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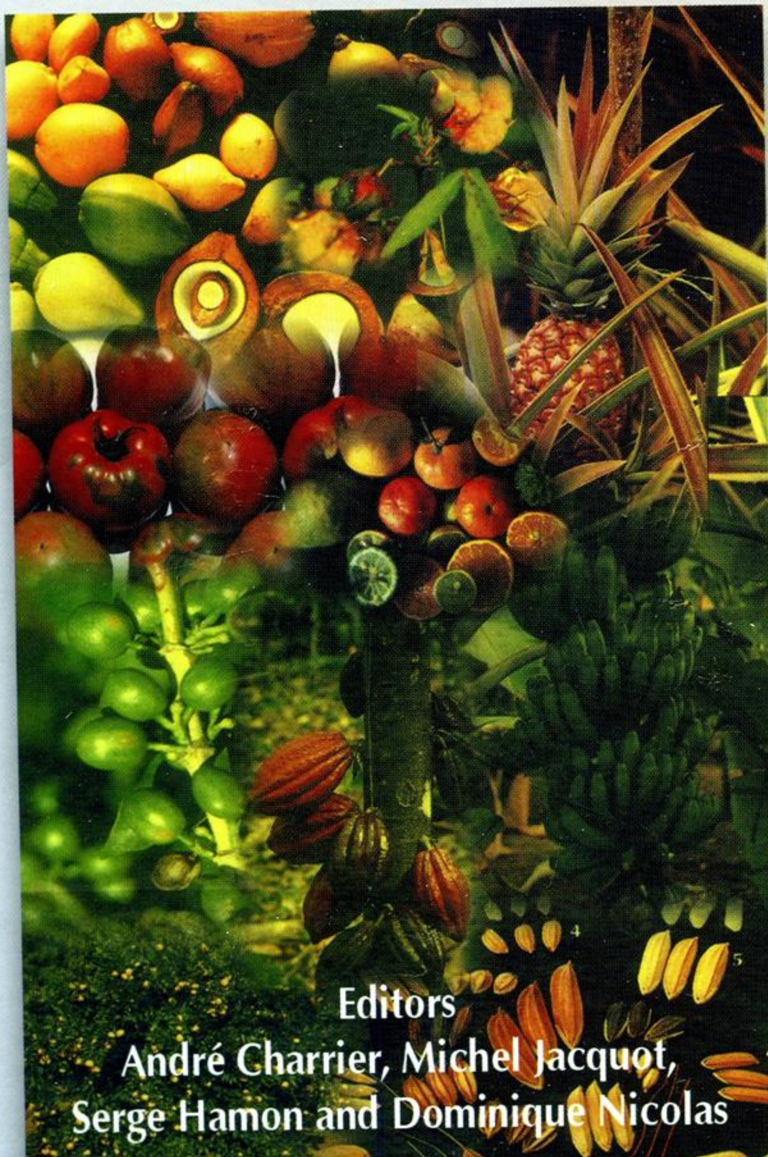
Tropical Plant Breeding



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CIRAD SPI

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Preface

Plant species grown in tropical countries—on small-scale family farms or commercial farms, to provide food for humans or livestock, in dry or humid regions—are highly abundant and taxonomically diversified.

A broad spectrum of biological and genetic knowledge—acquired and synthesized by geneticists and agronomists and essential for the progress of genetic improvement programmes—had to be reviewed for the purposes of this book. *Tropical Plant Breeding* thus covers many topics, including: methods for assessing genetic diversity and spatiotemporal variations; natural reproductive mechanisms and possible deviations that could give rise to novel varietal structures and potential genetic exchanges with neighbouring species; vegetative and reproductive cycles, while sometimes accurately specifying details like leaf and inflorescence emission rates; genetic origins of traits such as tolerance to biotic and abiotic constraints, along with the underlying physiological and genetic mechanisms.

Readers perusing the different chapters of this reference book will undoubtedly be impressed by how quickly information is accrued and effectively utilized, thanks to the interdisciplinary approach, and how readily new breeding techniques are adopted and implemented. Are not oil palm, coffee and rice essential model species for plant biotechnology development?

