bananas are seedless (parthenocarpic, i.e. developed without fertilization) fruit that derive mainly from two species, viz. *Musa acuminata* Colla (syn. *M. cavendishii* Lamb. Ex Paxt., *M. chinensis* Sweet, *M. nana*, *M. zebrina* Van Houtee ex Planch.) and *Musa balbisiana* Colla. *M. acuminata* is the wild, edible banana from which most dessert bananas derive. The plant is either diploid (normal 2 sets of chromosomes) or triploid (3 sets of chromosomes). The fruit of *M. balbisiana* is seeded and therefore unpalatable. However, the plant is valued as a parent in the breeding of disease-resistant edible bananas. Hybrids between *M. acuminata* and *M. balbisiana* are sterile and thus bear seedless fruit that are characterized by a slower conversion of starch to sugar. Plantains generally have some parentage from *M. balbisiana*. A simple method was designed to distinguish hybrids and represent parentage by assigning a two, three or four letter designation consisting of A's and B's to each type. AA represents the *M. acuminata* genome and BB the *M. balbisiana* genome. Bananas are therefore referred to by their ploidy level (number of chromosome sets) and the relative contributions of the *M. acuminata* and *M. balbisiana* genomes to their genetic makeup. Using their genomic composition and ploidy levels, bananas are classified as *Musa* AA, AAA, AB, AAB, ABB, BB, BBB etc. For example, Sucrier is referred to as *Musa* AA since it is a diploid of *M. acuminata*, while all the varieties in the Cavendish group (e.g. cv.'s Dwarf Cavendish, Giant Cavendish, Williams, Grand Nain, Valery and Red) and Gros Michel are triploids of *M. acuminata* referred to as *Musa* AAA. Examples of hybrids between *M. acuminata* and *M. balbisiana* are Ney Poovan (*Musa* AB), Plantain (*Musa* AAB) and Bluggoe (*Musa* ABB).

The banana plant is a large perennial monocotyledonous herb with a trunk-like pseudostem (false stem) formed by a spirally encircling aggregation of leaf petioles. The true stem of the plant is a fleshy underground rhizome (or corm) which produces the leaves and suckers or vegetative shoots. The

Figure 1: Longitudinal and cross sections through a banana pseudostem.

plant has 5 to 15 leaves that are up to 2.7 meters long and 60 cm wide. The inflorescence is a spike which originates from the apical meristem (growth tip) of the rhizome. It grows through the centre of the pseudostem and emerges at the top of the plant in the form of a large, purple, tapered bud. In some types the inflorescence remains erect after emerging from the pseudostem, but generally it bends downward to produce upside down pendant fruit bunches. A banana inflores-

Figure 2: Banana flowers on an influorescence.

cence bears female flowers on the lower portion (first 5 to 15 rows of the stem-end), neuter flowers with aborted ovaries and stamens in the middle and male flowers enclosed in bracts at the tip. The flowers are negatively geotropic (grows away from gravity) and turn upright during the first few weeks after bud opening. A female flower consists of one large inferior, epigynous ovary (floral parts attached to or near the summit of the ovary), a style with a six-lobed stigma, stamens that do not develop fully, and a perianth. The fruit is formed from the non-pollinated ovary of the female flower and is a parthenocarpic berry. These fruits are arranged spirally in a variable number of 'hands' along the floral axes. Each hand consists of two transverse rows of fruits known as 'fingers'. Fruits fill to harvest maturity in about 3-4 months after the flowers first appear. Bananas are climacteric fruit.

