Plant-Parasitic Nematodes of Coffee

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Cover picture: Histological section of a coffee root showing *Meloidogyne exigua* females and eggs (from Göldi, 1887) (published with permission)

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This book is dedicated to
the best of my world: Claudia, Lara and Anya
to my mother, Maria, with whom I share an endless joy in reading and writing.
and to James G. Baldwin, my former PhD supervisor, and the professors in the Dept. of Nematology at the University of California at Riverside, who decisively contributed to my scientific formation.

Preface

When I conceived this book, what I had in mind was what I did *not* know about coffee-parasitic nematodes (CPNs). Indeed, after reading many papers and several chapters in books, I felt far from having a comprehensive understanding of the subject. Not only would it be a daunting task to retrieve the numerous articles, reports, theses and dissertations on CPNs published since 1878, but it would also be impossible to learn, on my own, from all the enormous experience acquired by nematologists and coffee growers in so many countries.

Therefore, this book is dedicated to those with restless minds, who want to know more about CPNs and their importance in coffee production worldwide. This book has been diligently written by top scientists in their areas of expertise or country, and it has been meticulously edited to guarantee precision without compromising an enjoyable read. I learned a lot from this book . . . I'm sure you will too.

Finally, I'd like to thank Zuzana Bernhart from Springer, who believed in this project and decided to publish it; Susan Casement, who revised all chapters for grammatical correctness; and all the contributors, without whom this book would never have became a reality.

Campos dos Goytacazes, RJ, Brazil — Ricardo M. Souza

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Introduction

In 1878 the French naturalist Clément Jobert reported a disease affecting coffee plantations in the then Province of Rio de Janeiro, Brazil. Although he identified the causal agent, it was not until 1887 that the Swiss naturalist Emil A. Göldi described *Meloidogyne exigua*, as part of an extensive publication on that disease (see Chapter 12).

Since then, coffee-parasitic nematodes (CPNs) have grown to become a serious problem for coffee cultivation in many regions of the world, in which the extent of their direct and indirect impacts is yet to be estimated. Indeed, since the nineteenth century coffee cultivation has provided the first economic momentum of many tropical regions or whole countries. In recent decades, although industrialization and agricultural diversification have reduced the role of coffee trading in national GDPs, coffee cultivation remains crucial for the economic and social stability of millions of people across the globe. Under these circumstances, from the presumed yield losses that occur in the vast regions where no nematologists work, to the well-reported widespread decimation of plantations in Brazil, CPNs ought to be one of the most important nematode groups worldwide.

Despite their importance, CPNs have never until now been the subject of an in-depth review, in which hundreds of reports, papers published in national and international journals, dissertations and theses are critically examined. Instead of an individual work, a review prepared by several contributors provides different perspectives on CPNs, enriched by different educational backgrounds and by a broad range of expertise and research experiences. Furthermore, the review should also be a window to the nematode problems faced by coffee growers from several countries, and to the research efforts of and results obtained by these countries' nematologists.

This exchange of information is all the more important as one considers the technical and language difficulties that are still hurdles to the traffic of ideas and materials between nematologists located in tropical countries. All sort of difficulties, including poor internet connections, a lack of resources for foreign travel, the labyrinth of research funding and bureaucracy have created the present situation: there is virtually no international collaboration between nematologists dedicated to CPNs. Even in Brazil, where these nematodes have been studied for decades and by a sizable group of nematologists, virtually no one is aware of the nematode problems faced by coffee growers in Africa or Asia, for example, nor are they aware of the work performed by nematologists there.

The first chapter of this book introduces coffee – the plant and its cultivation - to those not familiar with it, providing a background for understanding many aspects of CPNs, such as their biology, interaction with their hosts, epidemiology and management.

In chapter 2, nematologists who often work on specific aspects of CPNs are invited to visit the evolution of the world coffee industry since the early twentieth century, and to see how its different phases and crises have influenced coffee cultivation and trading, research funding and technical support for growers.

From chapter 3 through 10, basic and applied aspects of the most damaging nematodes to coffee, *Meloidogyne* spp. and *Pratylenchus* spp., are discussed by top specialists in their areas of expertise. Chapter 11 reviews the information available on the many other nematode genera and species that have been reported associated with or as parasitic to coffee.