Tropical plants—grown in fragile environments or those weakened by poor cultivation practices, recently domesticated or subjected to controlled breeding, sometimes transplanted in limited numbers remote from their natural areas, intercropped with traditional crops or monocropped over vast areas—are often faced with extreme situations with respect to population genetics, genetic drift, climatic adaptation and pest and disease constraints.

A comparison of tropical and temperate plant breeding highlights that similar techniques are implemented and the specific biological constraints are comparable. What characterizes tropical species is the need to reconcile a high genetic potential with a capacity for adaptation to a wide range of agricultural conditions and environments. However, there is a less clear difference for these species with respect to genetic resources, elite material and improved varieties, which could be explained by the fact that the seed subsector is less industrialized in tropical countries. It also meets the need for adaptive flexibility, which is crucial in the tropics because of the high environmental and pest and disease risks.

The format adopted for all the chapters also highlights the importance allocated to the evolutionary organization of species, species complexes and varietal choices based on the prevailing agroeconomic context.

Note that this book is the result of considerable collaboration with different authors throughout the writing and editing process. It has benefitted from the skills and experience of researchers from CIRAD, INRA and IRD and others based in many different tropical countries. This type of collaboration reflects the team spirit that motivates international networks, while promoting the sustainability of genetic improvement programmes.

This updated reader-friendly book will meet the needs of plant breeders, pathologists and agronomists seeking a more in-depth understanding of genetic variability organisation and breeding of tropical plant species. The reader will readily understand their richness and find key elements necessary for a detailed study in the extensive bibliography.

Finally, in concluding I wish to convey to all authors with whom I have had the pleasure of working, that it was an enjoyable task to read this book and jointly ponder the potential of these knowledge-intensive genetic improvement programmes.

Yvette Dattée
Research Director, INRA
Director, GEVES

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Banana

Frédéric Bakry, Françoise Carreel, Marie-Line Caruana, François-Xavier Côte, Christophe Jenny and Hugues Tézenas du Montcel

The world production of bananas, estimated to be 88 million tons, ranks fourth in agricultural production. Bananas are cultivated in more than 120 countries in tropical and subtropical zones on five continents. Banana products represent an essential food resource and have an important socioeconomic and ecological role.

Edible bananas originated mainly from two wild diploid species, *Musa acuminata* (genome A) and *M. balbisiana* (genome B). Plants of these two species produce fruit filled with seeds (Plate I, 1). They reproduce both sexually and by vegetative propagation from shoots originating from axillary buds borne on an underground stem. Their development and domestication has resulted in sterile and parthenocarpic varieties.

Current varieties are generally sterile and seedless triploid clones of the single species *M. acuminata* (group AAA), or interspecific crosses between *M. acuminata* and *M. balbisiana* (groups AAB and ABB). More rarely, interspecific diploid varieties (AA and AB) and tetraploid clones are encountered.

There are two major production subsectors: bananas grown in pure stands whose fruit is intended for export and those grown in mixed-crop conditions with the fruit sold in local markets.

Clones cultivated for export—Grande Naine, Poyo and Williams—belong to the same subgroup of triploid bananas, Cavendish. They differ from each other only through somatic mutations affecting plant height or structure of the branches and fruit. They are generally monocropped under agro-industrial conditions, with many inputs and no alternating crop.

On the other hand, concerning bananas grown for local consumption, a large number of cultivars are used that are adapted to different cultural situations, diverse uses and varied tastes of consumers. Generally, few inputs are used in these production systems. Diploid bananas, related to the wild forms, are still cultivated in South-East Asia. Triploid cultivars belonging to different subgroups—Plantains, Silk banana, Lujugira, Gros Michel—are widely cropped on other continents.