3. *Nutrition*

The nutritional value* of fresh banana fruit per 100 g edible portion is:

Water	75%
Calories	89 kcal
Protein	1.1%
Fat	0.33%
Sugars (ripe)	12.2%
Starch (ripe)	5.4%
Fiber	2.6%

*USDA National Nutrient Database for Standard Reference, Release 21 (2008), http://www.nal.usda.gov/fnic/foodcomp/ cgi-bin/list_ nut_edit.pl

Minerals (mg):	
Calcium	5
Iron	0.26
Magnesium	27
Phosphorous	22
Potassium	385
Sodium	1
Vitamins (mg):	
Vitamin A	64 IU
Vitamin B_1 (thiamin)	0.03
Vitamin B_2 (riboflavin)	0.07
Vitamin C	8.7
Niacin	0.67

4. Harvesting and Quality Indices

Bananas are harvested when mature but still green and ripened by treatment with ethylene at the destination markets. In bananas, maturity is indicated by the plumpness of the fingers. Bananas are considered to be at optimum maturity when the fruit have filled out to 75% of their full size (full three-quarters) and the ridges have become less prominent. Bunch age is also used to determine optimum maturity. Bunch age is measured from the time that the first hand is exposed. Although maturity is more a matter of age than size, callipers can be used to measure the diameter of the middle finger of the second hand from the stem-end of the bunch. The minimum diameter for full three-quarter size is 32 mm (1¼ inch or 40 thirty seconds of an inch) and the maximum diameter is 36 mm ($1\frac{7}{16}$ inch or 44 thirty seconds of an inch). Light three-quarter size ranges from 29-32 mm in diameter. Fruit with a calliper grade of over 37 cm (full size) should be handled with great care because the peel can easily split during handling. Such fruit should not be packed for export. Eating quality is determined by texture and flavour (sweetness and aroma), and is unfavourably affected by starchiness and off-flavours. Visual quality is determined by colour, size, shape, gloss and freedom from outwardly visible defects, damage, scars, spray residues, latex stains and decay. The peel of fruit left to ripen on the plant often split and the fruit have poor texture.

Figure 3: Banana calliper.

5. Physiological Disorders

Bananas are tropical fruit and suffer chilling injury when exposed to temperatures below 13°C. The severity of this injury depends on the temperature, duration of exposure, cultivar, maturity at harvest and production area. Symptoms of chilling injury include surface discoloration of the skin, a dull yellow or grey-yellow skin colour in ripe fruit and browning of the subepidermal vascular bundles of the peel

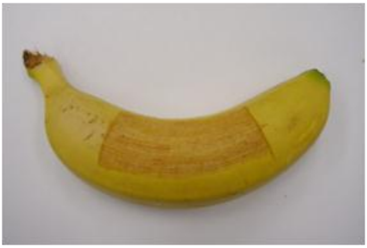

Figure 4. Chilling injury in banana fruit.

(green and ripe fruit). Prolonged exposure to low temperatures can cause flesh browning, off-flavours and failure to ripen properly. To avoid chilling injury, bananas are stored and shipped at a temperature of 13-14°C. The presence of ethylene increases the susceptibility of bananas to chilling injury, while storage in MAP and CA reduces the incidence of chilling injury.

6. Precooling and Storage

The optimum transport and storage conditions for mature green bananas are 13-14°C and 90-95% relative humidity. Although precooling is not generally done, it is advisable to cool down fruit that are exposed to temperatures above 30°C soon after harvest to remove field heat. Failure to do so can irreversibly inhibit ripening and result in heat damage indicated by failure to degreen properly, excessive pulp softening of green fruit, boiled appearance of the pulp and incomplete starch to sugar conversion. In addition, insufficient field heat removal or failure to precool can result in failure to reach the desired storage temperature, heat accumulation in the cool room and thus reduced longevity.

Precooling is done by forced-air or evaporative cooling. Different banana cultivars respond differently to CA conditions. Generally, storage in CA at 2-5% O_2, 2-5% CO_2, 90-95% RH and 12-15°C in the absence of ethylene can extend the postharvest-life of mature green bananas to 4-6 weeks. After storage, such fruit can still be ripened to good quality by treatment with ethylene. Excessively high CO_2 concentrations can be toxic to bananas and cause pulp softening of green fruit, internal browning and off flavour. The use of CA during ocean transport has made it possible to harvest bananas at the full mature stage. Bananas also respond well to MAP and green bananas can be stored in MAP at 13-14°C for more than 30 days. Ripe bananas can be stored in MAP at 13-14°C for up to 7 days.