From chapter 12 through 17, nematologists from several countries review the landmarks in nematological work on CPNs in their countries, and present their research efforts, results and prospects.

Part I
The Crop

Chapter 1
Coffee: The Plant and its Cultivation

Henrique D. Vieira

Abstract This chapter aims to introduce coffee (*Coffea* sp.) to those not familiar with it, as a platform for understanding the following chapters. Initially, a few interesting events in coffee history are outlined, followed by diagrams and color images that explain aspects of coffee botanics that are directly related to production. The most important *Coffea* species, for production or breeding, are described. Important features of coffee cultivation, such as soil preparation, seedling production, harvest and postharvesting processing, are explained. A comparative discussion is carried out on the most important technological aspects of this crop, such as full sun *vs* shaded cultivation systems, arabica *vs* robusta coffee production and low *vs* high technological input.

Keywords Coffee origin · coffee cultivation · *Coffea* diversity · coffee botanics · coffee world production

1.1 Introduction

The word 'coffee' is probably derived from the former Kingdom of Kaffa (today part of Ethiopia), where coffee (*Coffea* sp.) was first cultivated from around the fifth to the eighth century. From its legendary origin in the Ethiopian highlands, the beverage was introduced into the Arab world through Egypt and Yemen, where it became widely consumed since alcoholic drinks were not allowed. In the Yemen, coffee was being cultivated commercially around the fourteenth century. It was introduced into Europe through Venice, and despite complaints about the 'Muslin beverage', its consumption slowly spread through this continent, the Americas and Asia (Neves, 1974; Anonymous, 2004).

Despite efforts from the Arabs to control coffee cultivation – by prohibiting the export of unroasted beans and seedlings – in the early eighteenth century the Dutch

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started its cultivation in their Asian and South American colonies, as did the French in the Caribbean. Today, coffee is cultivated in dozens of tropical countries, supporting regional or national economies (see Chapter 2). Coffee consumption *per* capita has increased, driven by its property of increasing the alertness of those who drink it and by the pleasant ambience it fosters when it is drunk socially. Many reports exist on its benefits to health when consumed moderately (Ascherio et al., 2001; Van Dan and Feskens, 2002; Encarnação and Lima, 2003).

This chapter focuses on introducing coffee – the plant, its cultivation and postharvest processing – to those who are not familiar with it; hence, aspects of botanics, diversity and agronomic practices are outlined to provide a background to the chapters that follow. Text and images have, therefore, been combined in the hope that reading this will be as enjoyable as drinking a good cup of coffee.

1.2 Coffee Botanics

Depending on the species, coffee grows as a perennial shrub or tree, with an extensive root system concentrated on the 0–60 cm soil zone, although roots are found growing down to three meters deep (Fig. 1.1). The distribution of the root system may nonetheless be altered by factors such as water availability and soil structure (Rena et al., 1986; Rena and Guimarães, 2000).

Above ground, arabica coffee (*C. arabica* L.) typically presents one main trunk; 'suckers' may appear but they are usually pruned. Robusta coffee (*C. canephora* Pierre ex A. Froehner) is typically multi-trunk. In both species, orthotropic branches grow vertically from the trunk; from these, the plant emits more or less horizontal plagiotropic branches, on which blooming and production occur (Figs. 1.2; 1.3A). Through trimming and pruning, the plant's natural architecture may be altered (Wormer and Gituanja, 1970).

Most coffee species have persistent leaves, although defoliation may occur because of abiotic (such as drought) or biotic (such as disease) stresses. Such defoliation is inversely related to production, and may be responsible for yield losses of up to 20%. Leaves are continuously emitted, but climate pattern and occasional stressful weather conditions determine when new leaf flushes occur (Gindel, 1962; Barros and Maestri, 1972).

