

Handbook of Diseases of Banana, Abacá and Enset



Handbook of Diseases of Banana, Abacá and Enset

Edited by

David R. Jones



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The Editor: David Jones



Dr David R. Jones was born in Birmingham and grew up in nearby Dudley in the UK's West Midlands region. He graduated in botany from the University of Hull in 1968 and obtained an MSc degree in plant pathology from the University of Exeter in 1970 before undertaking research on rust fungi at the University of Keele. Awarded a PhD in 1973, he became a post-doctorate research fellow working with Dr Ed Ward at Agriculture Canada's research laboratory in London, Ontario, on resistant and susceptible interactions between various fungi and *Capsicum annum*. Dr Jones was next awarded a post-doctorate research fellowship to work with Professor Brian Deverall at the University of Sydney on the interactions between the *Lr20* gene in wheat and the rust fungus *Puccinia recondita*.

From 1977 to 1987, Dr Jones held the position of quarantine plant pathologist with the Queensland Department of Primary Industries in Brisbane, Australia. During these years, he

inspected and indexed imported plant germplasm, ranging from ornamental orchids to crop plants, as part of a national programme to prevent the introduction of exotic pathogens into Australia. He was the first pathologist to travel to the Torres Strait region and discovered black leaf streak and freckle diseases on local banana plants. Dr Jones later formulated guidelines for the safe introduction of *Musa* species into Australia. Subsequently, as a senior plant pathologist, he worked on banana leaf diseases and postharvest problems. He also visited Papua New Guinea and Southeast Asia as part of missions to collect valuable *Musa* germplasm and participated in a banana improvement project in the South Pacific.

In 1992, Dr Jones joined the International Network for the Improvement of Banana and Plantain (INIBAP) in Montpellier, France, as Crop Protection Research Coordinator. Later, as Scientific Research Coordinator, he played a role in developing INIBAP's plan of action. During this period, he also served as co-editor of INIBAP's magazine *Infomusa* and led a global project to test the resistance of new banana hybrids and other clones to significant diseases. Dr Jones also undertook banana disease surveys in Thailand and Malaysia. His collections of specimens led to the identification of banana bract mosaic virus in India and Sri Lanka and to the recognition of a new banana leaf spot disease in India, Sri Lanka, Malaysia and Thailand now known to be caused by *Pseudocercospora eumusae*.

Leaving INIBAP in 1996, Dr Jones took part in a European Union (EU)-funded project to improve the banana industry of the Windward Islands. He became well known on St Vincent as 'the banana doctor' as a result of extension broadcasts on local radio and television. Later, on his return to the UK, Dr Jones served as editor for the CAB International publication entitled *Diseases of Banana, Abacá and Enset*, which was published in 2000. That year, he also joined the Central Science Laboratory of the Department of the Environment, Food and Rural Affairs near York in England as a pest risk analyst formulating guidelines for the safe movement of plant material into the EU. Afterwards, he became a consultant for the European Food Safety Authority (EFSA) in Parma, Italy. Retiring in 2008, Dr Jones kept his interest in banana diseases and has also recently published a book on the Crimean War of the 1850s. He presently lives with his wife on the shores of Jervis Bay on the south coast of New South Wales, Australia.

Preface

Three to four years ago, I became aware that almost all copies of the CABI Publishing book entitled *Diseases of Banana, Abacá and Enset*, which I had edited and which was released at the turn of the century, had been sold and inflated prices were being asked by online retailers for the few that remained. Not long after this discovery, I approached CABI Publishing and offered to edit an updated version of the book in my retirement. After an investigation into the need for a new issue of the book, I was given the go ahead to begin work on finding authors for profiles of the various diseases and disorders of the crops involved. I was informed by CABI Publishing that the title of this new book would be *Handbook of Diseases of Banana, Abacá and Enset*.

Published results of research in certain areas seems to have grown exponentially in recent years. Since the previous publication, much work has been undertaken on the most important diseases of banana, such as black leaf streak, Fusarium wilt, Xanthomonas bacterial wilt, bunchy top and banana streak. This is reflected in the increase in the number of pages devoted to these particular problems. More is also known about some of the pathogens causing less serious and widespread diseases.

The nomenclature of many fungi affecting banana has changed or is changing as a result of genetic sequencing. Taxonomic mycologists have now abandoned the dual nomenclature system (sexual and asexual morphs) in favour of a natural classification based on one name for a fungal species (Wingfield *et al.*, 2012). If the chosen name is the sexual morph, then the asexual morph name becomes a synonym and vice versa. This approach has not been without its problems and, although the determination of which scientific name to use is based on the principle of priority and for the sexual morph, situations exist in which applying these principles strictly does not contribute to the nomenclatural stability of fungi (Rossman, 2014; Wingfield *et al.*, 2012). While these changes are in progress, it has been problematic to decide which fungal name to include in this publication. Most fungal names are those that are considered to be current in *Mycobank* and/or *Index Fungorum*. It will be for the editor or editors of the third edition of this book to resolve issues arising from future decisions made by the Nomenclature Committee for Fungi. As for virus species names, John Thomas has determined when they should and when they should not be written in italics.

Should the name of a disease that contains the genus of the causal fungal pathogen change when the fungus is accommodated in a different genus? I was faced with this dilemma in light of reclassifications of the causal agent and the new 'one name for one fungal species' nomenclature. For the sake of continuity, I have mostly kept the old disease names in this book even if the fungal genus in the name is no longer appropriate. Again, it is for the editor or editors of the next edition to determine if these diseases need renaming.

The book again follows the format laid down by the late Harry Stover in his 1972 publication entitled *Banana, Plantain and Abacá Diseases*. As before, chapters cover diseases caused by various groups of causal agents and disorders caused by unknown and known factors. By far the biggest chapter is devoted to fungal diseases of the foliage. The increase in information on diseases that has become available since 1999 means far more of the book discusses these problems. There are no chapters dedicated to conventional banana breeding and genetic engineering for disease resistance as in the first edition. Instead, these topics are covered under the sections on 'control' for the various diseases.

The revised book is now complete and I would like to thank those who contributed, all of whom are authorities in their fields and many my personal friends. I found my disease descriptions to be much more time consuming than I had anticipated before I started, mainly because I had underestimated increases in the relevant information available since the last edition. I would like to thank Rachael Russell and Alexandra Lainsbury of CABI Publishing for their patience with me, especially when I encountered setbacks. While most authors provided their own illustrations, some additional material was obtained from Tony Cooke and Jeff Daniells of the Queensland Department of Agriculture and Fisheries (QDAF). I would like to thank all contributors for sending me digital images of disease symptoms, most of which appear in this book. Roger Shivas of QDAF is also especially thanked for valuable discussions on fungal taxonomy and the new fungal nomenclature. I am also very grateful to Yu Pie Tan of QDAF for additional mycological information.

This book, like the last, is for all 'banana doctors' around the world. I hope that it serves as a useful field and laboratory guide plus a source of information to all those investigating problems of the banana, abacá and enset crops.

David R. Jones
Callala Beach, New South Wales
December 2017

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Publisher's note: Distribution Maps of Plant Diseases

Within this volume, Distribution Maps of Plant Diseases have been mentioned as the specific version referenced by the chapter author. These maps are the authoritative source for accurate data on the worldwide distribution of plant diseases of economic or quarantine importance. They were first published in 1942 and created in association with the European and Mediterranean Plant Protection Organization (EPPO). CABI has now published over 1000 Disease Maps. Please visit <https://www.cabi.org/dmpd/> to access the latest Distribution Maps of Plant Diseases.

1 Introduction to Banana, Abacá and Enset

D.R. Jones and J.W. Daniells

The Genera *Musa* and *Ensete*

Banana, abacá and enset belong to the Musaceae family of flowering plants in the order Zingiberales. The wild Musaceae grow mainly in tropical environments from the South Pacific to West Africa, but most diversity is found in the South-east Asia–New Guinea region. Characteristics of the Musaceae that differentiate this family from others in the same order are that the leaves and bracts are spirally arranged, male and female or hermaphrodite flowers are separated within one inflorescence and the fruit is a many-seeded berry (Stover and Simmonds, 1987). The family has two genera: *Musa* and *Ensete*. Banana and abacá belong to genus *Musa* and enset to the genus *Ensete*. Some species within the Musaceae are utilized as ornamentals, but banana, abacá and enset are the three most economically important crop plants.

Species within *Musa* and *Ensete* are large herbs with pseudostems of leaf sheaths. New leaves are formed from a meristem near ground level and push up through the pseudostem in a tight roll. Lamina are large, usually oblong, with a stout midrib and numerous parallel veins extending to the margin. The meristem later initiates a terminal inflorescence, which is thrust up the centre of the pseudostem by elongation of the true stem. Flowers are borne in clusters,

each cluster in the axil of a large spathaceous bract. The perianth consists of one compound lobed tepal and one narrow free tepal. The ovary is inferior with three locula, each loculus with numerous ovules in axile placentation. Seeds have a thick, hard testa, a straight embryo and copious endosperm. Pseudostems die after the fruiting phase (Purseglove, 1972; Stover and Simmonds, 1987).

Musa spp. have tightly clasping leaf sheaths and a slightly swollen pseudostem base. Basal flowers are generally female only and distal flowers male. Flowers and bracts are inserted independently on the peduncle and, except for functional female ovaries in basal hands, are commonly deciduous by abscission. Bracts are usually reddish, purple or violet due to anthocyanins. Suckers arise freely from an underground rhizome. Pollen grains are finely granular and seed is 7 mm or less in diameter (Purseglove, 1972).

In contrast, *Ensete* spp. have lax leaf sheaths and a pseudostem base which is usually markedly swollen. Basal flowers are usually hermaphrodite. Flowers and bracts are integral with each other and with the axis and are persistent. Suckers are not produced unless induced by humans. Pollen grains are warty and seed is 6 mm or more in diameter (Purseglove, 1972).

Species in the genus *Musa* were originally split into four groups known as sections, based

on chromosome number and phenotypic characters (Cheesman, 1947):

- Eumusa and Rhodochlamys – contain species that have 22 ($n = 11$) chromosomes.
- Australimusa and Callimusa – contain species that have 20 ($n = 10$) chromosomes.

Simmonds and Weatherup (1990) used numerical methods of classification and recognized the same four sections, with Eumusa divided into two distinct subgroups numbered 1 and 2. De Langhe (2000) considered that the characteristics known to be more stable in species evolution in the study of Simmonds and Weatherup (1990) should receive greater weighting and re-analysed their data accordingly. Whilst he found evidence of Eumusa and Rhodochlamys being in the same section, the same was not true for Australimusa and Callimusa.

Almost 70 *Musa* species have now been recognized (Häkkinen, 2013). Some have been found that have anomalous characters and are intermediate between sections. More recently, the results of amplified fragment length polymorphism analyses of DNA extracted from leaf tissue of *Musa* species and restriction fragment length polymorphism analysis of DNA from organelles of *Musa* species have provided evidence for the merger of the Eumusa and Rhodochlamys sections (Wong *et al.*, 2002; Nwakanma *et al.*, 2003). In addition, Wong *et al.* (2002) believed from their work that the Australimusa and Callimusa sections could also be combined. As a result of this and other work, Hakkinen (2013) proposed two sections called *Musa* and *Callimusa*. *Musa* with 33 species is a combination of Eumusa and Rhodochlamys while *Callimusa* with 37 species is a combination of Callimusa and Australimusa, but also contains *Musa ingens*, which had been proposed by Argent (1976) as belonging to a new section called *Ingentimusa*.

This new arrangement has oversimplified the taxonomic problem. The two sections cannot be defined in either geographical or morphological terms. Furthermore, the 'new' *Callimusa* section still contains species with chromosome numbers other than 20. Additional research is required to resolve the issue. Further discussion in this chapter is based on the original four sections proposed by Cheesman (1947).

Eumusa is the largest and most wide-ranging section of the genus and contains *Musa acuminata*

Colla and *Musa balbisiana* Colla, which are the principal progenitors of most edible banana cultivars. Another, much smaller group of edible *Musa*, comprising the Fe'i banana cultivars, is derived from wild species in the Australimusa series, representatives of which are found mainly on the island of New Guinea. Abacá is the species *Musa textilis* Née, which is also in the Australimusa section. *M. textilis* is native to the Philippines, but has been introduced to other countries for cultivation.

The genus *Ensete* comprises six to seven species, which are divided between Asia and Africa. In Africa, *Ensete ventricosum* (Welw.) Cheesm. (syn. *Musa ensete* Gmel.; *Ensete edule* (Gmel.) Horan.), which is extremely variable, is the most widely distributed and is found between Ethiopia and the Central African Republic, Sudan and South Africa. In Ethiopia, edible cultivars of enset have been selected and developed from *E. ventricosum*.

