II. Coffee genetic resources

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Introduction

Coffee has become one of the most popular beverages in the world, but its consumption remained low until the 17th century. Wild plants of *Coffea arabica* L. were discovered in about AD 850 in Ethiopia (Smith 1985), but the centre of genetic diversity also includes the Boma Plateau of Sudan (Thomas 1942) and Mount Marsabit of Kenya (Bridson 1982; Anthony et al. 1987). Coffee spread to Arabia (now Yemen) probably in the 14th century (Chevalier 1929a), then to Mecca, whence it was taken home by pilgrims to other parts of the Islamic world. Spread of coffee consumption to Europe is dated to 1615, when Venetian merchants brought coffee beans from Mocha to Europe (Smith 1985). This started a lucrative trade for the Arabians for 100 years, during which time they were the sole providers of coffee. Several expeditions were then sent by the Dutch, the French and the British to obtain coffee seeds or plants from Arabia, which led to the worldwide dissemination of two genetic populations—Typica and Bourbon—in the 18th century (see Chapter 4).

The interest in other coffee species came later, during the course of Africa's exploration at the end of the 19th century and the beginning of the 20th century. Only four coffee species were known in 1834 (Chevalier 1929b), but they were 36 in 1901 (de Wildeman 1901), about 50 in 1929 (Chevalier 1929b) and up to a hundred species nowadays (Chevalier 1947; Bridson and Verdcourt 1988; Stoffelen 1998). Several new species have been described recently (Stoffelen et al. 1996, 1997a, b, 1999, [2006], 2007; Davis 2001; Davis and Rakotonasolo 2000; 2001a, b, 2003; Cheek et al. 2002; Davis and Mvungi 2004; Sonké and Stoffelen 2004), indicating that the inventory of wild coffee is not yet complete. Based on flowering and flower characters, taxonomists have classified the coffee species into two genera, *Coffea* L. and *Psilanthus* Hook. f. (Leroy 1980; Bridson 1987), but this distinction is not supported by molecular data analysis (Lashermes et al. 1997; Cros et al. 1998). All *Coffea* species are native to the inter-tropical forests of Africa, Madagascar and the Mascarene islands, while the *Psilanthus* species originate from Africa, India, Malaysia, Papua New Guinea and Australia (Bridson 1987; Bridson and Verdcourt 1988). Three groups of species have been identified in the genus *Coffea* on the basis of biogeographical data: in the Madagascar region, in East Africa, and in Central and West Africa (Chevalier 1947; Bridson and Verdcourt 1988; Stoffelen 1998).

Coffee trees differ greatly in morphology, size and ecological adaptation. Particular attention has been paid to the genus *Coffea*, which includes the two cultivated species of economic importance, *C. arabica* (Arabica coffee) and *C. canephora* (Robusta coffee). Of the two, Arabica coffee accounts for 70% of the market, compared with 30% for Robusta. All *Coffea* species are diploid (2n=2x=22) and generally self-incompatible, except for *C. arabica*, which is tetraploid (2n=4x=44) and self-compatible. Nevertheless, the coffee species share a common genome, making possible interspecific hybridizations and hybrid production either within *Coffea* species (Charrier 1978; Louarn 1992; Le Pierrès 1995), or between *Coffea* and *Psilanthus* species (Couturon et al. 1998). This shows the potential value of genetic resources as sources for transfer of new characters from diploid species into the genome of *C. arabica* cultivars.

This chapter discusses the major collecting expeditions of coffee genetic resources made and the genebanks where the collected materials were introduced. The importance of the resources being conserved in these genebanks is then discussed, particularly in regard to some of the traits of agronomic interest to show their importance to coffee breeding programmes and genomic projects.