Bananas are used for many purposes. They are consumed mainly as fresh fruit or cooked vegetables—this applies to plantains—or fried, e.g. Pisang Awak. They are also processed into crisps, fries, fritters, purees, jams, ketchup, as well as alcohol, wine and beer. Banana beer is very common in East Africa. Banana consumption per inhabitant per day ranges from 30 to more than 500 grams in some East African countries. Other parts of the plant have been used for millenia: the pseudotrunk for textile fibre extraction and in fishing (*M. textilis* called abace) in the Philippines, and the leaves used in making shelters, and covers or wraps for culinary purposes. In Thailand, the floral buds of certain varieties, e.g., Pisang Awak, are used in many culinary preparations. Some varieties purportedly possess medicinal properties.

Banana plants, cultivated throughout the world, are threatened by many diseases and pests. Chemical control measures used in intensive cultivation are not available to small banana producers in developing countries. For some diseases, there are no effective chemical control measures. Genetic improvement has thus been focused mainly on obtaining varieties resistant to the principal diseases.

Breeding bananas by crossing, which began in the 1920s, is currently pursued at five research centres. FHIA (*Fundación Hondureña de Investigación Agrícola*) in Honduras, is breeding banana plants for export as well as the 'cooking' types. EMBRAPA-CNPMF (*Empresa Brasileira de Pesquisa, Agropecuária, Centro Nacional de Pesquisa de Mandioca e Fruticultura Tropical*) in Brazil, aims at breeding local types of 'dessert' bananas. CRBP (Centre de recherches régionales sur bananiers et plantains) in Cameroon and IITA (International Institute of Tropical Agriculture) in Nigeria, are conducting research on breeding plaintain bananas in Africa. These four research centres are mainly interested in developing new tetraploid varieties by crossing triploid varieties and wild or improved diploid clones with resistance to diseases. At its Guadeloupe research station, CIRAD has adopted another crossing strategy involving the development of triploid varieties directly from diploid plant material.

Together with these crossing activities, since 1980 other groups have focused on mutagenesis and selection of somaclonal variants that appeared as a result of the development of *in vitro* culture techniques designed for rapid industrial multiplication of micropropagated banana plants. IAEA (International Atomic Energy Agency), based in Austria, is presently evaluating the behaviour of mutant varieties induced by exposing vegetative buds to ionising rays. QDPI (Queensland Department of Primary Industry) in Australia and TBRI (Taiwan Banana Research Institute) in Taiwan are carrying out a clonal selection of variants to obtain export banana varieties resistant to race 4 of the Panama disease.

Lastly, with the advent of new cell and molecular biology techniques, some research teams are now focusing on genetic transformation of banana plants. Transformation by particle bombardment is being carried out in Europe at the Catholic University of Leuven (Belgium) and by CIRAD (France) in collaboration with the University of Paris XI and CATIE (*Centro Agronómico Tropical de Investigación y Enseñanza*) in Costa Rica. Cornell University (USA) has developed a technique using *Agrobacterium tumefaciens* for banana transformation.

Since 1994, all of these genetic improvement activities have been conducted within the international *Musa* breeders network, prompted and supported by INIBAP (International Network for Improvement of Banana and Plantain). This organisation, under the aegis of IPGRI (International Plant Genetic Resources Institute) has a mandate to promote, support, conduct and co-ordinate breeding activities worldwide. It also encourages exchanges of plant material and dissemination of scientific information among research groups.

EVOLUTIONARY ORGANISATION

Diversity of Cultivated Forms

Banana plants are monocotyledons of the genus *Musa*, family Musaceae, order Zingiberales. The genus *Musa* is composed of four sections: *Australimusa* (2n = 2x = 20), *Callimusa* (2n = 2x = 20), *Rhodochlamys* (2n = 2x = 22) and *Eumusa* (2n = 2x = 22). The latter section includes almost all cultivated bananas. Although wild plants are all diploid (2n = 2x = 22), cultivated varieties are sometimes diploid, often triploid (2n = 3x = 33) and rarely tetraploid (2n = 4x = 44).