Banana

Facts and figures

Banana is one of the most important, but undervalued, food crops of the world. It is grown predominantly in gardens and smallholdings in some 120 countries in the tropics and subtropics and provides sustenance to millions of people. Total world production of bananas in 2013 was estimated to be about 145 million tonnes (FAO, 2015). About 44% comes from the Asian–Pacific region, 31% from Africa and 25% from the Americas. Most fruit is consumed locally. The highest consumption rates are in the Great Lakes region of East Africa, where bananas occupy a large proportion of the diet and amount to 200–250 kg/person/year. This compares with consumption figures of 8–18 kg/person/year in Europe and North America (FAO, 2014). Bananas for export account for about 14% of total production and are mostly grown in Latin America and the Philippines.

Banana is an attractive perennial crop for farmers in developing countries. The fruit can be produced all year round, thus providing a steady cash income and/or supply of nutritious food. Bananas for domestic consumption are harvested

from a multitude of cultivars, which are grown on a wide variety of soils and in many different situations. These cultivars can be grown on holdings that range from small plantations to garden plots and jungle clearings. The number of different clones has been estimated to be about 1000 (INIBAP/IPGRI, 2000).

Bananas can be divided into two main categories: dessert bananas and cooking bananas. Dessert bananas, which constitute 59% of world production (Lescot, 2015), are eaten raw when ripe, as they are sugary and easily digestible. There are many different types of dessert bananas, but fruit from cultivars in the Cavendish subgroup are the most common and account for 46% of the world's total production. In some tropical countries, it is the custom to cook dessert bananas. However, cooking bananas, which account for the other 41% of world banana production (Lescot, 2015), are usually starchy when ripe and need to be boiled, fried or roasted to make them palatable. They are important in the diets of many peoples throughout the tropics and are mostly consumed locally. Plantains, the most well known of the cooking types, form 15% of the world's total production of bananas (Lescot, 2015).

As well as being eaten as a fresh or cooked fruit, ripe bananas can be sun- or oven-dried to make 'figs' or sliced and fried when unripe to make 'chips'. Bananas can also be turned into flour, brewed to make beer and, in the Philippines, even form the basis of a 'tomato' ketchup. In some countries in Southeast Asia, the male bud of the banana is eaten after the removal of the fibrous outer bracts. Banana is often grown in association with other crops, affording protection and shade. Leaves of banana are utilized as packaging for other foods and serve as plates, tablecloths and decorative items for religious ceremonies. Chopped pseudostems, peduncles and fruit peel can be fed to animals. The banana is a very versatile plant.

Botany

The banana is a large, herbaceous plant consisting of a branched underground stem (a *rhizome* in the strict botanical sense, but also often called a *corm*) with roots and vegetative buds, and an

erect *pseudostem* composed of tightly packed leaf bases (Fig. 1.1). The apical meristem, which is located in the centre of the pseudostem at about soil level, gives rise to a succession of leaf primordia. Each primordium grows upwards and differentiates into a leaf base, a petiole and a lamina. The petiole and tightly rolled lamina emerge at the top of the pseudostem in the centre of the cylinder formed by older leaf bases. The lamina begins to unfold when fully emerged, the left-hand side, when viewed from above and from the petiole end, unrolling before the right-hand side. Initially, the leaf forms a tunnel where rainwater or dew can collect and it is at this stage when infection by leaf pathogens can occur. Leaves emerge at different rates depending on the cultivar and environmental conditions. With cultivars in the Cavendish subgroup growing in Honduras, this varies from 3.5–3.8 leaves/month in summer to 2.5–3.0 leaves/month in winter. In winter in the cool subtropics, the leaf emergence rate can fall to 0.1–1.2 leaves/month.

A banana plant generally has ten to 15 functional leaves at flowering and five to ten at harvest, but numbers can be less due to environmental and disease constraints. Unless removed, old, senescing leaves hang down the pseudostem.

At a certain stage of plant development, usually after about 25–50 leaves have been produced, the apical growing point stops producing leaves and develops an inflorescence. Long photoperiods may promote the change to flowering, but do not seem to be essential for its initiation (Fortescue *et al.*, 2011). The inflorescence is forced out through the top of the plant as the true stem elongates. The portion of the true stem with the inflorescence that protrudes beyond the base of the uppermost leaf at flowering is known as the transitional *peduncle*. The bracts on the inflorescence lift to expose double layers of female nodes with tightly packed fruit known as *hands*. Individual fruit that arise from each flower are often referred to as *fingers*. Bracts later dry and fall off. This is followed along the peduncle by two or three clusters of neutral flowers, which commonly abscise. Clusters of male flowers then follow to the end of the male peduncle where the *male bud* is located, which contains the remaining male flowers tightly enclosed in their bracts. The male bud is sometimes called the *bell* and the male peduncle has been commonly known as the *rachis*. The underground rhizome, the aerial

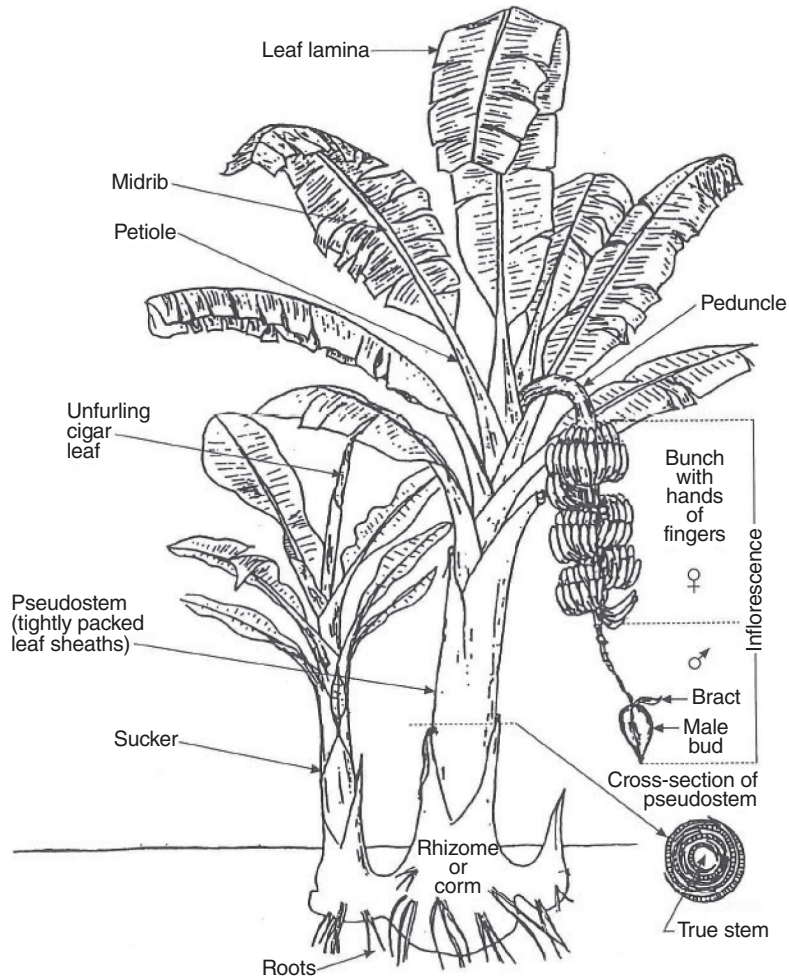


Fig. 1.1. Diagrammatic representation of a fruiting banana plant with suckers (from Champion, 1963).

stem (to which is attached the bases of the leaves present within the pseudostem) and the peduncle (to which is attached the inflorescence) are now recognized in banana as all being parts of the true stem.

The *bunch* is the collective name for the hands of fruit attached to the female peduncle. Bunch size and weight depend on plant vigour and health. In the tropics bunches can be harvested between 85 and 110 days after flowering, but in the cool subtropics fruit development can take up to 210 days. After harvest, the pseudostem dies back and is therefore usually cut down. The plant propagates by forming a *sucker*, which is an outgrowth of a vegetative bud on the

rhizome. A young sucker emerging from the ground is called a *peeper*. Several suckers can arise from each rhizome. One sucker is usually selected by the farmer as a *follower* to grow on and regenerate the plant. Other suckers are either removed physically or their apical meristems are destroyed chemically. If all suckers are allowed to grow, a *clump* consisting of plants of various sizes all arising from the same connected rhizome system or *mat* eventually develops.

Primary roots, which are about 5–8 mm in diameter, usually arise in groups of three or four from the fleshy rhizome. When healthy and vigorous, primary roots are white in colour, but later turn grey or brown before dying. A system

of secondary and tertiary roots develops from the primary roots. The root system is shallow, seldom penetrating much below 600 mm. Horizontal spread can be as far as 5 m, but more commonly 1–2 m. Banana roots are sensitive to adverse conditions, such as waterlogging, desiccation and compacted soil (Wardlaw, 1961; Robinson and Galán Saúco, 2010).

Cultivation and trade

Banana is believed to have been grown initially in Southeast Asia and Melanesia in small permanent gardens around settlements (Plate 1.1), in forest clearings by shifting cultivators (Plate 1.2) and in gardens with other crops (Plate 1.3). Many cultivars with differing genetic backgrounds and different responses to pathogens and pests were most probably cultivated together. Disease problems are unlikely to have been severe enough under these agrosystems to have influenced the selection of disease-resistant cultivars over susceptible ones. Horticultural characteristics were

probably the main considerations in the selection, propagation and spread of early landraces.

The first crop after planting is known as the *plant crop* and the second cycle as the *ratoon crop* or *first ratoon*. This is followed by the second ratoon, third ratoon, etc. Traditional planting material is either the *sucker* (Plate 1.4) or *bit*, which is a piece of rhizome with a vegetative bud. However, since the 1980s, plants derived from tissue culture have also been utilized in commercial operations. Tissue-cultured plants have the advantage of a higher establishment rate producing a more uniform crop, which typically gives a higher yield in the first crop cycle, and they also have the potential of being completely free of pests and diseases when planted. However, the use of this type of planting material is not without problems. Extra care needs to be taken during establishment and in the subsequent selection of followers. Young plants also have a greater susceptibility to pests and diseases (Daniells, 1997; Smith *et al.* 1998). In addition, some plants may be adversely affected as a result of somatic mutations occurring during the *in vitro* multiplication process (Daniells *et al.*, 1999).



Plate 1.1. Banana plots close to houses in Kasaka village, East New Britain, Papua New Guinea (photo: D.R. Jones, QDPI).



Plate 1.2. Banana growing in a temporary clearing in the rainforest near Kiunga, Western Province, Papua New Guinea (photo: D.R. Jones, QDPI).



Plate 1.3. Banana growing together with taro, cassava, sweet potato and sugarcane in a garden on Badu Island in the Torres Strait region of Australia (photo: D.R. Jones, QDPI).



Plate 1.4. A sucker of 'Robusta' (AAA, syn. 'Giant Cavendish') selected for planting in St Vincent, Windward Islands (photo: D.R. Jones, SVBGA).

Banana plants need ample supplies of water if they are to yield well. This has been estimated at 25 mm/week for satisfactory growth in the tropics (Purseglove, 1972). Banana grown in drier areas has to be irrigated to maintain optimal growth. Plants also usually require inputs of nutrients, such as nitrogen and potassium, to prevent deficiency problems.

Banana cultivated as a monocrop on a commercial scale is only a relatively recent phenomenon. Large plantation-scale methods of cultivation began in the late 19th century, after the advent of steamships and cool storage techniques, by a great increase in demand for the fruit in Europe and North America. 'Gros Michel' was the first export banana cultivar to be planted over thousands of hectares, but fruit for export today is mainly produced by cultivars in the Cavendish subgroup. In Latin America and the Philippines, export fruit is usually produced on extensive plantations on relatively flat coastal plains with

alluvial soils. In contrast, export bananas produced in the Windward Islands in the Caribbean are produced on smallholdings, which are often found on steeply sloping hillsides. The cultivation of genetically similar banana plants on vast tracts of land is not confined to areas where fruit is grown for export. Some popular banana cultivars whose fruit is produced for domestic markets can also be grown contiguously over large areas of land. Examples are 'Klavi Namwa' (ABB, Pisang Awak subgroup) in Thailand, 'Pisang Berangen' (AAA, Lakatan subgroup) in Malaysia and East African highland banana cultivars (AAA, Lujugira–Mutika subgroup) in Uganda (Plate 1.5).

Export bananas need to be as blemish-free as possible at markets to obtain premium prices. The bunch is therefore usually covered with a perforated, polyethylene *sleeve, cover* or *bag* (Plate 1.6) soon after emergence to protect the fruit from rubbing leaves and wind-blown debris. Bagging can also shorten the fruit maturation



Plate 1.5. Contiguous small plots of East African highland banana cultivars occupy large swathes of the countryside in the Rutoto Valley in the Bushenyi district of Uganda (photo: D.R. Jones, INIBAP).

period by 3–4 days and increase the weight of the bunch by 1.8–2.3 kg. If impregnated with insecticide, the bag offers protection from thrips and other fruit-attacking insects that cause damage. At about the time of bagging, the male bud is snapped off because in some circumstances this practice can also increase bunch weight. The bag is usually tied to the peduncle above the scar formed by the upper spathaceous bract. In windy areas, the bag is also tied at the bottom to prevent the polyethylene rubbing on the fingers, which causes scarring. If the bottom of the bag is tied, the knot is positioned at one side to allow rainwater to drain freely from the bag. This is because a build-up of humidity within the bag can lead to fungal disease problems on the fruit.