Coffee genetic resources collecting

Interest in coffee genetic resources increased during the second half of the 20th century, as breeders became aware that deforestation was causing the erosion of coffee habitats, thereby threatening coffee genetic resources. It was estimated that the closed high forest in Ethiopia had declined to only 18% by 1997, which represents a loss of 60% in less than 30 years (Gole et al. 2002). Considering the socio-economic importance of *C. arabica* cultivation, two large surveys were organized in Ethiopia: by FAO in 1964–65 (Fernie et al. 1968) and by ORSTOM (now IRD) in 1966 (Guillaumet and Hallé 1978). Collecting of other species started at the same period in the Madagascar region through a joint initiative of the Paris Museum of Natural History, CIRAD and ORSTOM. In Africa, survey missions were conducted in seven countries between 1975 and 1987 by ORSTOM (Table 2.1). Lastly, a mission was organized by IPGRI in Yemen (Eskes 1989), an area considered to be the first centre of dispersion for *C. arabica* outside Ethiopia (Meyer 1965).

Table 2.1. Main collections of coffee genetic resources (years of collection, countries surveyed, institutions involved, number of accessions collected, and references).

Year	Country	Institutions involved in the collecting missions	No. of accessions	Reference(s)
1964–65	Ethiopia	FAO	620	Fernie et al. 1968
1966	Ethiopia	ORSTOM	70	Guillaumet and Hallé 1978
1960–74	Madagascar	Museum of Natural History, Paris, France; CIRAD; ORSTOM	>3000	Charrier 1978
1975	Central African Republic	ORSTOM	>1200	Berthaud and Guillaumet 1978
1975–87	Côte d'Ivoire	ORSTOM	>2000	Berthaud 1986; Le Pierrès et al. 1989
1977	Kenya	ORSTOM	1511	Berthaud et al. 1980; Anthony et al. 1987
1982	Tanzania	ORSTOM	817	Berthaud et al. 1983; Anthony et al. 1987
1983	Cameroon	ORSTOM; IBPGR	1359	Anthony et al. 1985; Anthony 1992
1985	Congo	ORSTOM; IBPGR	1080	de Namur et al. 1987; Anthony 1992
1987	Guinea	ORSTOM; CIRAD	74	Le Pierrès et al. 1989
1989	Yemen	IBPGR	22	Eskes 1989

Notes: ORSTOM (Office de la recherche scientifique et technique outre-mer) is now Institut de recherche pour le développement (IRD), France.
CIRAD is Centre de coopération internationale en recherche agronomique pour le développement, France.
IBPGR (International Board for Plant Genetic Resources) became the International Plant Genetic Resources Institute (IPGRI), which in turn became Bioversity International.

The collected material generally comprised seed in the case of the autogamous species *C. arabica*, and stem cuttings, seedlings and seeds for the other species. An accession can thus correspond to one genotype when stem cuttings were collected or to several genotypes in the case of seed collecting. At least 11 700 accessions, representing 70 *Coffea* species, were collected and introduced into field genebanks (Table 2.2). Of these species, about 50 taxa were native to the Madagascar region; 8 taxa to eastern Africa, including *C. arabica*; 7 taxa to central Africa; and 4 taxa to West Africa (Figure 2.1). New species from Cameroon and Congo were recently described (Stoffelen *et al.* [2006], 2007) and others remain to be identified (Anthony 1992).

Table 2.2. Major coffee genebanks in the world and distribution of the *C. arabica* accessions collected in Ethiopia by FAO (Fernie et al. 1968) and ORSTOM (Guillaumet and Hallé 1978) surveys.

Area	Country	Institute	FAO collection	ORSTOM collection
Latin America	Costa Rica	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)	original	
	Colombia	Centro Nacional de Investigaciones de Café (CENICAFE)	duplicate‡	duplicate†
	Brazil	Instituto Agronômico de Campinas (IAC)	original	duplicate†
Africa	Côte d'Ivoire	Centre National de Recherche Agronomique (CNRA)	duplicate§	original
	Cameroon	Institut de Recherche Agronomique et de Développement (IRAD)		original
	Ethiopia	Jimma Agricultural Research Centre (JARC)	original	
	Kenya	Coffee Research Foundation (CRF)	duplicate¶	original
	Tanzania	Tanzanian Agricultural Research Organization (TARO)	original	duplicate††
	Madagascar	Centre National de Recherche Appliquée au Développement (FOFIFA)		original
Asia	India	Central Coffee Research Institute (CCRI)	original	
	Indonesia	Indonesian Coffee and Cocoa Research Institute (ICCRI)		

Notes: † germplasm introduced from Cameroon. ‡ germplasm introduced from Costa Rica. § germplasm introduced from Kenya. ¶ germplasm introduced from Tanzania. †† germplasm introduced from Côte d'Ivoire.