Hermaphrodite flowers are emitted in inflorescences on the axiles of plagiotropic branches (Figs. 1.3B; 1.4A). Therefore, any factor that compromises the development of these branches will affect production. In a given geographic area, all plants bloom synchronously (Fig. 1.4B). The number of times plants bloom *per* year depends on the region's latitude and rainfall pattern; for example, in southeast Brazil, where marked dry and rainy seasons occur, the plants bloom two to three times/year, while in equatorial, rainy Costa Rica the plants may bloom up to fifteen times/year (Alvin, 1960). This has major implications for harvesting and control of pests and diseases. For arabica coffee, one important aspect in the relationship between or biotic stresses (including nematodes) and productivity is the fact

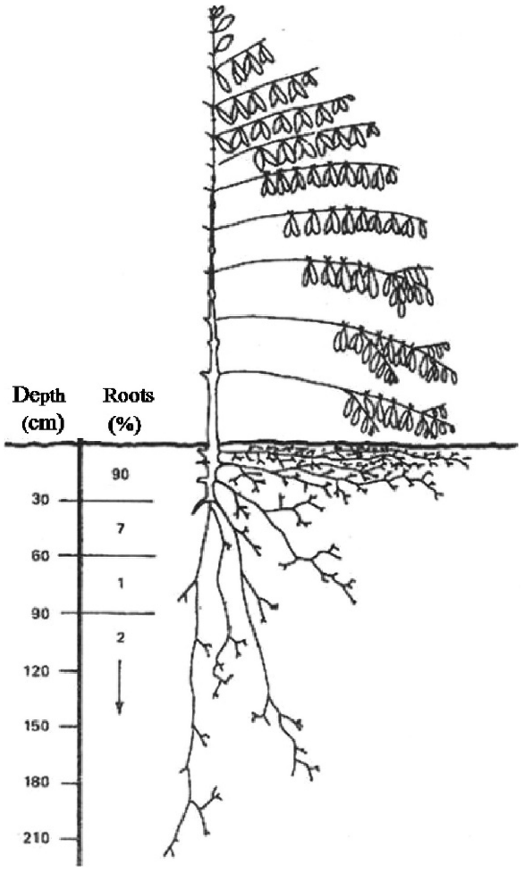

Fig. 1.1 Schematic representation of the root system of a cultivated coffee plant (from Rena, 1986, with permission)

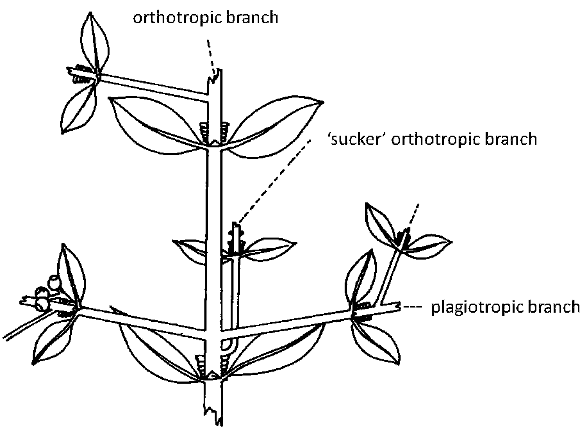

Fig. 1.2 Schematic representation of the aerial part of a cultivated coffee plant (adapted from Wormer and Gituanja, 1970, with permission)

Fig. 1.3 Coffee blooming and production. (**A**) on horizontal plagiotropic branches (Photo by H. Vieira). (**B**) anatomic details (from Köhler, 1887) (see color Plate 1, p. 315)