Rough handling of bananas leads to bruising, scarring and other damage. Export plantations have developed methods of handling bananas to minimize this wastage, including establishing cableways for moving bunches to packing sheds where fruit is de-handled, washed, treated with fungicide to reduce postharvest losses and placed into cardboard cartons for transport.

Mature banana fruit produces ethylene, which triggers ripening. Ripening involves the conversion of starch to sugar, a softening of the fruit texture and usually a change in peel colour from green to yellow. These physiological changes can also stimulate the development of post-harvest diseases. Locally consumed fruit can be left on the plant until ripening commences. However, bananas for export or consumption some distance away from growing areas are usually harvested at the mature hard green stage. Timing of harvest is important in these circumstances. This can be determined by tagging bunches on emergence and then calculating approximate harvesting dates. Usually, coloured ribbons are tied around the peduncle (Plate 1.6), the colour of the ribbon signifying the particular week of emergence. When the bunch reaches harvesting age, maturity or grade of the fruit is checked by measuring the diameter of the middle finger on certain hands with a caliper. The bunch is harvested at the desired grade.

Export fruit has to be held and transported at cool temperatures to minimize the respiration rate of fruit and associated ethylene release and



Plate 1.6. A protective polyethylene bag covering a bunch of a cultivar in the Cavendish subgroup growing in an export plantation in Ecuador. The bunch has been tagged with a blue ribbon, which identifies its week of emergence (photo: J.W. Daniells, QDAF).

so delay the onset of ripening. Even so, premature ripening can occur if fruit is over-mature, damaged physically or harvested from plants with high levels of leaf spot. Mixed ripe fruit is often rejected at wholesale markets. Controlled atmosphere conditions on ships transporting bananas can reduce the incidence of ripe and turning fruit. At markets, bananas can be stored under cool conditions until needed and then ripened artificially with ethylene.

Disease and pest problems have the potential to be more serious when plants with an identical genetic make-up are cultivated on a large scale. With banana, this first happened when ‘Gros Michel’ was grown on plantations in the Latin American–Caribbean region. In the course of time, *Fusarium* wilt destroyed the viability of this first major export cultivar. After 1960, the banana trade in the region was dominated by Cavendish cultivars and the problems associated with clones in this subgroup, such as Sigatoka leaf spot and burrowing nematode, became limiting factors requiring much research.

For many years, most banana scientists worked predominantly for multinational companies or for governments supporting export growers. However, in the past few decades, banana has been recognized as an important local fruit crop by developing countries in the Americas, Africa and Asia and local improvement programmes have been initiated. Associated with these programmes has been a need to identify constraints to local banana production, including pests and diseases. In countries where Cavendish is not the most popular type of banana, new disease problems are emerging as local cultivars are beginning to be grown as a monocrop and on a scale much larger than before.

Origin of the edible banana

Wild *Musa* species are seedy, generally opportunistic and in nature grow in forest clearings and along watercourses. Simmonds (1962) believed that early agriculturists initially selected plants with high levels of parthenocarpy, which is the ability to form fruit without fertilization. This fruit would have had fewer seeds, thus increasing edibility. At the same time, selection would also have been for female sterility, which would also lower the number of seeds. Selected plants would have been propagated by suckers, thus maintaining their genetic composition. The long-distance movement of vegetative planting material by humans enabled edible banana cultivars from Asia eventually to reach other regions of the world (Simmonds, 1962).

Evolution of edible banana cultivars from *Musa* species in the *Eumusa* section

Simmonds (1962) postulated that the evolution of edible cultivars derived from *Musa* species in the *Eumusa* section most probably began with wild *M. acuminata* subspecies, which occur naturally in an area stretching from South Asia to Australasia (Fig. 1.2). Another key event was believed to have been hybridization with *M. balbisiana*, a more drought tolerant species that now occurs in an arc from the Indian subcontinent through the southern China region to the Philippines and New Guinea (Fig 1.3). This would have

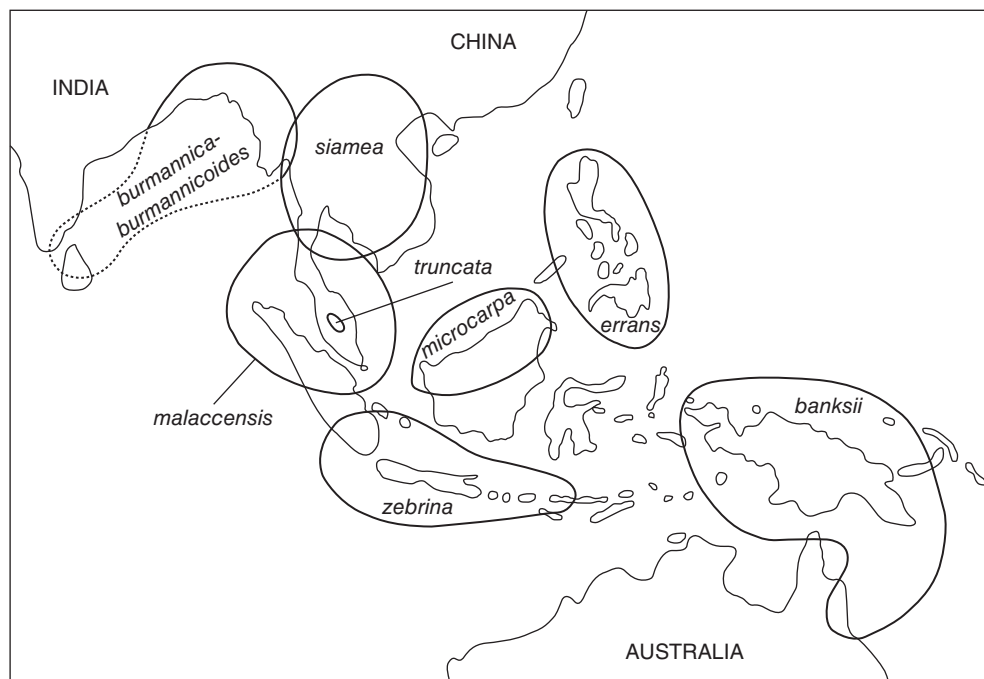


Fig. 1.2. Approximate natural distribution of *Musa acuminata* subspecies (adapted from Simmonds, 1962; Horry *et al.*, 1997).

led to the generation of cultivars that could be grown in drier areas.

Both *M. acuminata* and *M. balbisiana* are diploids. The genome of wild *M. acuminata* is represented by AAw and wild *M. balbisiana* by BBw. Fruit of these two wild species is not usually consumed as it is seedy. However, bananas from one selection of *M. balbisiana* known as 'Bhimkol' or 'Arthiyakol' are eaten in Assam, India, along with the tender inner pseudostem and male buds (Borborah *et al.*, 2016). Diploid cultivars derived solely from *M. acuminata* are designated by AA and diploid hybrids with *M. balbisiana* by AB.

Recent analyses of biotechnological taxonomic data by Perrier *et al.* (2011) indicated that edible AA cultivars were, as Simmonds (1962) suggested, derived from hybridizations between different *M. acuminata* subspecies. This is believed to have occurred in the islands of Southeast Asia and western Melanesia as a result of the movement by humans of *M. acuminata* subspecies and primitive AA cultivars to new areas. Their work also indicated that the structural heterozygosity of these first hybrids, caused by

chromosomal rearrangements between parental subspecies of *M. acuminata*, contributed to gamete sterility and that this sterility, in association with human selection for pulp enhancement, led to parthenocarpic fruits and edibility.

Perrier *et al.* (2011) believed that a consequence of the hybrid status of the AA cultivars was erratic meiosis occasionally producing diploid gametes and that the fusion of diploid gametes with haploid gametes would have generated sterile triploid (AAA) genotypes. Further, they argued that this spontaneous triploidization occurred in almost all diploid cultivars. Diploid cultivars can often be distinguished from triploids because of their more slender pseudostems and more upright leaves (Fig. 1.4). Triploid banana plants are typically bigger, sturdier plants with increased fruit size. This latter characteristic would have encouraged their adoption into farming systems. The integration of cultivars derived from *M. acuminata* subspecies with genetic components from *M. balbisiana* is thought by Perrier *et al.* (2011) to have occurred when the latter was spread by humans south to the

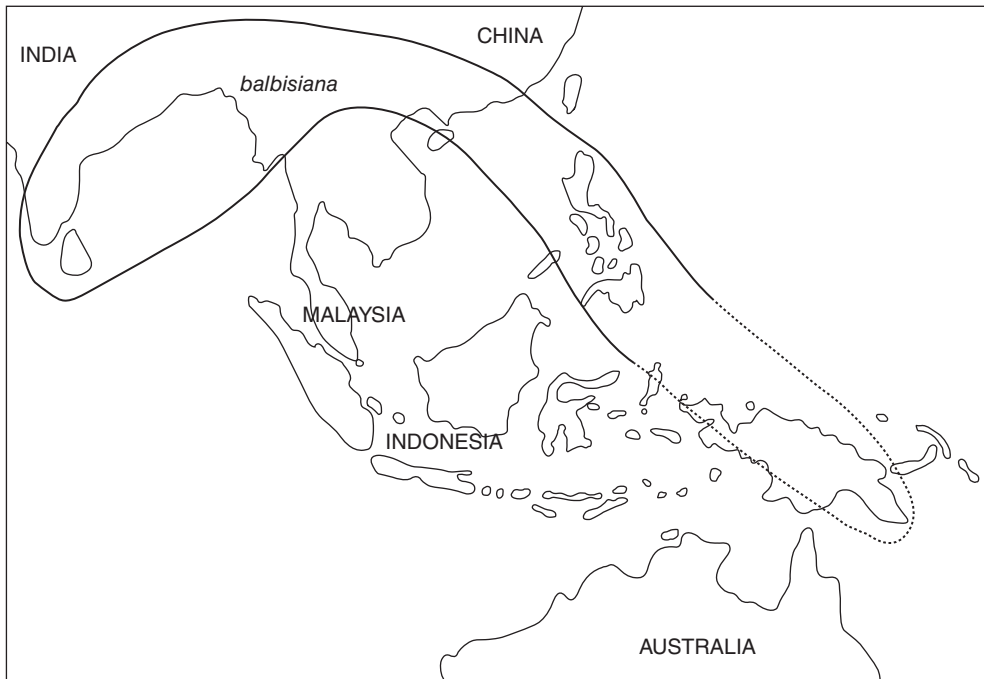


Fig. 1.3. Approximate natural distribution of *Musa balbisiana* (adapted from Simmonds, 1962). Argent (1976) believed that the species was introduced to New Guinea. Perrier *et al.* (2011) considered that the species was also introduced to the Philippines. Simmonds (1962) thought *M. balbisiana* to be indigenous to both locations.

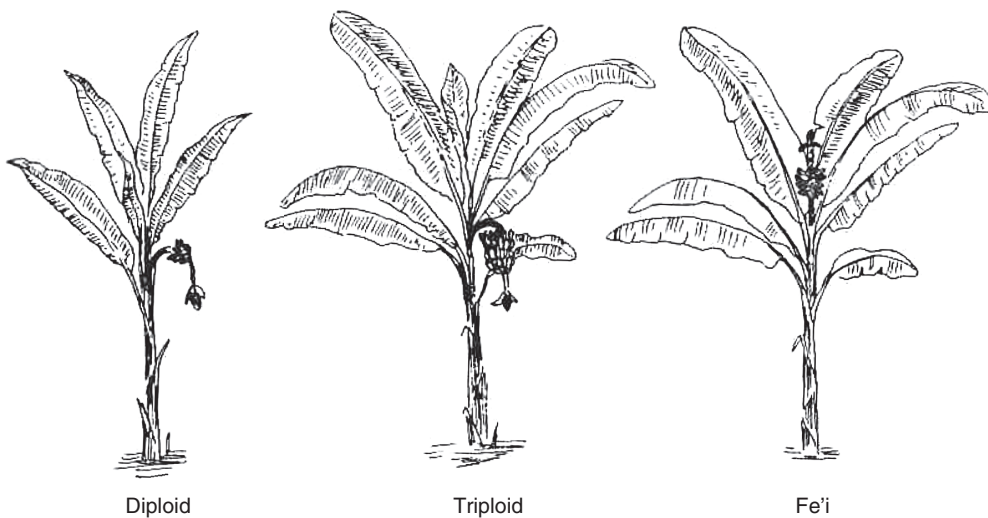


Fig. 1.4. General appearance of diploid and triploid cultivars in the *Eumusa* series of edible banana and Fe'i cultivars in the *Australimusa* series of edible banana (Bourke, 1976).