Existing coffee genebanks

The report *The State of the World's Plant Genetic Resources for Food and Agriculture* (FAO 1998) reported 21 087 coffee accessions conserved worldwide. As with other crops of economic importance, exchanges of genetic material have led to an increase in the number of duplicates in many genebanks. Accessions of the cultivated species *C. arabica* and *C. canephora* correspond either to wild plants collected in forest habitats or to cultivated plants selected in plantations and breeding centres. The accessions of the cultivated species *C. arabica* have been widely spread, while the other species have had a more restricted distribution.

Accessions of *C. arabica*

Most coffee genebanks were set up during the first half of the 20th century, the earliest being the Indonesian Coffee and Cocoa Research Institute (ICCRI) in 1900, the Agronomic Institute of

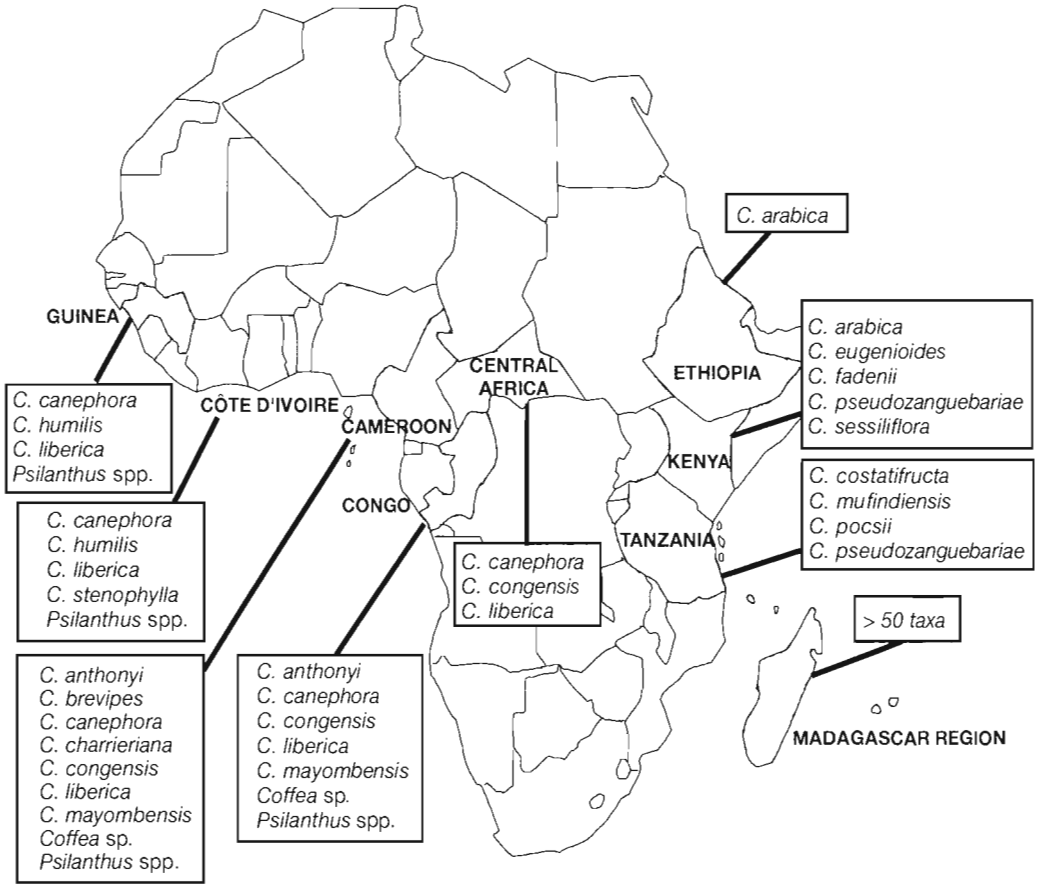

Figure 2.1. Coffee species collected on the African mainland and the Madagascar region, and introduced into field genebanks.