A

B

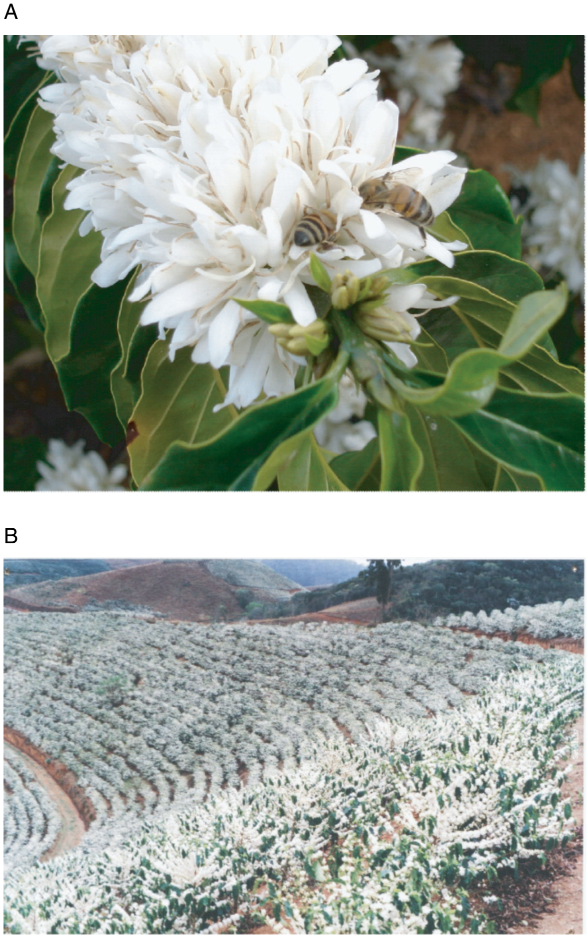

Fig. 1.4 Coffee blooming. (**A**) inflorescence on the axiles of a plagiotropic branch (Photo by F. Partelli, with permission). (**B**) synchronous blooming (Photo by H. Vieira) (see color Plate 2, p. 316)

that blooming occurs on the plagiotropic branches grown in the previous year. On robusta plants, blooming occurs on the branches grown in the current year (Dean, 1939; Moens, 1968).

In arabica coffee, ripe fruits ('berries') are red or yellow (Fig. 1.5A,B), with orange ones indicating cross pollination; in robusta plants, more hues occur. The format of the fruit, nearly round to oblong, varies with the *Coffea* species; the size of the fruit and of its endosperm (the 'bean') varies with the cultivar or variety planted and cultivation conditions. Usually two beans are produced/fruit (Fig. 1.3B). Most importantly, the bean contains proteins, caffeine, oils, sugars, dextrine, chlorogenic acid and several other substances that will determine the characteristics of the beverage; this will also be influenced by aspects of harvesting, processing and bean roasting (Rena et al., 1986).