Philippines and New Guinea from southern China. A scheme illustrating the various steps in the evolution of the main genomic groups is shown in Fig. 1.5. Human selection would have then led to the diversity of modern cultivated triploids, including pure *M. acuminata* cultivars (AA, AAA) and interspecific *M. acuminata* × *M. balbisiana* cultivars (AB, AAB, ABB). Vegetative propagation of the popular diploid and triploid cultivars over long periods of time resulted in the appearance of variants with different phenotypic characteristics. This process of natural somatic mutation would have increased morphological diversity (Noyer *et al.*, 2005).

Only a few natural cultivars have been recognized as belonging to the AAAA, AAAB, AABB and ABBB genomic groups (Richardson *et al.*, 1965; Shepherd and Ferreira, 1984). These tetraploids, which have robust pseudostems and leaves that tend to droop, are believed to have arisen from the fertilization of triploid egg cells by haploid pollen.

'Kluai Teparot', a cultivar long believed to have been an ABBB (Simmonds and Shepherd, 1955; Richardson *et al.*, 1965; Silayoi and Sompen, 1991), was found by flow cytometry in association with chromosome counting and molecular analysis in the late 1990s to be an ABB (Jenny *et al.*, 1997; Horry *et al.*, 1998). Similarly, 'Pisang Jambe' was discovered to be an AAA and

not an AAAA as previously thought (Horry *et al.*, 1998). However, 'Kluai Ngoen', which was identified as an AAB from phenotypic characteristics, has now been found to be an AAAB (Horry *et al.*, 1998). Clearly, some cultivars need to be investigated thoroughly before their ploidy can be determined with any degree of certainty.

Tetraploid hybrids have been artificially bred for disease resistance and are becoming important in some countries.

Classification of banana cultivars derived from *Musa* species in the Eumusa section

The genome of banana cultivars derived from *Musa* species in the Eumusa section has in the past been deduced from an analysis of morphological characters including pseudostem colour, shape of the petiolar canal and bract features (Simmonds and Shepherd, 1955). This taxonomic method has been proved over time to give a good approximation of the genetic composition generally correlating well with the results of modern molecular techniques. However, as noted under the previous subheading, more modern techniques are necessary to confirm ploidy.

Within each genomic group, morphological characters in addition to those used to define

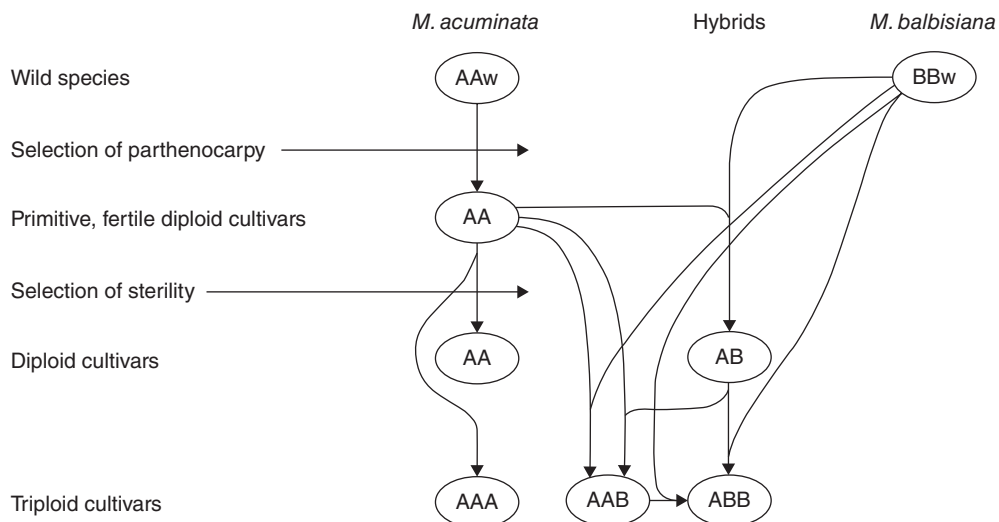


Fig. 1.5. Evolution of the main genomic groups of edible banana cultivars of the Eumusa series (after Simmonds, 1962; Carreel, 1995).

genomic group are used to identify clones. Many clones have mutated over time to form morphotypes that differ in certain characters, such as fruit and bunch morphology, pigmentation and height. Dwarfness is a common mutation and has occurred in many locations. Clones that are thought to have arisen originally from a base clone by mutation form subgroups. Major subgroups with large numbers of clones have formed in centres of secondary diversification. It is not always possible to identify the original base clone of major subgroups.

The same clone can have different names in different locations. This is especially true in Papua New Guinea, a country with over 700 languages, where the names of cultivars can vary between villages. In this publication, the synonym most frequently used by banana workers has been adopted to signify the clone. This 'best-known synonym' is in many cases the one applied to the clone in the Caribbean where much of the early taxonomic work was undertaken. Thus 'Silk', a synonym of West Indian origin, gives its name to the clone that is known in India as 'Rasthali', in the Philippines as 'Latundan' and in Australia as 'Sugar'.

Cultivar names in some countries begin with the local word for banana. For example, names in Malaysia and Indonesia begin with 'Pisang', in Thailand with 'Kluai', in Vietnam with 'Chuóí', in Hawaii with 'Mai'a' and in Samoa with 'Fa'i'. Some workers believe this word to be redundant and accessions in germplasm collections have been registered without using the prefix. However, the local word for banana has been retained in this publication because it is considered an integral part of the cultivar name and also gives an indication as to the original source of the material.

Cultivars are placed in subgroups if they are deemed to have been derived by mutation from a single original or base clone. Mutations affect pigmentation, height and other morphological characters. Over time, multiple changes could have occurred increasing diversity. Subgroups are named after the best-known synonym of the most important clone in the subgroup (e.g. Gros Michel and Bluggoe subgroups), the cultivars first described to identify the main characteristics of the subgroup (e.g. Iholena and Lujugira–Mutika subgroups) or a generic term (e.g. Cavendish and Plantain subgroups). In the case of the Plantain subgroup, it is believed that

more than one base clone exists (Stover and Simmonds, 1987).

To help the reader relate the cultivars mentioned in this publication to the subgroup or clone, cultivar names are followed in parentheses by the genomic group and then by either the subgroup or best-known synonym.

Subgroups and important clones of banana cultivars derived from *Musa* species in the Eumusa section

AA and AB genomic groups

Well-known AA and AB clones and some of their synonyms are listed in Table 1.1.

The most important AA clone is 'Sucrier', which has exceptional fruit quality. It is quite common in Southeast Asia and is present elsewhere in the world. 'Sucrier' is exported from the Philippines and Latin America. 'Pisang Lilin' is another popular AA clone, but is not grown widely outside Malaysia and Thailand. Fruit of both 'Sucrier' and 'Pisang Lilin' can often be seen on sale in Thailand (Plates 1.7 and 1.8). Other AA diploids are cultivated in Southeast Asia, but are not as common. For example, 'Inarnibal' is found in Malaysia, Indonesia and the Philippines. There are also many AA clones in Papua New Guinea with more than 100 listed by Arnaud and Horry (1997). In general, they are not very productive, but are grown for their eating qualities and ethnic preferences. Some produce a bunch quickly while others soften rapidly when cooked compared with the widespread 'Kalapua' (ABB).

'Pisang Lilin' and 'Paka' from East Africa and 'Pisang Jari Buaya' from Malaysia have been used in breeding programmes because of their resistance to disease.

The only AB clones of note are 'Ney Poovan' (Plate 1.9) and 'Kunnan'. 'Ney Poovan' is not common, but is found in many countries. In Uganda, it is used for making beer.

AAA genomic group

The AAA genomic group contains some of the most productive clones, which are widely grown and constitute about half of the world's total output of banana fruit (Lescot, 2015). Major AAA subgroups are presented in Table 1.2.

Table 1.1. AA and AB genomic groups – important subgroups.

Subgroup	Clones/Synonyms	Location	Main use of fruit
AA genomic group			
Sucrier	‘Sucrier’/‘Figue Sucrée’	West Indies	Dessert
	‘Pisang Mas’	Indonesia, Malaysia	
	‘Kluai Khai’	Thailand	
	‘Amas’	Philippines	
	‘Lady’s Finger’	Hawaii	
Pisang Lilin	‘Orito’	Ecuador	Dessert
	‘Pisang Lilin’	Malaysia	
Inarnibal	‘Kluai Lep Mu Nang’	Thailand	Dessert
	‘Inarnibal’	Philippines	
	‘Pisang Lemak Manis’	Malaysia	
Pisang Jari Buaya	‘Pisang Lampung’	Indonesia	Dessert
	‘Pisang Jari Buaya’	Indonesia, Malaysia	
AB genomic group			
Ney Poovan	‘Ney Poovan’/‘Safet Velchi’	India	Dessert
	‘Kisubi’	Uganda	Brewing
Kunnan	‘Kunnan’	India	Dessert

**Plate 1.7.** Fruit of ‘Kluai Khai’ (AA, Sucrier subgroup) for sale at roadside stall near Kamphaeng Phet, north-western Thailand (photo: D.R. Jones, INIBAP).

‘Gros Michel’ is a tall clone and was the first banana of the export trades. Despite its susceptibility to *Fusarium* wilt, it is still grown for local consumption in many countries around the world because of its superior flavour and golden yellow appearance when ripe. ‘Gros Michel’ produces a few seeds when pollinated. As a

consequence, ‘Gros Michel’ and its shorter variants (‘Cocos’, ‘Highgate’ and ‘Lowgate’) have been utilized in breeding programmes.

Cavendish cultivars may have originated in Indochina (Perrier *et al.*, 2011). Two ‘Dwarf Cavendish’ plants were sent to the UK from Mauritius in 1829 having been collected in China



Plate 1.8. Fruit of 'Kluai Lep Mu Nang' (AA, Pisang Lilin subgroup) for sale in Bangkok, Thailand (photo: D.R. Jones, INIBAP).



Plate 1.9. Bunch of 'Ney Poovan' (AB) on a plant growing in the germplasm collection at the South Johnstone Research Station, North Queensland, Australia (photo: J.W. Daniells, QDAF).

2–3 years previously. One was grown and propagated in a glasshouse at Chatsworth House belonging to William Cavendish, the 6th Duke of Devonshire. These plants were described as *Musa Cavendishii* by Paxton (1837). From Chatsworth, suckers were taken to Samoa and then other Pacific Islands.

The Cavendish subgroup is responsible for 46% of the world's production of banana fruit (Lescot, 2015). Stover and Simmonds (1987) recognize four major clone sets distinguished on height: 'Dwarf Cavendish' types are the shortest in stature, 'Grande Naine' types are medium dwarfs, 'Giant Cavendish' types are taller and 'Pisang Masak Hijau' types the tallest (Stover and Simmonds, 1987). This classification is somewhat arbitrary as in reality there is an almost continuous gradation in height from 'Extra-Dwarf Cavendish', which is shorter than 'Dwarf Cavendish', upwards to 'Pisang Masak Hijau'. Each clone set contains different cultivars, some of which are listed in Table 1.2.

As well as height, clones in the Cavendish subgroup differ in other morphological characters such as petiole length, leaf length/breadth ratio, bract persistence, bunch grade and pseudostem colour. Other characteristics, such as leaf emergence rate and length of crop cycle, have also been used to differentiate cultivars (Daniells, 1990b).

Table 1.2. AAA genomic group – Gros Michel, Cavendish and Lujugira–Mutika subgroups.