Campinas (IAC) in Brazil in 1924 and the Central Coffee Research Institute (CCRI) in India in 1925 (van der Vossen 2001). Coffee farmers supplied genebanks with materials which displayed good agronomic performance or presented specific traits. Many mutants were thus isolated, as well as numerous varieties selected from the base populations of Typica and Bourbon that were disseminated from Yemen during the 18th century (see Chapter 4). Such selected accessions represent 72% of the genetic resources conserved in the CATIE genebank (see Chapter 3). The accessions collected by FAO and ORSTOM in Ethiopia in the 1960s were introduced in five and four genebanks, respectively (Table 2). Further introductions occurred from these genebanks in Colombia, Côte d'Ivoire and Kenya for the FAO accessions and in Costa Rica, Colombia and Kenya for the ORSTOM accessions. This has contributed to the preservation of corresponding genetic resources, although genetic diversity in duplicated germplasm was often lower than in the original one.

Accessions of other species

Large genebanks of *C. canephora* accessions were set up in several coffee producing countries, including Côte d'Ivoire, Cameroon, Madagascar and India (Charrier and Berthaud 1985). As for *C. arabica* genetic resources, introductions of *C. canephora* originated from plantations and

breeding centres in the first instance, until the collecting of wild plants began in the 1980s. However, only part of the known diversity has been conserved in each genebank, as recently shown in a study using molecular markers (Prakash et al. 2005). Of the five genetic groups identified in this species (Dussert et al. 2003), only one group was well represented in India, two groups were little represented and two other groups were lacking.

Most of the other wild coffee species (i.e. not cultivated) have been introduced into only two genebanks, namely in Madagascar for the Mascarocoffea species and in Côte d'Ivoire for the mainland African species. These unique collections are threatened in the long term because they are nowhere safely duplicated. In the Malagasy genebank, 25% of the accessions and 50% of the genotypes were estimated to have been lost over a period of 20 years (Dulloo et al. 2001). In Côte d'Ivoire, the climate is not optimal for coffee culture and the risk of damage by fire is high (Dulloo et al. 2001). There is therefore an urgent need for duplication of the wild coffee genetic resources conserved in these genebanks. A few genotypes of some species, principally *C. eugenioides* S. Moore, *C. liberica* Hiern, *C. racemosa* Lour. and *C. stenophylla* G. Don, are, however, present in several other genebanks.

Insight into coffee genetic diversity

The genus *Coffea* is characterized by a large number of species whose differentiation has occurred relatively recently, about 5 to 25 million years ago (Anthony and Lashermes 2005). It is thought that the diversity of coffee species and the genetic diversity within them have been the result of a rapid speciation and adaptive radiation process (Cros 1994; Lashermes et al. 1997). Diversity can be analysed at the genetic and morphological levels, the latter often being used as a proxy of the former. Only few studies have been undertaken to examine the level of genetic diversity in wild coffee plants. A good insight into coffee genetic diversity—using phenotypic characteristics such as data on plant morphology, adaptation, biochemical compounds and resistance to pests and diseases as proxies—is given below.