Biology and Reproduction

The banana is a giant herb whose pseudostem formed by interlocking leaf sheaths reaches 1 to 8 metres in height (Champion, 1963; Fig. 1.1). The leaves emerge from the apical meristem of the true stem, incorrectly termed the underground 'bulb', which is small in size. The bud at the axil of each leaf eventually gives rise to a shoot. Shoot production is the natural reproductive mode for cultivated varieties. At the end of the vegetative phase, a quick change in function of the central meristem induces the 'flower' primordia, followed by growth and elongation of the true stem within the pseudostem, and later by emergence of the inflorescence. The inflorescence (vertical, pendant or subhorizontal) is indefinite and fascicle-shaped. It consists of overlapping spathes arranged spirally, and single or double rows of flowers appear at its axils.

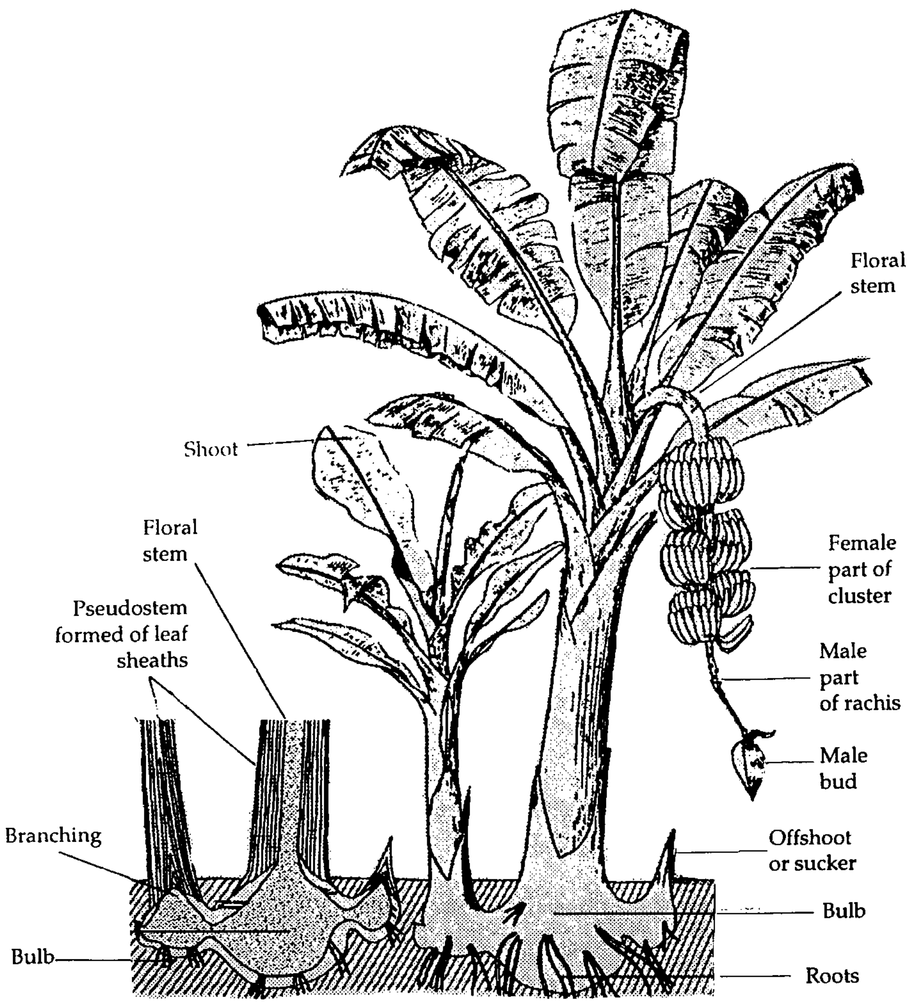

Fig. 1.1: Diagram of a banana plant at fruiting, with shoots and a longitudinal stem section (from Champion, 1967).

These are the first rows of flowers, usually called 'hands', from which the fruit bunches develop. The first hand contains flowers (termed female) with an ovary in the inferior position and non-functional stamens reduced to the state of staminodes. Sometimes the stamens develop, however, and these first flowers are hermaphrodite. In cultivated banana plants, the ovaries of female flowers are filled with pulp that forms the fruit without pollination or seed formation. Female sterility is quite high or complete in many clones. Some cultivated clones can produce fruit with seeds when they are pollinated.