Subgroup	Clone	Clones/synonyms	Location	Main use of fruit		
Gros Michel	'Gros Michel'	'Gros Michel'	West Indies	Dessert		
		'Pisang Embun'	Malaysia			
		'Kluai Dok Mai'	Thailand			
		'Anamala'	Sri Lanka			
		'Bluefields'	Hawaii			
		'Pisang Ambon Putih'	Indonesia			
	'Cocos'	'Cocos'	Honduras	Dessert		
	'Highgate'	'Highgate'	Jamaica	Dessert		
	'Lowgate'	'Lowgate'	Honduras	Dessert		
Subgroup	Clone set	Some cultivars in clone set	Location	Main use of fruit		
Cavendish	Extra-Dwarf Cavendish Dwarf Cavendish	'Dwarf Parfitt'	Australia	Dessert		
		'Dwarf Nathan'	Israel			
		'Dwarf Cavendish'	Australia			
			'Basrai'	India, Pakistan	Dessert	
			'Petite Naine'	French Antilles		
			'Grand Nain'	Latin America		
		Grande Naine	'Grande Naine'	French Antilles	Dessert	
			'Umalag'	Philippines		
			'Giant Cavendish'	General		
		Giant Cavendish	'Robusta'	India, Windward Islands	Dessert	
				'Williams'		Australia, South Africa
				'Zhong Ba'		China
				'Poyo'		West Africa
			'Pei-Chiao'	Taiwan		
			'Chuói Tieu'	Vietnam		
			'Veimama'	Fiji		
			'Nañicao'	Brazil		
			'Valery'	Latin America		
			'Pisang Masak Hijau'	Malaysia		
	Pisang Masak Hijau	'Buñgulan'	Philippines	Dessert		
			'Pisang Ambon Lumut'		Indonesia	
			'Lacatan'		Latin America	
Subgroup	Clone set	Some cultivars in clone set	Location	Main use of fruit		
Lujugira–Mutika	Musakala	'Musakala', 'Enyoya', 'Mudwale', 'Mukazialanda'	Uganda	Cooking		
	Nakabululu	'Nakabululu', 'Butobe', 'Kibuzi', 'Mukite'	Uganda	Cooking		
	Nakitembe	'Nakitembe', 'Mbwazirume', 'Nasaala', 'Waikova'	Uganda	Cooking		
Nfuuka	'Nfuuka', 'Enyeru', 'Nakhaki', 'Kasenene'	Uganda	Cooking			

'Dwarf Cavendish' (Plate 1.10) was the basis of local banana trades in the subtropics, but suffered from 'choke' (impeded bunch emergence) in the cooler weather. Here and elsewhere, the clone has been progressively replaced by medium dwarf and giant Cavendish cultivars, which are higher yielding and better meet market specifications. The medium dwarf 'Grande Naine', which is less prone to wind damage, but more susceptible to drought than other Cavendish cultivars, has replaced 'Valery' ('Giant Cavendish'-type) as the most popular cultivar in international trade in tropical areas. The next most important clone is 'Williams'. 'Robusta' ('Giant Cavendish'-type), which is less susceptible to a water deficit than 'Grande Naine', is still grown extensively in the Windward Islands where irrigation is not widely available and seasonal droughts occur.

In addition to being the principal banana types grown for export fruit in the Latin American–Caribbean, African and Southeast Asian regions, Cavendish cultivars form the backbone of domestic banana industries in such places as

Australia, China, Egypt, India, Pakistan, South Africa and Vietnam (Plate 1.11). They have higher yields than all other natural clones (Robinson and Galán Saúco, 2010).

Cultivars in Lujugira–Mutika subgroup are the predominant banana grown in the Great Lakes region of East Africa. They are also often referred to as belonging to the East African highland banana (EAHB) subgroup, though other AAA cultivars, including those in the Ilalyi subgroup, and the AA cultivars 'Mshare' and 'Muraru' are found in the same environment and have been considered part of a EAHB complex (De Langhe *et al.*, 2001; Karamura *et al.*, 2016). It has been estimated from figures published by Lescot (2015) that approximately 10% of all banana fruit produced globally comes from clones of EAHB subgroup. 'Lujugira' and 'Mutika' are the cultivars that represent the two main subdivisions proposed for this subgroup by Shepherd (1957). This division is based on fruit morphology, with further differentiation related to other characteristics (Stover and Simmonds, 1987). A numerical taxonomic study of over 200 Ugandan accessions in the subgroup distinguished five different clone sets (Karamura, 1999). However, a recent genetic analysis of 90 cultivars has shown only a limited amount of variation that could not be correlated with previous divisions based on morphological characteristics (Kitavi *et al.*, 2016).

The fruit of the 'Lujugira–Mutika' subgroup, like fruit from other AAA clones, is sweet when ripe. However, East Africans either cook the fruit as 'matooke' or use it for brewing to make 'banana beer'. The pulp qualities of the fruit determine if a cultivar is a cooking or brewing type. Some cooking cultivars can change spontaneously to become beer cultivars. This change occurs with more frequency above 1400 m. A checklist of East African highland types in Uganda lists 145 cooking cultivars and 88 beer cultivars together with synonyms (Karamura and Karamura, 1994). Fruit from these cultivars are very important in the diets of people in the eastern part of the Democratic Republic of Congo, Rwanda, Burundi, Uganda, Tanzania and western Kenya. Bunch features of this subgroup are illustrated in Plate 1.12.

The AAA group also contains a number of other subgroups, some of which are listed in Table 1.3. 'Red', and its common sport 'Green



Plate 1.10. 'Dwarf Cavendish' (AAA) growing in a back-garden in Abepura, Papua, Indonesia. Note the persistent bracts on the peduncle just above the male bud (photo: J.W. Daniells, QDAF).



Plate 1.11. Bunches of 'Chuai Tieu' (AAA, syn. 'Giant Cavendish') being transported to market near Pho Ho, Vietnam (photo: J.W. Daniells, QDAF).



Plate 1.12. Bunches from cultivars in the Lujugira–Mutika subgroup (AAA) at a village in the Bushenyi district of Uganda awaiting transportation to market in Kampala (photo: D.R. Jones. INIBAP).

Table 1.3. AAA genomic group – Red, Lakatan and Ibota subgroups.

Subgroup	Clones/synonyms	Location	Main use of fruit
Red	'Red' – 'Green Red'	West Indies	Dessert
	'Pisang Raja Udang' – 'Pisang Mundam'	Malaysia	
	'Morado' – 'Moradong Puti'	Philippines	
	'Ratambala' – 'Galanamalu'	Sri Lanka	
	'Chenkadali' – 'Venkadali'	India	
Lakatan	'Red Dacca' – 'Green Dacca'	Australia	Dessert
	'Lakatan'	Philippines	
	'Pisang Berangan'	Malaysia	
Ibota	'Pisang Barangan'	Indonesia	Dessert
	'Ibota Bota'	Dem. Rep. of Congo	
	'Kluai Khom Bao,' 'Kluai Khai Thong Ruang'	Thailand	
	'Pisang Saripipi'	Indonesia	
	'Yangambi Km 5'	Widely distributed accession	

'Red', are widely distributed tall garden clones. The difference between the two cultivars is in their pigmentation, especially in the fruit peel. Immature fruit of 'Red' is red in colour (Plate 1.13) while fruit of 'Green Red' is green. 'Red' has dwarf forms, such as 'Figue Rose Naine'. 'Lakatan', a banana with an excellent flavour, is very popular in Southeast Asia (Plate 1.14). 'Ibota Bota' is a clone highly resistant to disease. A semi-dwarf variant has been described (Daniells and Bryde, 1995).

Many other AAA clones, which are important locally, have been identified (Stover and Simmonds, 1987). 'Pisang Nangka' is found in Malaysia and Indonesia and in the Philippines as 'Nangka'. 'Pisang Susu' is grown in Indonesia. 'Paji' from Zanzibar is resistant to black leaf streak disease. 'Pisang Ambon' and 'Orotava' accessions collected in Indonesia in the 1980s are different from clones in the Gros Michel and Cavendish subgroups (Carreel, 1995). Ten distinct AAA clones were collected in Papua New Guinea in 1988/89 (Arnaud and Horry, 1997).

AAB genomic group

Four of the major subgroups recognized within the AAB genomic group are presented in Table 1.4.

The Plantain subgroup is very important as plantain cultivars provide food for many millions

of people in the West and Central Africa and Latin American–Caribbean regions. Cultivars are also found in East Africa and South and Southeast Asia. A total of 15% of the world's production of banana fruit comes from plantain (Lescot, 2015). The term plantain is often used for all cooking banana types, but in this publication it refers only to those cultivars belonging to the Plantain subgroup within the AAB genomic group of banana (Shepherd, 1990).

Cultivars in the Plantain subgroup are placed in four main clone sets, which are distinguished on bunch and inflorescence characteristics. 'French' plantain types have many hands with comparatively small fingers and an inflorescence axis covered with persistent hermaphrodite and male flowers. The large male bud is also persistent. The bunch features of 'French' plantain are illustrated in Plate 1.15. At the other extreme, 'Horn' plantain types have few hands of very large fingers, no hermaphrodite flowers and no male axis. 'French Horn' and 'False Horn' plantain types are intermediate classification categories between 'French' and 'Horn' plantain. The male bud is absent at maturity in both of these types, but there are many hermaphrodite flowers on 'French Horn' cultivars and few on 'False Horn' cultivars (Tezenas du Montcel and Devos, 1978; Swennen, 1990). Tezenas du Montcel (1979) later proposed six



Plate 1.13. Bunches of 'Cevvazhai'/'Sevazhai' (AAA, Red subgroup) for sale at a wholesale market in Tiruchirappalli, Tamil Nadu State, India (photo: J.W. Daniells, QDPI).



Plate 1.14. Fruit of 'Pisang Barangan' (AAA, Lakatan subgroup) is very popular in Indonesia. (photo: J.W. Daniells, QDAF).

subdivisions ('Giant French', 'Average French', 'Dwarf French', 'French Horn', 'False Horn' and 'True Horn') after an analysis of many different characteristics ranging from the colour and circumference of the pseudostem to orientation of the fingers and male bud characteristics. West and Central Africa is an important centre of secondary diversification of plantain. De Langhe (1961), who recognized 56 cultivars in the Democratic Republic of Congo, believed that they all arose from one clonal source. Recent investigations of over 200 plantain cultivars indicate that genetic diversity is very low. No correlation has been found between the diversity that has been found and morphological characteristics (Christelová *et al.*, 2016). 'Agbagba', a 'False Horn'

Table 1.4. AAB genomic group – Plantain, Pome, Maoli/Popoulu and Iholena subgroups.

Subgroup	Clone set	Clones/synonyms	Location	Main use of fruit		
Plantain	French	'Obino l'Ewai'	Nigeria	Cooking		
		'Njock Kon'	Cameroon			
		'Nendran'	India			
		'Dominico'	Colombia			
	French Horn	'French Sombre'	Cameroon			
		'Mbang Okon'	Nigeria			
		'Batard'	Cameroon			
	False Horn	'3 Vert'	Cameroon			
		'Agbagba'	Nigeria			
		'Orishele'	Nigeria			
		'Dominico-Hartón'	Colombia			
	Horn	'Cuerno'	Central America			
'Barraganete'		Ecuador				
'Ihitisim'		Nigeria				
'Pisang Tandok'		Malaysia				
		'Tindok'	Philippines			
Subgroup	Clones	Synonyms	Location	Main use of fruit		
Pome	'Pome'	'Pome'	Canary Islands	Dessert		
		'Prata'	Brazil			
		'Virupakshi', 'Vannan', 'Sirumalai'	India			
		'Kijakazi'	Zanzibar			
	'Prata Anā'	'Brazilian'	Hawaii			
		'Prata Anā'	Brazil			
		'Prata Catarina'	Brazil			
'Pacovan'	'Pacovan'	Brazil	Dessert			
	'Pachanadan'	'Pachanadan'	India	Dessert		
		'Lady Finger'	Australia			
Subgroup	Clones/synonyms	Location	Main use of fruit			
Maoli/Popoulu		'Mai'a Maoli', 'Mai'a Ele'ele'	Hawaii	Cooking		
		'Mei'a Ma'ohi Hai', 'Mei'a Mao'i Maita'	French Polynesia			
		'Comino', 'Pompo', 'Maqueño'	Ecuador			
		'Pacific Plantain'	Australia			
		'Mai'a Ka'io', 'Mai'a Huamoa'	Hawaii			
		'Mei'a Po'u Hu'amene', 'Mei'a Po'upo'u'	French Polynesia			
		'Popoulou'	CRBP ^a			
		Iholena	'Mai'a Ha'a', 'Mai'a Kapua', 'Mai'a Lele'		Hawaii	Cooking and Dessert
			'Mei'a Ore'a 'Ute 'Ute', 'Maritú'		French Polynesia	
					Colombia	

^aGermplasm collection of the Centre régional bananiers et plantains, Cameroon.



Plate 1.15. Bunches of ‘Dominicio’ (AAB, syn. ‘French Plantain’) for sale near Guayaquil, Ecuador (photo: J.W. Daniells, QDAF).

plantain, has been reported to revert occasionally to ‘French’ plantain (Tezenas du Montcel *et al.*, 1983). The Linnaean name *Musa paradisiaca* has been applied to ‘French’ plantain, but should not be used today (Stover and Simmonds, 1987).

Cultivars in the Pome subgroup are important dessert banana types in India and Brazil, where their subacid flavour is much appreciated. The taste is also popular in Australia and Hawaii. However, cultivars are generally not very productive. Uma and Sathiamoorthy (2002) recognized 17 distinct cultivars of the Pome subgroup in India. ‘Prata Anã’ and a selection named ‘Prata Catarina’ are synonymous dwarf variants of ‘Prata’ from Brazil. ‘Santa Catarina Prata’ (Plate 1.16) from Hawaii originated in Brazil. ‘Pacovan’ is a large fruited variant from Brazil. Both ‘Prata Anã’ and ‘Pacovan’ have been used in breeding programmes. The ‘Lady Finger’ cultivar grown commercially in Australia may be synonymous with ‘Pachanadan’ of India.