Morphology

There can be wide diversity among morphological traits in coffee plants. Coffee plants can be shrubs or trees, whose height varies from 1 m in *C. humilis* Chev. up to 20 m in *C. liberica* var. *dewevrei* (Chevalier 1947). Leaf size varies considerably, from 2 cm (e.g. *C. eugenioides*) to 48 cm (e.g. *C. magnistipula* Stoff. & Robbr.) in length, and from 0.8 cm (*C. eugenioides*) to 30 cm (e.g. *C. liberica* var. *dewevrei*) in width (Chevalier 1947; Bridson and Verdcourt 1988; Stoffelen 1998). Mature fruits are generally red (e.g. *C. arabica*, *C. canephora*), but also yellow (e.g. *C. liberica*), orange (e.g. *C. congensis* Froehner), violet (e.g. *C. racemosa*) or black (e.g. *C. salvatrix* Swynnerton & Phillipson). Further, white fruits were observed in a *Psilanthus* taxon collected in Congo (Anthony 1992). Bean size is another variable character, which makes necessary the definition of an adequate desiccation time prior to cryopreservation (Dussert et al. 1998). Extreme values of 1000-bean weight were 29 g (e.g. *C. pseudozanguebariae* Bridson) and 198 g (e.g. *C. liberica* var. *liberica*) (Clifford et al. 1989).

Adaptation

Altitude is an important factor structuring forest habitats in Africa (White 1983). The coffee species are distributed from sea level (e.g. *C. liberica* var. *liberica*) to 2100 m (e.g. *C. eugenioides*). Among the cultivated species, *C. canephora* grows in lowland forests, up to 1400 m (Bridson and Verdcourt 1988) while *C. arabica* is found in submontane forests between 1000 and 2000 m (Meyer 1965; Gole et al. 2002). These ecological differences of habitat could explain the variations observed in cold sensitivity among *in vitro* microcuttings of different species stored at various temperatures (Engelmann et al. 1993).

Some species are widely distributed, colonizing diverse environments, e.g. *C. canephora* and *C. liberica* from Guinea to Uganda, but most species have a restricted distribution and display specific adaptations, e.g. *C. congensis* to seasonally flooded areas in the Zaire basin and *C. racemosa* to very dry areas in the coastal region of Mozambique (Charrier and Berthaud 1985). In Kenya, *C. pseudozanguebariae* was found on a coral reef substrate (Anthony et al. 1987). Such ecological data are essential for selecting appropriate growing conditions for living genebanks and for testing of agronomic performance for cultivation (Charrier and Berthaud 1985).

Biochemical components

Our knowledge of the origin of the biochemical diversity in coffee has greatly improved following the analysis of biochemical compounds from wild coffee species collected in Africa in the 1970s and 1980s. Of the numerous compounds found in green coffee beans, attention was firstly focused upon caffeine because of its known pharmacological actions and influence on beverage bitterness. Caffeine content of cultivated species appears moderate in *C. arabica*, varying between 0.76 and 1.82% dry mass basis (% dmb), and high in *C. canephora*, between 1.51 and 3.33% dmb (Anthony et al. 1993; Ky et al. 2001). This constitutes the maximum caffeine content in coffee (Campa et al. 2005). Caffeine-free species were reported in the Madagascar region (d'Ornano et al. 1965), eastern Africa (Hamon et al. 1984) and central Africa (Stoffelen et al. 2007). The other species present a caffeine content ranging from 0.47 to 2.64% dmb (Anthony et al. 1993).

Table 2.3. Variation of biochemical compounds (% dry matter basis) in green coffee (*Coffea* spp.) beans.

Compound	Minimum	Maximum	Reference
Caffeine	0.00	3.19	Clifford et al. 1989
Chlorogenic acids	0.61	14.40	Campa et al. 2005
Sucrose	3.81	10.87	Campa et al. 2004
Trigonelline	0.36	1.99	Campa et al. 2004

Other aroma precursors have been studied, such as chlorogenic acids, which increase bitterness of beverage, and sucrose and trigonelline, which give rise to appreciated flavour products. The data vary greatly for all compounds analysed, especially for chlorogenic acids, where the maximum value is 23 times that of the minimum value (Table 2.3). A relation was found between caffeine and chlorogenic acids, since large contents of dicaffeoylquinic and feruloylquinic acids were only detected in species which contain at least 0.6% dmb caffeine (Anthony et al. 1993). Chlorogenic acids are lower in *C. arabica* than in *C. canephora*, while fat, sucrose and trigonelline are higher (Clifford 1985; Ky et al. 2001).