After the female flowers, two or three hands of neutral flowers appear with undeveloped floral parts, followed by hands of male flowers (opposite the female flowers) with reduced undeveloped ovaries and well-developed stamens. In some cultivars, growth of the apical meristem of the inflorescence is interrupted immediately after emergence of the first female flowers, but the inflorescence generally continues to grow indefinitely to form the so-called male bud. If it is not cut, this male bud will continue to grow until fruit maturity and stem withering. In addition to wild species, many cultivars have male flowers with some degree of pollen fertility.

Agromorphological Variations

Morphotaxonomy has made it possible to characterise different banana varieties and to establish the basis of the current botanical classification (Table 1.1). There is considerable variability with respect to the aerial parts. Vegetative parts mainly vary with respect to pseudostem colour, the presence and colour of spots at the petiole base, the shape of the petiolar canal section, and the plant height and habit. There may also be colour chimeras and variations due to dwarfism—obstruction or deformation of the inflorescences caused by highly compact interlocking of the leaf sheaths, stocky appearance of the leaves and shoot inhibition. The most important of these variations concern the inflorescences and consequently the fruit bunches. Differences between fruit are determined by their size, shape and colour along with the pulp colour. Plantains have a very firm orangish-yellow flesh, unlike cooking bananas (Laknao, Popoulou, Bluggoe and Monthan). East African bananas are quite unique and, depending on the clone, used for cooking or brewing beer. Dessert bananas vary in taste and aroma: very sweet in some diploid Pisang Mas cultivars, sweet and acidulous in Figue Pomme (Silk Banana) of Brazil, and bland in the universally appreciated export Cavendish bananas. Morphological variability in the male floral bud involves differences in the shape and colour of the bracts and male flowers. The duration of the cycle is a varietal characteristic that is subject to wide variations, depending on the cultural conditions. It ranges from nine to

Table 1.1: Classification and geographic distribution of the principal banana cultivars

Subgroup	Cultivar	Type of fruit	Distribution
Group AA			
Sucrier	Pisang Mas, Frayssinette, Figue Sucrée	dessert, sweet	all continents
Pisang Lilin	—	dessert	Indonesia, Malaysia
Pisang, Berangan	—	dessert	Indonesia, Malaysia
Lakatan	—	dessert	Philippines
Group AAA			
Cavendish	Lacatan, Poyo, Williams, Grande Naine, Petite Naine	dessert	exporting countries
Gros Michel	Gros Michel, Highgate, Cocos	dessert	all continents
Figue Rose	Figue Rose, pink Figue Rose, green	dessert	Philippines, Pacific region, Antilles
Lujugira	Intuntu, Mujuba	beer and cooking	East Africa
Ibota	Yangambi km5	dessert	Indonesia, Africa
Group AB			
Ney Poovan	Safet Velchi, Sukari	dessert, sweet-acidic	India, East Africa
Group AAB			
Silk banana	Maça, Silk	dessert, sweet-acidic	all continents
Pome	Prata	dessert, sweet-acidic	India, Malaysia, Australia, Brazil, West Africa
Mysore	Pisang Ceylan	dessert, sweet-acidic	India
Pisang Kelat	Pisang Kelat	dessert	India, Malaysia
Pisang Rajah	Pisang Rajah Bulu	cooking	Malaysia, Indonesia
Plaintains	French, Corne, Faux Corne	cooking	Central and West Africa, Caribbean, Latin America
Popoulou	Popoulou	cooking	Pacific region
Laknao	Laknao	cooking	Philippines
Pisang Nangka	Pisang Nangka	cooking	Malaysia
Group ABB			
Bluggoe	Bluggoe, Matavia, Poteau, Cacambou	cooking	Philippines, Caribbean, Latin America
Pelipita	Pelipita	cooking	Philippines, Latin America
Pisang Awak	Fougamou	dessert	Thailand, India, East Africa, Philippines
Peyan	—	cooking	Philippines, Thailand
Saba	Saba	cooking	Philippines, Indonesia Malaysia
Group AAAA	Champa Nasik	dessert	—