Traditional cooking-banana cultivars found on islands in the Pacific Ocean have been placed in the Maoli/Popoulu subgroup of the AAB genomic group. The ‘Maoli’ and ‘Popoulu’ types of Hawaii differ in aspects of fruit shape and bunch appearance (Pope, 1926; Kepler and Rust, 2011), and isozyme studies by Lebot *et al.* (1994)



Plate 1.16. ‘Santa Catarina Prata’ (AAB, Pome subgroup) photographed at the South Johnstone Research Station in North Queensland came from Hawaii, but originated in Brazil, where it is popular as are other ‘Prata Anã’ selections. (photo: J.W. Daniells, QDAF).

suggested that the two types may have had independent origins. However, their separation into two distinct subgroups does not appear to be supported by simple sequence repeat (SSR) marker studies (Christelová *et al.*, 2016). Furthermore, there are several cultivars from the subgroup in the western Pacific that are intermediate between ‘Maoli’ and ‘Popoulu’ in their characteristics, such as ‘Pacific Plantain’ grown in Australia (Plate 1.17). The original base clones of the ‘Maoli’ and ‘Popoulu’ types, which may have originated in the New Guinea area (Daniells, 1990a; Lebot *et al.*, 1994), were probably carried by Polynesians on their migrations across the Pacific.

Iholena is the name given to a third type of AAB banana found in the Pacific, but mainly in Hawaii. The fruit is sweet, but is primarily used for cooking (Plate 1.18). Cultivars, which differ in some morphological characteristics, are also thought to have arisen from a base clone carried by migrating Polynesians from the New Guinea area (Lebot *et al.*, 1994). The occurrence of a few representatives of the Iholena and Maoli–Popoulu

subgroups in the Andes region of South America has led to speculation that banana may have been introduced to the continent from the Pacific in pre-Columbian times (Langdon, 1993).

Some other important clones in the AAB genomic group are listed in Table 1.5.

‘Silk’, which has fruit with a sweet-acid taste, is a very popular dessert cultivar in South and Southeast Asia, East Africa and Latin American–Caribbean regions (Plate 1.19). Uma and Sathiamoorthy (2002) recognized five distinct variants in India. ‘Silk’ has been described under the Linnaean name *Musa sapientum*, but this and all other Latin names for banana should be disregarded (Stover and Simmonds, 1987).

‘Mysore’ is grown on a large scale in South Asia (Plate 1.20) and like ‘Silk’ has sweet-acid fruit. However, outside India and Sri Lanka, it is usually only occasionally encountered. Exceptions are Trinidad, where it is used to shade cocoa, and Samoa. Only a few sports of ‘Mysore’ have been identified.

‘Pisang Raja’ is a clone found in Malaysia and Indonesia, but is rare elsewhere (Plate 1.21). ‘Pisang Kelat’ is a dessert banana from Malaysia.



Plate 1.17. ‘Pacific Plantain’ (AAB, Maoli/Popoulu subgroup), seen here at East Palmerston in Queensland, is grown commercially on a small scale in Australia (photo: J.W. Daniells, QDAF).



Plate 1.18. Bunch of ‘Uzakan’ (AAB, Iholena subgroup) in a germplasm collection at Mbarara, Uganda (photo: J.W. Daniells, QDAF).

Table 1.5. AAB genomic group – Silk, Mysore, Pisang Raja, Pisang Kelat, Sukari Ndizi and Laknau subgroups.

Subgroup	Clones/synonyms	Location	Main use of fruit
Silk	'Silk Fig'	West Indies	Dessert
	'Rasthali'	India	
	'Kolikutt'	Sri Lanka	
	'Pisang Rastali'	Malaysia	
	'Pisang Raja Sereh'	Indonesia	
	'Latundan'	Philippines	
	'Maçã', 'Manzano'	South America	
	'Pukusa'	Zanzibar	
Mysore	'Sugar'	Australia	Dessert
	'Mysore'	West Indies, Australia	
	'Poovan'	India	
	'Embul'	Sri Lanka	
	'Fa'i Misiluki'	Samoa	
	'Pisang Keling'	Malaysia	
Pisang Raja	'Kikonde Kenya'	Zanzibar	Dessert and cooking
	'Pisang Raja'	Malaysia, Indonesia	
Pisang Kelat	'Grindy'	Windward Islands	Dessert
	'Pisang Kelat'	Malaysia	
Sukari Ndizi	'King'	Trinidad	Dessert
	'Laknau'	Philippines	
Laknau	'Pisang Raja Talong'	Malaysia	Cooking
	'Kune'	Papua New Guinea	

**Plate 1.19.** Fruit of 'Rasthali' (AAB, Silk subgroup) for sale in Tiruchirappalli, Tamil Nadu State, India (photo: D.R. Jones, INIBAP).



Plate 1.20. Bunches of 'Poovan' (AAB, Mysore subgroup) for sale at the wholesale banana market in Tiruchirappalli, Tamil Nadu State, India (photo: D.R. Jones, INIBAP).



Plate 1.21. Bunch of 'Pisang Raja' (AAB) in the MARDI germplasm collection at Serdang, Selangor State, West Malaysia. Note the persistent male flowers (photo: D.R. Jones, INIBAP).

'Laknau' is a plantain-like cultivar that has been used for breeding. 'Sakali Ndizi' is popular in East Africa (Plate 1.22).

One AAB clone is an oddity. 'Pisang Seribu' has hundreds of small, tightly packed fingers on the bunch and has been described under the Latin name *Musa chiliocarpa* Backer (Plate 1.23).

ABB genomic group

ABB cultivars are generally hardy and disease-resistant. Most produce starchy fruit, which is cooked.

The popular cultivar 'Bluggoe' gives its name to a major ABB subgroup (Table 1.6), and is regarded as the base clone. 'Silver Bluggoe', a common, waxy-fruited variant, is also important. Both are widely distributed. A number of other variants have been described from India, the likely origin of the subgroup and centre of diversity. Dwarfing to create the 'Dwarf Bluggoe' type is rare and may have only occurred in the western hemisphere. Fruit of 'Bluggoe' has a distinctive angular shape (Plate 1.24).

Other important clones in the ABB genomic group are listed in Table 1.7.

'Monthan' gives its name to another ABB subgroup that seems likely to have originated in India. Clones are morphologically similar to cultivars in the Bluggoe subgroup. 'Monthan' and



Plate 1.22. Fruit of ‘Sakali Ndizi’ (AAB) being transported to market near Jinja, Uganda (photo: D.R. Jones, INIBAP).

‘Bluggoe’ distinguished by the pronounced cylindrical apex on fruit of the former compared with the tapering apex of fruit of the latter. Uma and Sathiamoorthy (2002) recognized six clones in the Monthan subgroup.

There are a number of ABB cooking-banana cultivars in the Philippines, typified by ‘Saba’, which forms a distinct subgroup. Valmayor *et al.* (2002) recognized 13 cultivars. They include the waxy-fruited sport ‘Abuhon’, the larger-fruited ‘Cardaba’ and ‘Gubao’, the fused-fingered ‘Inabaniko’, the small-fruited ‘Turangkog’ and its waxy-fruited mutant ‘Sabang Puti’. A bunch of ‘Pisang Kepok’, an Indonesian cultivar in the Saba subgroup, is illustrated in Plate 1.25.

‘Pisang Awak’ is a widely disseminated, high-yielding cooking/dessert cultivar, which is also used as a beer banana in East Africa. It is very common in Thailand, Vietnam and elsewhere in Indochina. Subclones in Thailand differ in fruit pulp colour. ‘Kluai Namwa’ (syn. ‘Pisang Awak’)



Plate 1.23. Bunch of ‘Kluai Roi Wi’ (AAB, syn. ‘Pisang Seribu’), which has hundreds of small fingers, at the Surat Thani Research Station in southern Thailand (photo: D.R. Jones, INIBAP).

has yellow pulp, ‘Kluai Namwa Khao’ has white pulp and ‘Kluai Namwa Daeng’ has pink pulp. ‘Kluai Namwa Khom’ is a dwarf form (Silayoi and Chomchalow, 1987). One variant, which has been collected in West Malaysia, has sweeter fruit containing many more seeds and an apparent increased susceptibility to freckle disease.

‘Pelipita’, which is known as ‘Pelipia’ in the Philippines, has been planted in Central America as a Moko bacterial wilt-resistant cultivar. ‘Ney Mannan’, which is a clone from South Asia, is very popular in Sri Lanka, where it is known as ‘Alukehel’ or ‘Ash Plantain’. ‘Pata Sina’ in the Ney Mannan subgroup is shown in Plate 1.26. ‘Peyan’ is another South Asian clone. ‘Kalapua’ is a common clone in Papua New Guinea with several variants, including a dwarf form. ‘Pitogo’ is a cultivar from the Philippines with almost round fruit (Plate 1.27). ‘Kluai Teparot’, the fruit of which is also shown in Plate 1.27, is now included in the ABB group following the finding that it is not a tetraploid.

Table 1.6. ABB genomic group – Bluggoe subgroup.

Clone	Synonyms	Location	Main use of fruit
'Bluggoe'	'Bluggoe', 'Moko' 'Pisang Abu Keling' 'Nalla Bontha' 'Fa'i Pata Samoa' 'Kidhozi', 'Kivuvu' 'Matavia' 'Kluai Som' 'Largo'	West Indies Malaysia India Samoa East Africa Philippines Thailand Hawaii	Cooking
'Silver Bluggoe'	'Square Cooker', 'Mondolpin' 'Silver Bluggoe', 'Silver Moko' 'Kluai Hakmuk' 'Thella Bontha' 'Katsila'	Australia West Indies Thailand India Philippines	Cooking
'Dwarf Bluggoe'	'Chamaluco Enano'	Puerto Rico	Cooking



Plate 1.24. Bunch of 'Bluggoe' (ABB) at South Johnstone, Queensland, Australia (photo: J.W. Daniells, QDAF).

The male axis is occasionally absent from this robust clone, which is found in many countries in Southeast Asia (Stover and Simmonds, 1987).

Genomic groups with S and T components

Shepherd and Ferreira (1984) and Arnaud and Horry (1997) identified some cultivars in Papua New Guinea believed to contain genetic elements of *Musa schizocarpa*, another wild species in the Eumusa section. Genomic groups were designated AS, AAS and ABBS, where S indicates hybridization with *M. schizocarpa*. Other cultivars were thought to have genetic components from species in the Australimusa section. AAT, AAAT and ABBT genomic groups have been recognized, where T indicates hybridization with an Australimusa species. Research using molecular taxonomic methods has indicated that *M. schizocarpa* and one or more species in the Australimusa section did play a role in the origin of some Eumusa cultivars present in Papua New Guinea (Carreel, 1995). However, cultivars with these unusual combinations of genomic constituents seem to be only occasionally found in cultivation.

BBB genomic group

There is no evidence to suggest that parthenocarpy occurred in *M. balbisiana* as it did in *M. acuminata*. Although 'Saba'-type cultivars have been classified as having a BBB genome using the scoring method of Simmonds and Shepherd (1955) (Pascua and Espino, 1987), this has been challenged on morphological grounds

Table 1.7. ABB genomic group – Monthan, Saba, Pisang Awak, Pelipita, Ney Mannan, Peyan, Kalapua and Kluai Teparot subgroups.

Subgroup	Clones/synonyms	Location	Main use of fruit
Monthan	'Monthan'	India	Cooking
Saba	'Saba'	Philippines	Cooking
	'Pisang Kepok'	Indonesia	
	'Pisang Abu Nipah'	Malaysia	
Pisang Awak	'Pisang Awak'	Malaysia	Cooking and Dessert
	'Kluai Namwa'	Thailand	
	'Katali'	Philippines	
	'Chuói Tay'	Vietnam	
	'Karpuravalli'	India	
	'Kayinja'	East Africa	
	'Ducasse'	Australia	
Pelipita	'Pelipita'	Central America	Cooking
	'Pelipia'	Philippines	
Ney Mannan	'Ney Mannan'	India	Cooking
	'Alukehel', 'Ash Plantain'	Sri Lanka	
	'Blue Java'	Fiji, Australia	
	'Ice Cream'	Hawaii	
Peyan	'Peyan'	India	Cooking
Kalapua	'Kalapua'	Papua New Guinea	Cooking
Kluai Teparot	'Kluai Teparot'	Thailand	Cooking
	'Tiparot'	Philippines	
	'Pisang Abu Siam'	Malaysia	

**Plate 1.25.** Young bunch of 'Pisang Kepok' (ABB, Saba subgroup) at Besum, Papua, Indonesia (photo: J.W. Daniells, QDAF).**Plate 1.26.** Bunch of 'Pata Sina' (ABB, Ney Mannan subgroup) near Apia, Upolu, Samoa (photo: J.W. Daniells, QDAF).