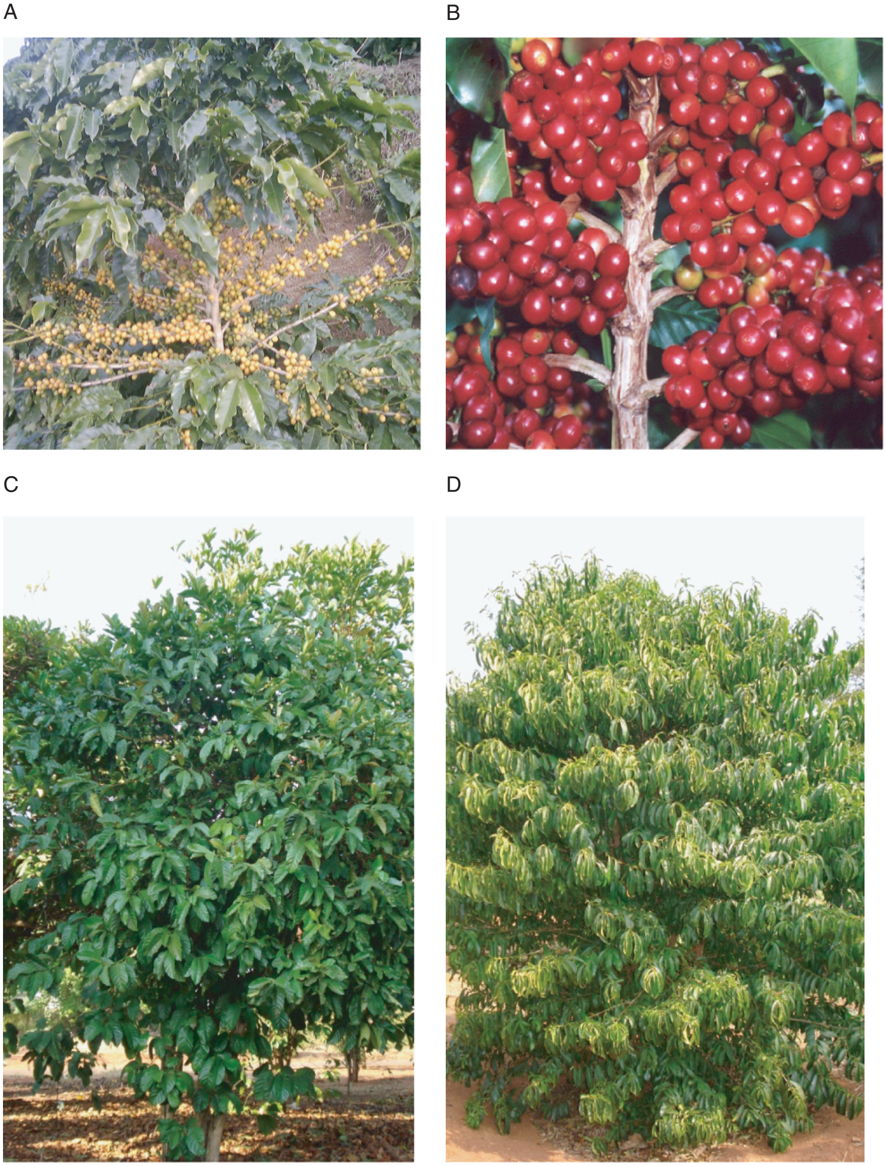

Fig. 1.5 *Coffea* species. (**A, B**) *C. arabica*. (**C**) *C. dewevrei*. (**D**) *C. stenophylla* (Photos by H. Vieira) (see color Plate 3, p. 317)

1.3 Coffee Diversity

The genus *Coffea* belongs to the family Rubiaceae, being composed of 103 species (Davis et al., 2006). These are divided in the sections Eucoffea, Mascarocoffea, Argocoffea and Paracoffea; the first three originate from Africa and the latter from Asia. The section Eucoffea is the only one with economic and breeding relevance, for it includes arabica and robusta coffees as well as the species discussed below. In natural conditions, most *Coffea* species occur in tropical Africa, particularly in Madagascar and mainland surrounding countries. Some species occur in India. Part of *Coffea* sp. diversity has been preserved in germplasm banks, and a fraction of it has been screened for nematode resistance (see Chapter 9).

Apart from *C. arabica*, all species are diploids (2n = 22); the exception is probably a natural tetraploid hybrid (2n = 44), and it is autogamous, although about 10% of cross pollination occurs. *C. arabica* and *C. canephora* are virtually the only commercially cultivated species, with the former representing 70% of world production. Many cultivars, mutants and hybrids of arabica coffee are grown throughout the world or used in breeding programs (see Chapter 9); the same occurs with robusta (Carvalho, 1958; Medina Filho et al., 1984).

According to some authors, *C. congensis* A. Froehner may be one of the parentals that gave rise to *C. arabica*. That species and *C. liberica* W. Bull ex Hiern are cultivated in limited areas in Africa and Vietnam. *C. racemosa* Ruiz and Pav. is appreciated in Mozambique, being deciduous and remarkably resistant to high temperatures and drought; some plants are resistant to 'leaf miner'(*Leucoptera coffeella* Guerin-Mèneville and Perrottet). Because *C. dewevrei* De Wild. and T. Durand (Fig. 1.5C) produces poor beverage, it is not commercially cultivated; nonetheless, it is considered important for breeding programs due to its adaptability to poor soils and drought. Likewise, *C. eugenioides* S. Moore is not produced commercially, but it is maintained in germbanks as a repository of genes to be transferred to *C. arabica. C. stenophylla* G. Don (Fig. 1.5D) is of interest for its resistance to 'leaf miner' (Chevalier, 1947; Carrier, 1978; Bridson, 1982).

1.4 Coffee Cultivation

Special attention should be paid to agronomic and phytosanitary aspects of coffee seedlings, since the plantation is expected to have a life-span of at least 20 years. Seedlings are produced through seeds (in the case of the autogamous arabica coffee, Fig. 1.6A) or vegetative cloning from orthotropic branches (Fig. 1.6B), which is recommended for the allogamous robusta coffee to reduce variability in the plant stand. Alternatively, grafted seedlings may be produced (Fig. 1.6C,D,E), combining an arabica scion with a robusta rootstock, which may have been selected for nematode resistance (Matiello et al., 2005; Ferrão et al., 2007; see Chapter 9).