Ethylene and Ripening

Bananas are climacteric fruit that exhibit typical climacteric patterns in both their respiration and ethylene production rates during ripening. Since exposure to ethylene accelerates ripening in these fruit, bananas must be kept apart from other ethylene-producing fruit such as mangoes and melons. Bananas are harvested when mature but still green and ripened at the destination market by treatment with 100-150 $\mu L\ L^{-1}$ (ppm) ethylene at 15-20°C (depending on the required ripening rate) and 90-95% RH. Careful attention should be paid to temperature and CO_2 management during ethylene treatment and ripening. To avoid suppression of ethylene action, CO_2 levels should never be allowed to exceed 1%. In CA, the low O_2 and high CO_2 levels suppress ethylene production by the fruit. Treatment with 1-MCP greatly delays ripening of green fruit as indicated by a delay in softening and colour change.

RIPENING FACILITIES AND CONTROL OF RIPENING

Fruit ripening is done in specialized airtight rooms equipped with systems and equipment to control ethylene, CO_2, temperature and RH. Air circulation and distribution in the room must be adequate and efficient to evenly distribute ethylene and effectively remove respiration heat. In ordinary ripening rooms (cold rooms with circulating air) boxes are open-stacked (pigeonhole stacking) on pallets to allow sufficient air circulation around the product. Ripening with

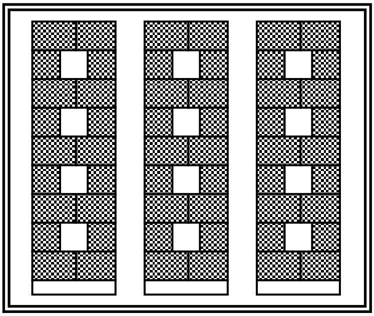

Figure 5: Open-stacked pallets.

forced-air (pressure ripening) is by far the most reliable way of ensuring that the product temperature remains constant and that ethylene is distributed evenly through the boxes. Ripening rooms must be designed with wide doors and passages to allow easy access for forklifts. Since ripening is done at 15-21°C, isolation of the room is not as critical as in rooms used for cold storage if the rooms are installed inside a temperature controlled ripening facility. Sufficient space should be available in the room to allow operators to inspect the product with ease.

Figure 6: Forced-air ripening room.

Ripening is usually done at temperatures higher than the optimum storage and transport temperatures. During ripening, the room temperature is gradually increased from the storage temperature to the specified ripening temperature, after which the temperature is held constant until the required stage of ripening is reached. The higher the temperature within the physiological range, the faster is the rate of ripening and the shorter is the time period for which the product is held at the ripening temperature. Thereafter, the temperature is lowered again to the desired storage temperature. It is essential to monitor the pulp temperature of the fruit continually during ripening, since the rate of ripening is to a large extent controlled by the pulp temperature. Since the rate of respiration increases during the climacteric stage of ripening, heat production will increase during this stage also and sufficient air circulation must be provided to effectively remove the extra heat. Forced-air systems usually provide sufficient air circulation to ensure adequate temperature control. However, the efficiency of a forced-air system depends on the ease with which the air is forced through the packages. For example, some forced-air ripening rooms are designed to force the air vertically from the bottom to the top of the stack (through the height of the stack). Due to the high resistance to airflow in these vertical systems, heat removal and ethylene distribution is much less efficient (causing heat damage and uneven ripening) than in systems that employ a horizontal air flow in which the path of air flow (the width of the stack), and thus the resistance to airflow, is much less. Horizontal airflow systems are, therefore, much more effective and reliable to accurately control fruit ripening than vertical systems. A relative low rate of airflow is required to evenly distribute ethylene in the ripening room. However, the flow rate required for heat removal is much higher than for ethylene distribution. The pressure difference between the two sides of the stack must be at least 250 Pa to accommodate both processes. Airflow for produce with a high rate of respiration such as bananas must be between 0.35 and 1 L sec^{-1} kg^{-1}. These flow rates are more than adequate for heat removal and ethylene distribution and to ensure sufficient air movement around the pallet stacks and through the boxes where the resistance to air flow is highest.