Pathogen resistance

Resistance to the Coffee leaf rust caused by *Hemileia vastatrix* Berk & Br. was first observed in existing genebanks because of strong attacks in coffee plantations in eastern Africa, India and south Asia in the 1950s, then worldwide. Accessions displaying a high level of resistance were identified in *C. canephora* (Berthaud and Lourd 1982; Kushalappa and Eskes 1989; Montagnon and Leroy 1993), *C. pseudozanguebariae* (Rodrígues Jr. 1980), and with less frequency in *C. liberica*, *C. eugenioides* and *C. salvatrix* (Rodrígues Jr. et al. 1975; Rodrígues Jr. 1980). Accessions highly resistant to *Colletotrichum kahawae* Waller & Bridge (ex *C. coffeanum* Noack) causing the Coffee berry disease (CBD) were detected in *Coffea arabica* and *C. canephora* collections (van der Vossen and Walyaro 1980; Van der Graaf 1981; Rodrígues Jr. et al. 1992).

Resistance to pests has been also sought in genebanks, principally to the root-knot nematodes (*Meloidogyne* spp.) that represent the strongest constraint on *C. arabica* cultivation in many Latin American countries. No accession resistant to *M. exigua* Goeldi was found in *C. arabica*, but some resistance exists in *C. canephora* and *C. racemosa* (Bertrand et al. 2001; Anthony et al. 2003). Resistance to *M. arabicida* López & Salazar and *M. paranaensis* Carneiro, Carneiro, Abrantes, Santos & Almeida was observed in *C. arabica* and *C. canephora* (Anthony et al. 2003). Finally, resistance to the Coffee leaf miner (*Leucoptera coffeella* Guérin-Méneville) was reported in *C. racemosa* (Medina Filho et al. 1977a, b; Guerreiro Filho et al. 1991) and *C. stenophylla* (Cardenas-Murillo and Posada-Ochoa 1984; Guerreiro Filho et al. 1991).

Conclusion

A large amount of coffee genetic diversity has been collected and introduced into field genebanks. Of the 100 species described by taxonomists, more than half have entered conservation, suggesting a large sampling of available genetic resources. However, it has been observed that the coffee genetic resources being conserved in living collections (or field genebanks) are quickly eroding, due to a multitude of reasons, including adaptability problems, vandalism, natural catastrophes and—above all—insufficient funds for maintaining the collections (Dulloo et al. 2001). In Côte d'Ivoire, it was estimated that the cost of germplasm acquisition and genebank establishment represented less than 10% of the total budget allocated to the breeding programme (Charrier et al. 1989). Moreover, except for the cultivated species, the wild species are conserved in a single site: in Madagascar for the species endemic to the region; and in Côte d'Ivoire for the African mainland species. Another problem in coffee genetic resources conservation is the lack of an international structure able to coordinate conservation activities at a global level. There is an urgent need to place the conservation of coffee genetic resources on more secure grounds, and to establish a global strategy for a more efficient and cost-effective rational conservation of these precious resources.

References

Anthony, F. 1992. Les ressources génétiques des caféiers : collecte, gestion d'un conservatoire et évaluation de la diversité génétique. Collection Travaux & Documents Microfichés 81, IRD, Paris.

Anthony, F. & Lashermes, P. 2005. The coffee (*Coffea arabica* L.) genome: diversity and evolution. pp. 207–228, *in:* A.K. Sharma and A. Sharma (editors). Plant Genome: Biodiversity and Evolution, Vol. 1B: Phanerogams. Science Publishers Inc., New Hampshire, USA.

Anthony, F., Couturon, E. & Namur (de), C. 1985. Résultats d'une mission de prospection effectuée par l'ORSTOM en 1983. pp. 495–505, *in:* Proceedings of the 11th International Scientific Colloquium on Coffee. Lomé, Togo, 11–15 February 1985. ASIC, Montpellier, France.

Anthony, F., Berthaud, J., Guillaumet, J.-L. & Lourd, M. 1987. Collecting wild *Coffea* species in Kenya and Tanzania. Plant Genetic Resources Newsletter No. 69:23–29.