The necessary operations involved in establishing a plantation vary according to the previous use of the area, topography and availability of equipment and implements. In the full sun cultivation system (see below), the area is cleaned of

Fig. 1.6 Coffee seedling production and cultivation. (**A**) nursery. (**B**) seedlings vegetatively produced from orthotropic branches. (**C, D**) grafting of seedlings. (**E**) grafted seedling. (**F**) full sun cultivation (Photos by H. Vieira) (see color Plate 4, p. 318)

vegetation, the soil may be plowed, disced and receive fertilizers. In upland plantations, special care must be taken to establish the plantation along contour lines. In the shaded cultivation system, the original vegetation is maintained and its canopy is managed to allow suitable amounts of sunlight to reach coffee plants (Rena et al., 1986; Matiello et al., 2005).

The recommended plant density/hectare (ha) varies with the cultivar or variety planted, soil topography and fertility, climate and available labor. Generally speaking, higher densities reduce the productivity *per* plant and increase it in terms of area used; on the other hand, higher densities create a microclimate that is favorable to 'leaf rust' (caused by *Hemileia vastratrix* Berk and Br.) and the 'berry borer' (*Hypothenemus hampei* Ferrari); no relationship between plant density and infestation has been established for nematodes. In full sun, plant density varies from three to 10 thousand plants/ha. In the shade, plant density is even more variable. Currently, there is a tendency to plant at higher densities in a number of countries, such as Brazil, Colombia and Mexico.

With regard to exposure to sunlight, there exists a great divide in coffee cultivation. Virtually all plantations in Brazil are in full sun (Fig. 1.6F), which presents higher productivity/plant and area in comparison to the shaded system; it also allows mechanization and intercropping (Fig. 1.7A). This system has been introduced in countries where shaded plantations (Fig. 1.7B) is predominant, such as those in Central America, particularly Colombia. Full sun plantations are nevertheless exposed to higher risks of hydric stress; in regions of higher technological input, irrigation may be used (Fig. 1.8A).

Most coffee plantations in Central America, India, Vietnam and Indonesia are shaded (see Chapters 13–16). This system is more commonly adopted in regions of accentuated topography, low technological input or where coffee is just one of several crops cultivated by smallholders. It has the advantage of causing less environmental disturbance and providing protection from soil erosion (Rena et al., 1986).

The coffee industry has yet another divide: arabica and robusta coffees. The former is better adapted to higher altitudes and milder climate; it has higher market value and provides a better beverage. However, the most commonly grown cultivars and varieties are susceptible to leaf rust and root-knot nematodes (*Meloidogyne* sp.). In comparison, robusta coffee is better adapted to hydric deficit; it is resistant to 'leaf miner' and 'leaf rust', but more susceptible to mites, 'berry borer' and *Colletotrichum* spp. It is more often used to produce instant coffee, or it is mixed with arabica coffee to produce 'blends' (Anonymous, 1985; Matiello et al., 2005).

As regards the production system, throughout the world coffee is cultivated under a variety of agronomic practices and input levels. For example, the plant architecture may be left unmanaged, or the grower may trim or prune the plants routinely or when he is trying to recover a plantation that has suffered abiotic or biotic stresses. Robusta coffee plants are more often trimmed than arabica ones so as to manage the former's multi-trunk habit, and to facilitate harvesting. For example, in India robusta plants are continuously trimmed to keep them short and easy to harvest (Fig. 1.8B). In Vietnam, plants are trimmed so that plagiotropic branches are emitted from the

A

B

Fig. 1.7 Coffee cultivation. (**A**) full sun plantation intercropped with beans (Photo by F. Partelli). (**B**) shaded plantation (Photo by K. Sreedharan, with permission) (see color Plate 5, p. 319)

plant's top; upon production, these branches incline downward, giving the plant the aspect of an open umbrella (Jansen, 2005).

As regards technological input, coffee plantations may be managed entirely without fertilization, irrigation or pest and disease control. In most regions, such inputs vary according to the traditions of coffee cultivation, the grower's financial resources and the prospects of profit from upcoming harvests; naturally, the growers' profits are greatly influenced by the world coffee market (see Chapter 2). In some areas in Brazil, plantations receive a high technological input, which includes routine fertilization, proper control of pests and diseases, and irrigation. Alternatively, 'organic' coffee, which receives low agrochemical-input, is being increasingly produced in Brazil and other countries, despite technical difficulties, high cost of certification and labor and reduced productivity. Mexico remains the largest producer of 'organic' coffee.