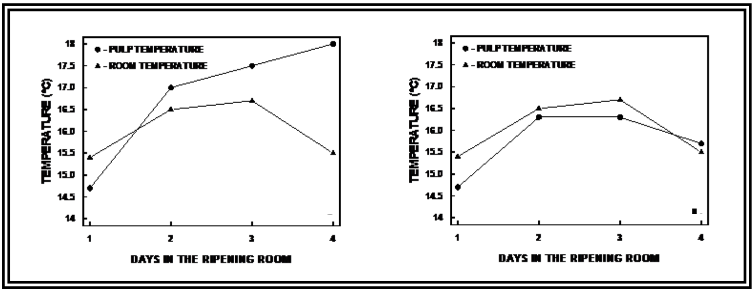

Figure 7: Comparison of the control of banana pulp temperature in vertical (left) and horizontal (right) forced-air systems.

Ripening is usually done at a RH ranging from 90 to 95%. A lower RH results in excessive moisture and weight loss. Low humidity in the ripening room also causes desiccation of the fruit peel resulting in a dull colour and blackening of damaged parts of the peel surface. Humidifiers could be used to raise the RH in the room atmosphere to the required level. Wet coil refrigeration units can also be used to keep the humidity high. The strength of fibreboard boxes must be sufficient to withstand the deterioration caused by moisture absorption.

Figure 8: Pressurized ethylene gas cylinders.

As soon as the product has reached the desired ripening temperature, ethylene is released into the ripening room from pressurized gas cylinders or a generator that converts ethanol to ethylene. Ethylene stimulates fruit ripening at concentrations ranging from 0.1 to 1.0 $\mu L\ L^{-1}$. However, the ethylene concentration in the ripening room is set at around 100 $\mu L\ L^{-1}$ (ppm) to ensure that all the fruit are constantly saturated with ethylene for the duration of the exposure period and to make provision for possible leakages from the room. After the product has been exposed to ethylene for 24 hours, the ripening room is ventilated to get rid of excess CO_2 in the atmosphere, since ethylene action is inhibited by high levels of CO_2. Levels higher than 1% inhibit the effect of ethylene in initiating ripening. After ethylene exposure, the room is ventilated continuously at a rate of 1 room volume every 2 to 6 hours to maintain the CO_2 levels below 5%. If the room is not equipped with a continuous ventilation system, ventilation can be done by opening the door for 10 to 20 minutes once or twice a day while the refrigeration fans are running. However, this practice can result in undesirable temperature fluctuations that can interfere with the exact control of the ripening process. Once the product has reached the desired colour or stage of ripening, the room temperature is lowered again to the normal storage temperature before the product is removed to storage, transported to the market or processed.

Banana ripening rooms must be cleaned and disinfected regularly to prevent infection of the fruit. Room surfaces must be scrubbed down with a suitable disinfectant as prescribed by the manufacturer.

GENERAL RIPENING PROCEDURES

- Quickly load product in the ripening room and gradually raise the flesh temperature to the ripening level.
- Temperature monitoring is critical. Flesh temperature must be accurately maintained during ripening.
- Treat with ethylene for 24-48 hours.
- After this, ventilate continuously.
- Lower the flesh temperature to storage temperature when the desired ripening stage is reached.