Anthony, F., Clifford, M.N. & Noirot, M. 1993. Biochemical diversity in the genus *Coffea*: chlorogenic acids, caffeine and mozambioside contents. Genetic Resources and Crop Evolution 40:61–70.

Anthony, F., Topart, P., Anzueto, F., Astorga, C. & Bertrand, B. 2003. La resistencia genética de *Coffea* spp. a *Meloidogyne* spp: identificación y utilización para la caficultura latinoamericana. Manejo Integrado de Plagas y Agroecología 67:4–11.

Berthaud, J. 1986. Les ressources génétiques pour l'amélioration génétique des caféiers africains diploïdes. Evaluation de la richesse génétique des populations sylvestres et de ses mécanismes

organisateurs. Conséquences pour l'application. Collection Travaux & Documents n° 188, ORSTOM [now IRD], Paris.
Berthaud, J. & Guillaumet, J.-L. 1978. Les caféiers sauvages en Centrafrique : résultats d'une mission de prospection (janvier-février 1975). Café-Cacao-Thé 3:171–186.
Berthaud, J. & Lourd, M. 1982. La résistance à *Hemileia vastatrix* des caféiers de l'espèce *Coffea canephora* de Côte d'Ivoire. Etude de la transmission de ce caractère par croisements contrôlés. Garcia de Orta 9:89–96.
Berthaud, J., Guillaumet, J.-L., Le Pierrès, D. & Lourd, M. 1980. Les caféiers sauvages du Kenya : prospection et mise en culture. Café-Cacao-Thé 24:101–112.
Berthaud, J., Anthony, F. & Lourd, M. 1983. Les caféiers sauvages de Tanzanie. Résultats d'une mission de prospection effectuée du 5 mars au 11 avril 1982. Café-Cacao-Thé 27:245–258.
Bertrand, B., Anthony, F. & Lashermes, P. 2001. Breeding for resistance to *Meloidogyne exigua* of *Coffea arabica* by introgression of resistance genes of *C. canephora*. Plant Pathology 50:637–643.
Bridson, D. 1982. Studies in *Coffea* and *Psilanthus* (*Rubiaceae* subfam. *Cinchonoideae*) for Part 2 of 'Flora of Tropical East Africa': *Rubiaceae*. Kew Bulletin 36:817–859.
Bridson, D. 1987. Nomenclatural notes on *Psilanthus*, including *Coffea* sect. *Paracoffea* (*Rubiaceae* tribe *Coffeeae*). Kew Bulletin 42:453–460.
Bridson, D. & Verdcourt, B. 1988. *Coffea*. pp. 703–727, *in:* R.M. Polhill (editor). Flora of Tropical East Africa. Rubiaceae (Part 2). A.A. Balkema, Rotterdam, The Netherlands.
Campa, C., Ballester, J.F., Doulbeau, S., Dussert, S., Hamon, S. & Noirot, M. 2004. Trigonelline and sucrose diversity in wild *Coffea* species. Food Chemistry 88:39–43.
Campa, C., Doulbeau, S., Dussert, S., Hamon, S. & Noirot, M. 2005. Qualitative relationship between caffeine and chlorogenic acid contents among wild *Coffea* species. Food Chemistry 93:135–139.
Cardenas-Murillo, R. & Posada-Ochoa, L. 1984. Observaciones sobre resistencia de seis materiales de *Coffea* al daño del minador de las hojas (*Leucoptera coffeella* G.M.). Cenicafé 35:3–8.
Charrier, A. 1978. La structure génétique des caféiers spontanés de la région Malgache (*Mascarocoffea*). Leurs relations avec les caféiers d'origine africaine (*Eucoffea*). Mémoires ORSTOM 87, IRD, Paris.
Charrier, A. & Berthaud, J. 1985. Botanical classification of coffee. pp. 13–47 *in:* M.N. Clifford and K. Willson (editors). Coffee botany, biochemistry and production of beans and beverage. Croom Helm, London. UK.
Charrier, A., Berthaud, J. & Anthony, F. 1989. Coût et valorisation des ressources génétiques caféières. pp. 429–437, *in:* Proceedings of the 13th International Scientific Colloquium on Coffee. Paipa, Colombia, 21–25 August 1989. ASIC, Montpellier, France.
Cheek, M., Csiba, L. & Bridson, D. 2002. A new species of *Coffea* (*Rubiaceae*) from western Cameroon. Kew Bulletin 57:675–680.
Chevalier, A. 1929a. Les caféiers du globe. I. Généralités sur les caféiers. Encyclopédie biologique 5. P. Lechevalier, Paris, France.
Chevalier, A. 1929b. La culture du café dans les colonies françaises par les Européens et les Indigènes. Communications et Procès verbaux de l'Académie des Sciences Coloniales, Paris, France.
Chevalier, A. 1947. Les caféiers du globe. II. Les vrais et faux caféiers. Nomenclature et systématique. Encyclopédie biologique 28. P. Lechevalier, Paris, France.
Clifford, M.N. 1985. Chemical and physical aspects of green coffee and coffee products. pp. 305–374, *in:* M.N. Clifford and K. Willson (editors). Coffee botany, biochemistry and production of beans and beverage. Croom Helm, London. UK.
Clifford, M.N., Williams, T. & Bridson, D. 1989. Chlorogenic acids and caffeine as possible taxonomic criteria in *Coffea* and *Psilanthus*. Phytochemistry 28:829–838.