Plate 1.27. Fruit of ‘Kluai Teparot’ (left), an ABB clone with angular fingers found in a number of Southeast Asia countries and ‘Pitogo’ (right), an ABB clone with small rounded fingers grown in the Philippines (photo: D.R. Jones, INIBAP).

(Shepherd, 1990) and on molecular evidence (Jarret and Litz, 1986; Carreel, 1995). However, ‘Kluai Lep Chang Kut’ from Thailand may be a BBB as it has no *M. acuminata* characteristics and resembles *M. balbisiana* morphologically. This clone may have arisen from a cross between an ABB cultivar, such as ‘Kluai Teparot’, and *M. balbisiana* (Shepherd, 1990; J.P. Horry, Montpellier, 1999, personal communication).

For more information on subgroups and clones, see Stover and Simmonds (1987) and Daniells *et al.* (2001). Consult Robinson and Galán Saúco (2010) for data on bunch weights and yields/ha of various banana cultivars.

Advances in knowledge on the origin of cultivars derived from *Musa* species in the Eumusa section

M. acuminata has a number of subspecies and each has its own area of distribution (see Fig. 1.2). The Malayan peninsula was suggested by Simmonds (1962) as the location of the origin of edible banana because *M. acuminata* ssp. *malaccensis* was believed by him to be the primary source of edibility. However, this hypothesis was challenged by Carreel (1995). With the aid of restriction fragment length polymorphism (RFLP)

markers, she compared DNA from chloroplasts (inherited through the female parent), mitochondria (inherited through the male parent) and the nucleus of many *Musa* species, subspecies and landraces. Her work gave an insight into the wild species and subspecies that have contributed to the genetic make-up of cultivars derived from *Musa* species in the Eumusa section. This in turn has given clues as to probable location of origin of cultivars.

The wild *Musa* species and subspecies implicated in the ancestry of the cultivated Eumusa banana cultivars are listed in Table 1.8. As discussed earlier, the first crucial step in banana domestication is believed to be hybridization between geographically isolated subspecies of *M. acuminata* found in Southeast Asia and western Melanesia (Perrier *et al.*, 2011). Three regions where this hybridization is likely to have occurred have been identified. One southern contact zone stretched from New Guinea to Java, one eastern contact zone from New Guinea to the Philippines and another northern contact zone from the Philippines to mainland Southeast Asia (Perrier *et al.*, 2011). In the southern contact zone, *M. acuminata* ssp. *banksii* (Plate 1.28), *zebrina* and *microcarpa* may have interbred with ssp. *banksii* and *errans* crossing in the eastern contact zone and ssp. *microcarpa*, *malaccensis* and *errans*

Table 1.8. Wild *Musa* implicated in the ancestry of the Eumusa series of edible banana cultivars (Carreel, 1995).

Species	Subspecies	Geographical distribution ^a
<i>Musa acuminata</i>	<i>banksii</i> ^b <i>errans</i> ^b	New Guinea, north-east Queensland (Australia), Samoa ^c Philippines
<i>Musa acuminata</i>	<i>burmannica</i> ^d (<i>burmannicoides</i>) <i>siamea</i> ^d	Myanmar Thailand, Indo-China
<i>Musa acuminata</i>	<i>malaccensis</i>	Southern Thailand, West Malaysia, Sumatra (?)
<i>Musa acuminata</i>	<i>microcarpa</i>	North Borneo
<i>Musa acuminata</i>	<i>zebrina</i>	Java
<i>Musa balbisiana</i>		Indochina, northern Myanmar, India, Sri Lanka, Philippines, New Guinea, ^e Malaysia, ^f Thailand ^f
<i>Musa schizocarpa</i> ^g		New Guinea
<i>Australimusa</i> species ^h		New Guinea, Solomon Islands

^aBased on information from Simmonds (1962), Shepherd (1990), Carreel (1995) and Daniells *et al.* (2016).

^bThe nuclear genomes of *M. acuminata* ssp. *banksii* and ssp. *errans* are similar, but the cytoplasmic genomes are different.

^c*Musa acuminata* ssp. *banksii* is believed to have been introduced to Samoa (Simmonds, 1962).

^dThe nuclear, chloroplastic and mitochondrial genomes of *M. acuminata* ssp. *burmannica*, *burmannicoides* and *siamea* accessions in international collections are similar (Carreel, 1995).

^eSimmonds (1962) believed *M. balbisiana* to be indigenous to Papua New Guinea, but Argent (1976) and Perrier *et al.* (2011) thought the species was introduced.

^f*Musa balbisiana* was introduced to Malaysia and Thailand, where it was cultivated.

^gThis species has contributed to the genome of some cultivars found in Papua New Guinea.

^hOne or more species within the *Australimusa* section may be contributing to the genome of some cultivars in Papua New Guinea.

in the northern contact zone. Hybridization with *M. balbisiana* (Plate 1.29) is believed to have occurred in the eastern and southern contact zones after its dissemination south from the Asian mainland. India is thought to be another area where *M. balbisiana* hybridized with introduced cultivars (Perrier *et al.*, 2011).

The work of Carreel (1995) indicated that *M. acuminata* ssp. *banksii* or ssp. *errans* contributed genetically to very many edible cultivars. Numerous cultivated parthenocarpic diploids are now thought to have arisen as a result of crosses between these subspecies (or their fertile derivatives) disseminated by humans to new areas and the local subspecies.

Other interesting information has emerged from Carreel's study. Cooking and beer-making cultivars in the Lujugira–Mutika subgroup (AAA), which are common in a secondary centre of diversity in the highlands of East Africa, contain genetic components of *M. acuminata* ssp. *banksii* and ssp. *zebrina*. It is believed that the progenitor of the distinct East African highland banana types had its origin in south-eastern Indonesia where genetically close AAA clones are

still cultivated (Perrier *et al.*, 2011). Banana is considered by some historians to have reached the east coast of Africa at about the same time as other Southeast Asian food crops and to have been transported by Indonesian voyagers (Simmonds, 1962). Carreel (1995) also confirmed that both the A genomes of AAB Plantain and Maoli/Popoulu subgroups were derived from *M. acuminata* ssp. *banksii*, as had been suggested by earlier workers (Horry and Jay, 1990; Lebot *et al.*, 1994).

From a plant pathological perspective, it is interesting to note that *M. acuminata* ssp. *banksii* and ssp. *errans*, which are genetically close, are recognized as having considerably more disease problems than other *Musa* species and subspecies of *M. acuminata* (Vakili, 1965, 1968; Argent, 1976). If almost all edible banana cultivars in the Eumusa section have inherited some component of their genetic make-up from *M. acuminata* ssp. *banksii* and ssp. *errans*, it may explain their susceptibility to certain diseases to varying degrees. Current research is throwing more light on the origin of today's cultivars. Greater knowledge of genetic backgrounds will ultimately



Plate 1.28. *Musa acuminata* ssp. *banksia* (AAw), pictured here growing wild in north-western Papua New Guinea, is the probable progenitor of the first edible banana cultivars in the Eumusa series (photo: D.R. Jones, QDPI).

explain the reactions of landraces to disease and assist breeding programmes.

Edible banana cultivars derived from *Musa* species in the Australimusa section

A second distinct group of edible cultivars called Fe'i banana is found in eastern Indonesia, New Guinea and islands in the Pacific. Cultivars in this group have mostly upright fruit bunches (see Fig. 1.4), orange fruit when ripe and sap varying from pink through to purple (Plate 1.30). These similarities to *Musa maclayi*, a wild Australimusa species found in Papua New Guinea, led Simmonds (1962) to believe that *M. maclayi* must have played a major role in the evolution of Fe'i cultivars, though he did not rule out an interspecific origin.

Cheesman (1947) noted similarities between the Fe'i banana and *Musa lolodensis*, another



Plate 1.29. Bunch of a black-pigmented *Musa balbisiiana* (BBw, accession 'Pisang Klutuk Wulung') growing in a germplasm collection in Guadeloupe (photo: J.W. Daniells, QDAF).

species in the Australimusa section from New Guinea. Close links have been demonstrated between three Fe'i cultivars and *M. lolodensis*, using RFLP analysis. This led Jarret *et al.* (1992) to speculate that the section may be derived solely from this species. However, work by Carreel (1995) indicated that the Fe'i banana may have an interspecific origin as the nuclear genome of some of the cultivars she analysed were close to *M. maclayi*, some close to *M. lolodensis* and some close to *Musa peekelii*, which is yet another species in the Australimusa section found in Papua New Guinea. She also discovered that some cultivars are diploid whilst others are triploid.

It seems very likely that Fe'i cultivars originated in the New Guinea–Solomon Islands area and spread eastwards across the Pacific with migrating Polynesians (MacDaniels, 1947). The Fe'i cultivars seem highly resistant to diseases of the foliage, but little is known about their reaction to root diseases or their response to viruses and bacteria. This lack of knowledge is a reflection of the relatively unimportant role that these types now play as foodstuff in most



Plate 1.30. ‘Pisang Tongka Langit Alifuru’ (Fe’i cultivar with upright bunch) growing on Seram Island, Maluku Province, Indonesia (photo: J.W. Daniells, QDAF).

countries where they are still cultivated. However, in recent years there has been a revival of interest after the fruit of some clones was discovered to contain high levels of provitamin A carotenoids (Englberger *et al.*, 2003). High concentrations correlated with orange-coloured pulp. The fruit of the cultivar ‘Utin Iap’ of Pohnpei was determined to have levels of provitamin A 100 times greater than Cavendish (Englberger *et al.*, 2006).

Importance of banana classification to banana pathologists

Often in the past, research has been conducted on incorrectly identified germplasm, which has led to much confusion in the scientific literature. It is important that banana germplasm that is the subject of research be accurately identified by scientists and agriculturists. Only then can valid comparisons be made between the results of work undertaken at different times and at different locations.

One of the main challenges facing banana taxonomists today is to resolve synonymy among the many different names for banana clones and develop a system whereby cultivars can be easily identified. This would enable research workers to define their material more accurately.

It is just as important for plant pathologists to know the correct identity of material being tested or screened for disease resistance as it is for them to know the correct identity of the pathogen. Photographs of the banana host being assessed for disease would help taxonomic specialists to confirm the clone’s identity. With this knowledge, the reaction of a particular clone (with a particular genetic composition) to a disease can be put into perspective *vis-à-vis* the reaction of other clones. An attempt has been made in this volume to provide information on the reaction of the different types of banana to each disease. Inevitably, more information is available on the responses of cultivars to serious and widespread diseases that have been well studied than on host responses to minor diseases of limited distribution.

As mentioned previously, to help the reader place germplasm named in the text of this publication into perspective, the name of the genomic group, followed by the best-known synonym or subgroup, has been placed in parentheses after the cultivar name at appropriate places throughout the text.

Biodiversity International has recently developed an online *Banana Cultivar Checklist* on its ProMusa website that has the names of cultivars, their synonyms and subgroups.

Abacá

Abacá is indigenous to the Philippines, where most is grown, and is often called ‘Manila hemp’, a name given to it by early European traders, who found it for sale in the Manila market. Abacá produces the strongest of the cordage fibres and is used to make the best grades of commercial cables and ropes. Because it has a high degree of resistance to sea water and a low degree of swelling when wet, it is particularly suited to marine cordage. Large amounts are also pulped and used to make high-quality paper and specialties such as tea bags, paper sacks and movable walls

for Japanese houses (Purseglove, 1972). More recently, it is being used in the automobile industry for dashboards and car interiors.

Abacá grows best in the wet tropics where the annual precipitation is 2000–3200 mm, spread evenly throughout the year. The average annual temperature should be about 27°C, but not below 21°C, and the relative humidity around 80%. Abacá thrives in well-drained, deep, fertile soil, rich in humus and potash. Although these soils have relatively high fertility levels, continuous cropping of abacá leads eventually to yield declines because of the rapid rate of nutrient uptake by plants. In the Philippines, the crop is usually grown on land below 500 m (Berger, 1969; Purseglove, 1972).

The fruit of abacá, which is about 7.5 cm in length, is inedible, containing numerous black seeds. Bunches are also small (Plate 1.31). The plant has an underground rhizome with numerous small roots, which do not penetrate far into the soil. Erect pseudostems arise from the rhizome and reach a height of 5–8 m. As with banana, pseudostems consist of thickened, clasping leaf bases. The fibre from the outer sheaths is coarser,

stronger and darker in colour than the innermost fibre, which is whiter and weaker.