BANANA RIPENING

Ethylene

Fruit ripening is a genetically programmed process that is controlled by plant hormones and accelerated or retarded by certain environmental factors. Plant hormones control the expression or suppression of specific genes involved in these processes. Some plant hormones delay ripening , while others such as ethylene accelerate the process in climacteric commodities such as bananas. Ethylene is a unique gaseous plant hormone. It stimulates respiration, accelerates fruit softening as a result of cell wall hydrolysis due to the stimulation of the transcription of cell wall degrading enzymes such as polygalacturonase, causes degreening due to the stimulation of chlorophyll breakdown, causes decompart-mentation of the cell due an increase in membrane permeability, changes the metabolism of organic compounds such as carbohydrates, organic acids and proteins and stimulates the production of aroma volatiles.

In climacteric fruit ethylene production follows a similar pattern to the climacteric pattern of respiration. During the pre-climacteric phase, ethylene is produced at very low levels, followed by a sharp increase just prior to or during the climacteric rise in respiration to reach a peak just before, coincident with or just after the peak in respiration rate. Many researchers maintain that ethylene initiates the changes associated with ripening during the pre-climacteric phase as soon as the sensitivity to ethylene starts to increase.

Bananas are climacteric fruit and as such show a marked increase in ethylene production during ripening concomitant with the climacteric rise in respiration rate. Ripening of bananas is accelerated by treatment with 100 µL L^{-1} (ppm) ethylene at 14-18°C for 24 hours after harvest. Careful attention should be paid to temperature and CO_2 management during ethylene treatment and ripening. Exposure to ethylene stimulates ethylene production by the fruit and removal of ethylene from the storage atmosphere increases storage-life. In CA, the low O_2 and high CO_2 levels suppress ethylene production by the fruit. Treatment with 1-MCP greatly delays ripening of banana fruit as indicated by a delay in softening and colour change. It also reduces chilling injury.

Ripening Rooms

Bananas should preferably be ripened in a forced air room to prevent heat build-up and facilitate even distribution of ethylene gas. The refrigeration equipment must be adequate to raise or lower the temperature between 14°C and 18°C in a few hours. Air circulating fans must be strong enough to provide an air flow rate of 0.02-0.06 m^3 per minute per kg fruit in the room. Although ripened can be ripened in non-forced air store rooms, it is best to use forced air rooms for this purpose since they provide for more accurate temperature control and even distribution of ethylene in the room. When ordinary cold stores are used, boxes should be stacked in an open stacking pattern such as pigeonhole stacking where an open spaces are left in the stack to improve air flow during ripening and storage. It is also important to leave adequate space between the pallets to allow for unrestricted air circulation since cooling of the pallet is mostly by conduction.

Ripening Protocol

Upon arrival at the ripening room, boxes should be selected from the middle of each palet and the pulp temperature of a fruit from each box checked (14°C). The stage of maturity should be determined visually or with a calliper. Individual fingers should be between light three-quarter and full three-quarter size. Over-sized fruit ripens rapidly and should be handled with great care because the peel can easily split during handling, while under-sized fruit will not ripen normally.

After determining the maturity, pallets are placed in the ripening room and the air circulation system turned on. The fruit is heated or cooled to the desired ripening temperature (14ºC-18ºC, do not exceed 20ºC pulp temperature during the ripening cycle). Temperature controls the rate of ripening and high temperatures will result in "green" ripening, i.e. softening of the pulp without degreening of the peel. As soon as the pulp has reached the set temperature, ethylene is introduced into the ripening room with an ethylene generator or bottled ethylene to maintain the levels at 100 ppm for a duration of 24 hours. After ethylene treatment the room should be vented to get rid of excess ethylene and CO_2. Thereafter, the rooms should be vented at least two times per day for 20 minutes or continuous with exhaust fans to keep the CO_2 levels below 1%. CO_2 levels above 1% will inhibit the ripening process. the fruit should be kept at the required temperature until it has reached the desired stage of ripeness. Pulp temperatures must be recorded throughout the room on a daily basis and the relative humidity should be kept at 90-95% throughout the ripening cycle. Once the fruit has reached the desired level of ripeness (desired firmness), it should be cooled down to 14ºC to slow ripening, and placed in a cold store at 14ºC. Ripened fruit are less prone to chilling injury than unripe fruit. Further ripening after storage can be controlled by time and temperature. The higher the pulp temperature, the shorter is the time required to reach eat ripeness. The pulp temperature should never be allowed to rise above 20°C during ripening.