Fig. 1.8 Coffee cultivation and harvest. (**A**) plantation being irrigated (Photo by D. Barbosa, with permission). (**B**) harvesting of robusta coffee (Photo by K. Sreedharan, with permission) (see color Plate 6, p. 320)

1.5 Coffee Harvesting and Processing

Harvesting is the most important operation in coffee cultivation. When done by hand, it employs 50% of the man-hours required by this crop, and it represents 25–35% of the production cost. It also has a strong influence on the quality of the beverage obtained. The harvest season varies with the region's climate, rainfall and the cultivar or variety grown. For example, in Brazil most plantations are harvested from June through September (the dry season); occasionally, harvesting may take place from March through May, or in November and December.

Ideally, only ripe coffee berries should be harvested because they provide the best beverage. Nonetheless, in most production systems practical constraints lead the growers to conduct a less selective harvest, which includes unripe and overripe berries. These should not represent more than 20% of the production if a high quality beverage is to be produced. The grower should also pay attention to dirt, debris, insect-bored or defective berries which compromise product classification and the grower's revenue.

In Brazil, 90% of the plantations are harvested manually; the berries are stripped from the plant branches (Fig. 1.9A) and fall on the ground, into baskets or on fabric or plastic strips laid under the plant (Fig. 1.9B,C). Letting the berries fall on the ground is not recommendable because dirt, debris, moldy and rotten berries end up being collected as well.

In many countries, harvesting is a nearly continuous operation because the plants bloom several times a year, which results in marked inconsistencies in the ripeness of berries collected; in these cases, stripping the trees results in a high percentage of unripe berries mixed with ripe ones. In such cases, growers selectively pick ripe berries only. Although this system requires much labor, the product reaches a better market price, and its consistent quality results in a top-quality beverage.

In Brazil, mechanical harvesting (Fig. 1.10A,B) has been increasingly used because it is so difficult to hire, manage and pay the large labor force required for manual harvesting; operational costs may drop by 40%. Mechanical harvesting is more suitable for medium to large plantations in areas with slopes of up to 20% incline (Matiello et al., 2005).

Upon harvesting, the berries undergo either dry or wet processing. In the former, debris and some of the damaged berries are eliminated through flotation in washing channels. Right after this, the berries are spread out on terraces and turned several times a day until they have dried evenly under the sun (Fig. 1.10C). Depending on weather conditions, this process may take weeks to complete, during which time mold and bacteria must not develop on the berries. Alternatively, drying machines may be used to quicken this process.

In the wet processing method, debris and part of the damaged berries are eliminated in washing channels. The berry's outer layer and part of its pulp is mechanically removed; the remaining pulp is usually removed by fermentation and washing. Therefore, in this method, the coffee beans, not the berries, are sun dried.

After being sold by the growers, the beans undergo further processing, which is generally conducted by industry: hulling, polishing, cleaning, sorting by size, density or color, grading, roasting and grinding, which results in top-quality coffee beans (Fig. 1.10D,E,F).

1.6 Coffee Production Worldwide

About 60 tropical and subtropical countries (Fig. 1.11) produce coffee extensively, with 21 of these producing over one million 60 kg-bags/year; the top 15 producers are listed in Table 1.1. By continent, about 60% of the coffee produced comes from the Americas, 24% from Asia, 14.5% from Africa and 1.5% from Oceania (Matiello et al., 2005; Anonymous 2008b).

As regards types of coffee grown, arabica coffee is largely predominant in the Americas, although Brazil has reached the mark of seven to nine million bags/year of robusta coffee. In Africa, 60% is robusta coffee, which is also predominant in Asia.