Planting material may be either suckers or whole corms or pieces of corm with a vegetative bud. However, suckers are rarely used, because of the difficulty of transport. True seed can also be planted, but plants take longer to mature. 'Seed' pieces, the equivalent of banana bits, are planted 2.5–3.0 m apart in holes/furrows and covered with 5–10 cm of soil. Young plants may be partially shaded for protection from excessive heat. The date of the first harvest depends on the cultivar, soil conditions and climate, but full-grown pseudostems can be harvested from 18 to 24 months after planting. After the first harvest, two or four pseudostems can be harvested from each mat every 4–6 months. Yields are initially small, but reach a maximum after 4–5 years, when 12.5 t of dry fibre/ha can be obtained. Yields decline after 7–8 years and the crop is replanted after 10–15 years.

Optimum cutting time is just before the *flag leaf* emerges. The flag leaf is the rudimentary and very small leaf that precedes the appearance of the inflorescence and its emergence can be anticipated because plant growth slows and leaf blades gradually shorten. Abacá is harvested by first trimming off the leaves and then cutting the pseudostem close to the ground. The percentage of fibre in a pseudostem is 1.5–3.0% of the weight. Fibre is extracted as soon after harvest as possible by hand stripping, spindle stripping or using a decorticating machine. Extracted fibre is either sun-dried in the open or air-dried in sheds. It is then tied in bundles, graded and baled for export. Abacá fibre consists of collections of sclerenchyma cells about 2.5–12 mm long. Strands of fibre can reach a length of 1.5–3.0 m. They are three times as strong as cotton and twice as strong as sisal fibres. Low-quality fibre comes from plants harvested too young or too old. Abacá fibre deteriorates during prolonged storage. The main fungi responsible have been identified as *Aspergillus fumigatus* and *Chaetomium funicolum* (Purseglove, 1972).

Abacá is traditionally a crop of the Philippines where *Musa textilis* occurs in nature. Here, the bulk of the crop is grown in the eastern Visayas and Bicol regions (E.O. Lomerio, Legazpi City, 1996, personal communication). In 2013, 65,000 t were produced on 138,250 ha. Ecuador was the next largest producer, with 36,500 t



Plate 1.31. Bunch of *Musa textilis* (abacá) in a germplasm collection in Guadeloupe (photo: J.W. Daniells, QDAF)

grown on 25,300 ha. Minor suppliers are Costa Rica with 1225 t, Indonesia with 600 t and Equatorial Guinea with 250 t (FAO, 2016).

More than 100 cultivars of abacá have been identified in the Philippines, but only about 20 are of commercial significance (Anunciado *et al.*, 1977). These are listed in Table 1.9. Cultivars are distinguished by the colour and shape of their flowers and pseudostem, yield and quality of fibre and resistance to disease. Some, like 'Itom', are natural hybrids of *M. textilis* × *M. balbisiana* and are used to make 'Canton fibre' (Purseglove, 1972).

Enset

Enset (Fig. 1.6) is cultivated in Ethiopia to the south and southwest of Addis Ababa (Fig. 1.7) contributing to the food security of many in this densely populated area. The enset plant provides a starchy foodstuff and animal feed and is a source of fibre for making rugs, sacks, bags and ropes. In addition, fresh leaves are used to wrap food and serve as plates. Dried petioles and midribs are burnt as fuel and their pulp is utilized as cleaning rags and brushes, baby nappies and cooking-pot stands. Certain cultivars and parts of enset are used medicinally to treat humans and livestock to heal wounds and bone fractures, as a treatment for some childbirth problems and as a cure for diarrhoea. As an abortifacient, it is also utilized in birth control (ECA, 1996; Brandt *et al.*, 1997).

Table 1.9. Abacá cultivars recommended for growing in the Philippines (information from E.O. Lomerio, Legazpi City, 1996, personal communication).

Region	Cultivar
Visayas	'Inosa', 'Linawaan', 'Linino', 'Linlay'
Mindanao	'Tangoñgon', 'Maguindanao', 'Bongolanon'
Bicol	'Itom', 'Sogmad', 'Tinawagan Pula', 'Tinawagan Puti', 'Lausigon', 'Abaub', 'Casilihon', 'Lausmag 24', 'Itolaus 45', ' <i>M. textilis</i> 52', ' <i>M. textilis</i> 51', ' <i>M. textilis</i> 50'
Southern Tagalog	'Tinawagan Pula', 'Tinawagan Put'i', 'Sinibuyas', 'Putian'

Enset forms an important part of the diet of about 17.5 million people, which represents nearly 20% of the Ethiopian population. Enset farming is believed to be one of Africa's few surviving examples of indigenous, sustainable agriculture, which has evolved over hundreds of years. Enset is probably one of the oldest useful plants in Africa and has magic-religious significance in many areas. The Ari people preserve enset genetic resources by a highly ritualized, *ex situ* conservation of wild plants, which maintains the genetic diversity of landraces through a constant gene flow between wild and cultivated plants (Shigeta, 1990).

The system of cultivation, by planting enset mainly around the homestead, coupled with a continuous use of manure and household refuse, enables farmers to grow enset in the same plot for generations without the aid of chemical fertilizers. Enset is resistant to climatic and environmental fluctuations and produces edible products that can be stored for months, if not years. It is a high-yielding crop. Only 42 mature plants grown on a small plot of land can support the annual food demand of a household of seven (Alemu and Sandford, 1991; Kippe, 2002).

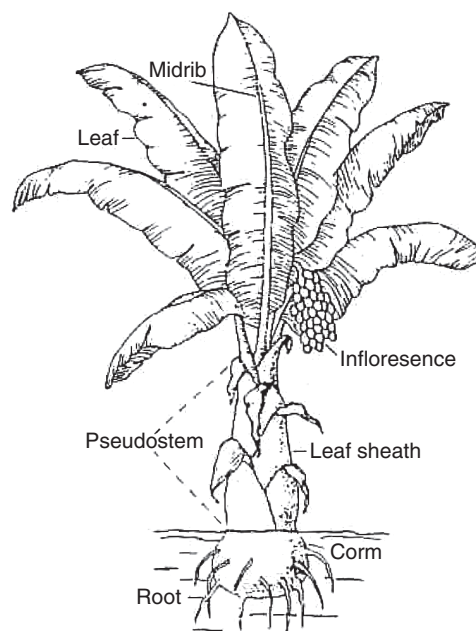


Fig. 1.6. Diagrammatic representation of enset (*Ensete ventricosum*) (from Brandt *et al.*, 1997).

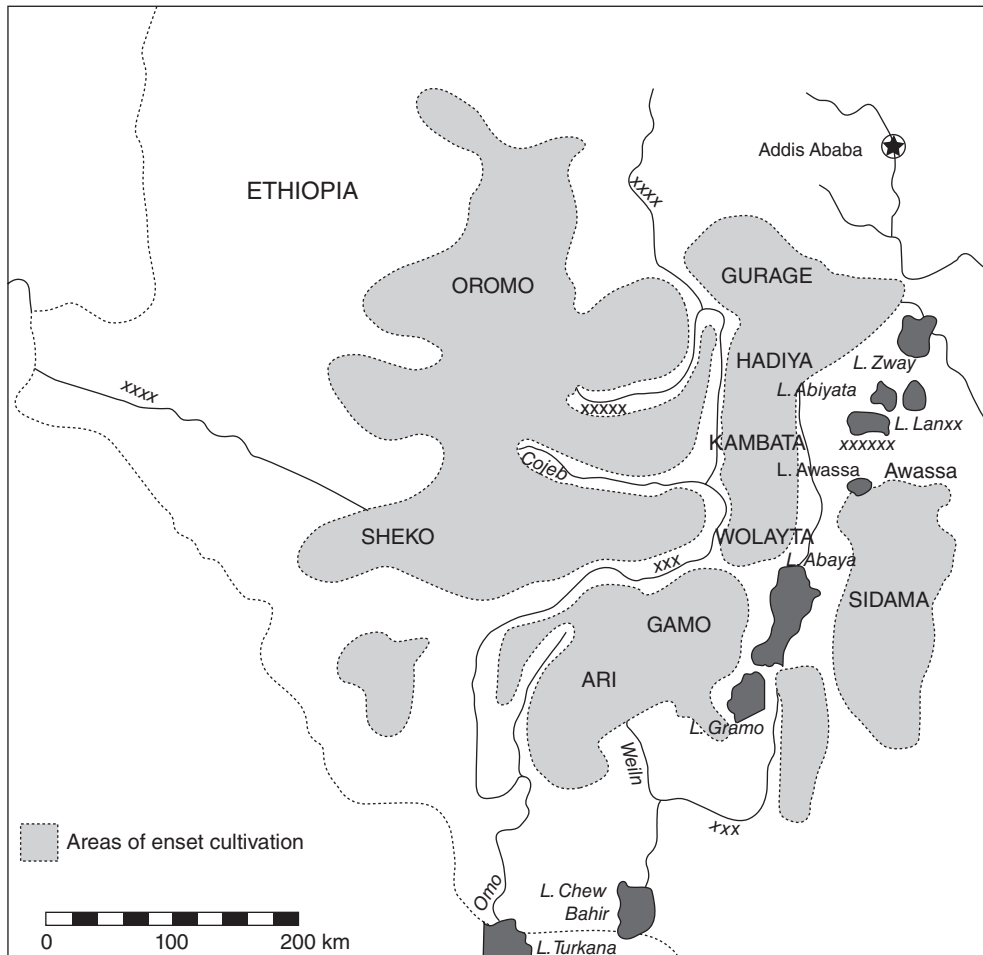


Fig. 1.7. Enset-growing areas in southwest Ethiopia with names of enset-cultivating ethnic groups (from Brandt *et al.*, 1997).

Enset is planted at altitudes ranging from 1200 m to 3100 m, but grows best at elevations of 2000–2750 m. The average temperature where it is grown varies from 10°C to 21°C, with a relative humidity range of 63–80%. Like banana, enset does not tolerate freezing and frost damage is often observed above 2800 m. The annual rainfall of most growing areas is 1100–1500 mm, with the majority falling between March and September. Irrigation is used to supplement rainfall at altitudes below 1500 m, where rainfall decreases and there is a greater evaporative demand. Enset grows in most soil types if they are sufficiently fertile and well drained. Cattle manure is used as the main organic fertilizer.

Ideal soils for enset cultivation have a pH of 5.6–7.3 and contain 2–3% organic matter (Brandt *et al.*, 1997).

Enset development is similar to banana in that leaves are successively produced by an apical meristem until flowering. The plant is normally 5–7 m in height and the pseudostem has a circumference of 0.5–3.0 m at maturity. It has a shallow rooting system, which extends 2–3 m.

It takes about 6–7 years at the optimum altitude for growth for an enset plant to reach maturity and form an inflorescence. The fruit, which is seedy and leathery, is inedible and varies in size and weight between clones. After fruiting, the plant declines.

Although enset only reproduces by seed in nature, the Ethiopian people have developed a technique by which vegetative shoot formation is induced, thus enabling superior plants to be clonally propagated. The central apical meristem at the top of the rhizome of a 3–4-year-old plant is hollowed out and the rhizome is then usually split into two equal parts, which are buried and covered with manure. About 40–200 buds are produced by this method and the suckers emerge from the soil after 4–6 weeks (Demeke, 1986). The suckers are later severed from the corm and planted in nurseries. Management varies considerably after this stage, depending on the ethnic community and household requirements. Plants may be transplanted up to four times at ever wider spacing. Some may be harvested young, while others are left for harvesting when mature. Generally, a leaf canopy is maintained that covers the soil for most of the year. Enset may grow alone or in mixed plantings with other crops, such as maize, cabbage, coffee and citrus (Brandt *et al.*, 1997).

As the developing inflorescence uses up starch reserves in the plant (Purseglove, 1972) farmers usually harvest enset at flower emergence (Yemataw *et al.*, 2012). The rhizome is grated using either a special hardwood implement or a bamboo scraper (Plate 1.32). After decortication, the pulp of the leaf sheaths that make up the pseudostem is also removed. Enset fibre is a by-product of this process.

A fermentation process that lasts for a month or more takes place in a pit lined with enset leaves and transforms the rhizome and leaf sheath scrapings into a soft starchy mass called *kocho*. This is the most important of the different food products made from enset and it can be kept for many months or several years. The amount of *kocho* obtained is dependent on the number of transplants before harvesting and the space between each plant, with a maximum experimental yield of 33.2 t/ha/year being reported by Tsegaye and Struik (2001). These authors calculated that the edible yield of enset in terms of weight and energy was



Plate 1.32. Women, who traditionally process enset (*Ensete ventricosum*) in Ethiopia, abrading decorticated rhizomes with hardwood graters (foreground) and a leaf sheath with a bamboo scraper (background) near Jima in the Kefa district (photo: G. Blomme, BI).

much higher than those of other carbohydrate-rich root and tuber crops or cereals cultivated in Ethiopia.

Another food product is *bulla*, which is a porridge, pancake or dumpling made from dehydrated juice obtained from the scrapings of the leaf sheath, peduncle and grated corm. *Amicho* is the boiled rhizome, usually from a young plant (Brandt *et al.*, 1997).

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