Ripening schedule	**Fruit pulp temperature (°C)**							
	Days in the ripening room							
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**
4 days	18 ethylene	18	16.5	15.5	store at 14.5			
5 days	16.5 ethylene	16.5	16.5	16.5	15.5	store at 14.5		
6 days	16.5 ethylene	16.5	15.5	15.5	15.5	14.5	store at 14.5	
7 days	15.5 ethylene	15.5	15.5	15.5	15.5	14.5	14.5	store at 14.5
8 days	14.5 ethylene	14.5	14.5	14.5	14.5	14.5	14.5	14.5

Uneven Ripening

Uneven ripening in a box, pallet or load is a common problem encountered in fruit that are ripened after harvest. The most common causes of uneven ripening are improper ripening techniques, insufficient ethylene levels, incorrect exposure time, incorrect ripening temperature, RH below 90%, temperatures above 21°C during ripening, improper air circulation, excessive holding periods before the start of the ripening cycle, variable fruit age, variable fruit maturity, wide variations in pulp temperature upon arrival at the ripening room, exposure to temperatures below 12°C prior to ripening and exposure to extreme high temperatures prior to ripening (heat damage).

POSTHARVEST PATHOLOGY

The most widespread postharvest diseases of bananas are anthracnose, crown rot, cigar-end rot and stem-end rot. Anthracnose is an important disease of bananas and is caused by the fungus *Colletotrichum musae*. On green fruit, the symptoms are large, brown to black lesions, while on ripening fruit the symptoms are numerous small dark spots that grow together and become sunken. The fungus gains entry via injuries sustained during harvesting and handling and causes the large lesions on green fruit. This decay can spread into the pulp. The small round lesions on ripe fruit are the result of infections that occur in the field and develop as the fruit ripens. Crown rot is the principle postharvest disease of bananas caused by one or more pathogenic fungi which infect the cut surface of the hand (crown) from where it can spread into the neck of the finger. Fungi that have been associated with crown rot include *Colletotrichum musae*, *Ceratocystis paradoxa* (syn. *Thielaviopsis paradoxa*), *Verticillium theobromae* and *Acremonium* spp., *Acremonium strictum*, *Cephalosporium* spp., *Fusarium moniliforme*, *F. pallidoroseum*, *Fusarium* spp., *Lasiodiplodia theobromae* and *Nigrospora* spp. Cigar-end rot is caused by *Verticillium theobromae* and *Trachyspaera fructigena*. It occurs at the tip-end of the fruit and has the appearance of the ashy end of a burnt cigar. Stem-end rot by is caused by *Ceratocystis paradoxa* and *Colletotrichum musae* which invades the fruit through the cut-end or stem-end of the hand.

Proper control of postharvest decay should start in the plantation and continue right until the fruit is sold to the final consumer. Appropriate pre- and postharvest sanitation, fungicide application and handling practices must be implemented to reduce the amount of decay found on fruit in packed boxes. Most postharvest banana diseases originate in the field from infected plant debris. It is therefore important not to use banana leaves as padding for trailers to transport bunches to the packing shed and to avoid carrying debris to the shed. Dead flower remains must also be removed before the bunches are carried into the packing shed. After washing to remove dirt and latex, bananas should be treated with a fungicide such as thiabendazole or imazalil prior to packing. Fungicides can be applied as a spray, cascade or dip.

NOTES