Fig. 1.9 Coffee harvest. (**A**) strip harvesting (Photo by F. Partelli, with permission). (**B, C**) harvested coffee in basket and fabric strip, respectively (from Anonymous, 1985, with permission) (see color Plate 7, p. 321)

Fig. 1.10 Coffee harvesting and processing. (**A, B**) mechanical harvesting (from Anonymous, 1985, with permission). (**C**) coffee berries being sun dried. (**D, E, F**) damaged, high grade and roasted coffee beans, respectively (Photos by H. Vieira) (see color Plate 8, p. 322)

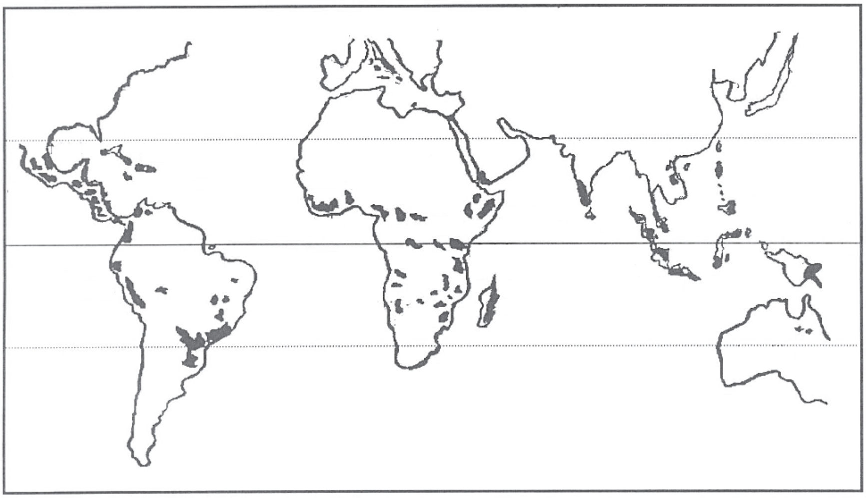

Fig. 1.11 World inter-tropical coffee-growing region (adapted from Matiello et al., 2005, with permission)

Table 1.1 Ranking of the top 15 coffee-growing countries according to 2006/2007 data, and their proportion of arabica and robusta production

Countries	Arabica coffee (%)	Robusta coffee (%)	Production (2006/2007) (× 1,000 60-kg bags)[a]
Brazil	65	35	38,000
Vietnam	10	90	13,200
Colombia	100	0	11,000
Indonesia	10	90	6,600
India	40	60	4,800
Mexico	97	3	4,100
Ethiopia	100	0	4,000
Guatemala	90	10	3,700
The Ivory Coast	0	100	2,900
Uganda	10	90	2,900
Peru	100	0	2,900
Honduras	100	0	2,900
Costa Rica	100	0	2,000
El Salvador	100	0	1,500
Nicaragua	100	0	1,400

[a] Anonymous (2008b).

In the last 30 years, world coffee production has increased at the rate of about one million bags/year, from 65–70 million in the early 1970s to 110 to 115 million nowadays. It is forecast that production will soon reach 120 million bags. This rise in production has not been matched by demand, which has caused a downward trend in international coffee prices for nearly a decade; this has had major consequences for the whole industry (Matiello et al., 2005; Anonymous, 2008a; see Chapter 2).

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Chapter 2
The Coffee Industry: History and Future Perspectives

Denis O. Seudieu

Abstract This chapter focuses on changes which have characterized the world coffee industry since its development as a marketable commodity, and the impact of these changes on coffee research. Three main periods have been identified through these changes. The first one is the free market, with Brazil dominating it until the early 1950s; this was followed by the period of controlled market within the frame of international cooperation between exporting and consuming countries (1960s through 1980s); the third period is the current free market situation within the framework of international cooperation, which started in mid-1989. During the first period, efforts to increase yields were undertaken through scientific research supported mainly by Governments. The public sector in Brazil and Colombia was the major driver of research and development in the coffee industry. In the second period, also known as the post-war period, the increased investment in agricultural research encouraged the development of new techniques for intensive production and better management of nematodes, pests and diseases. To address price fluctuations, governments set up price regulation mechanisms through international cooperation, creating the International Coffee Organization to manage it. Governments and their parastatals were driving coffee industry in producing countries and specialized assistance was available to farmers; in many countries research institutions benefited from substantial funding. The current period is characterized by the return to a free market, with the government withdrawing from the coffee industry. In many countries this new environment has weakened research institutions and extension services, since the private sector has not been prepared to replace the government in providing core services.

Keywords Coffee market changes · coffee research · coffee regulation · coffee production

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