Couturon, E., Lashermes, P. & Charrier, A. 1998. First intergeneric hybrids (*Psilanthus ebracteolatus* Hiern × *Coffea arabica* L.) in coffee trees. Canadian Journal of Botany 76:542–546.

Cros, J. 1994. Implications phylogénétiques des variations de l'AND chloroplastique chez les caféiers (genres *Coffea* L. et *Psilanthus* Hook.f.). Doctoral thesis, Université Montpellier II, Montpellier, France.

Cros, J., Combes, M.-C., Trouslot, P., Anthony, F., Hamon, S., Charrier, A. & Lashermes, P. 1998. Phylogenetic relationships of *Coffea* species: new evidence based on the chloroplast DNA variation analysis. Molecular Phylogenetics and Evolution 9:109–117.

Davis, A.P. 2001. Two new species of *Coffea* L. (Rubiaceae) from eastern Madagascar. Kew Bulletin 56:479–489.

Davis, A.P. & Mvungi, E.F. 2004. Two new and endangered species of *Coffea* (Rubiaceae) from the Eastern Arc Mountains (Tanzania) and notes on associated conservation issues. Botanical Journal of the Linnean Society 146:237–245.

Davis, A.P. & Rakotonasolo, F. 2000. Three new species of *Coffea* L. (Rubiaceae) from Madagascar. Kew Bulletin 55:405–416.

Davis, A.P. & Rakotonasolo, F. 2001a. Two new species of *Coffea* L. (Rubiaceae) from northern Madagascar. Adansonia 23:337–345.

Davis, A.P. & Rakotonasolo, F. 2001b. Three new species of *Coffea* L. (Rubiaceae) from NE Madagascar. Adansonia 23:137–146.

Davis, A.P. & Rakotonasolo, F. 2003. New species of *Coffea* L. (Rubiaceae) from Madagascar. Botanical Journal of the Linnean Society 142:111–118.

Dulloo, M.E., Charrier, A., Dussert, S., Anthony, F., Tesfaye, S., Rakotomalala, J.J. & Agwanda, C. 2001. Conservation of coffee genetic resources: constraints and opportunities. Ref. B208 *in:* Proceedings (CD-ROM) of the 19th International Scientific Colloquium on Coffee, Trieste, Italy, 14–18 May 2001. ASIC, Montpellier, France.

Dussert, S., Chabrillange, N., Engelmann, F., Anthony, F. & Hamon, S. 1998. Cryopreservation of seeds of four coffee species (*Coffea arabica*, *C. costatifructa*, *C. racemosa* and *C. sessiliflora*): importance of seed water content and of freezing rate. Seed Science Research 8:9–15.

Dussert, S., Lashermes, P., Anthony, F., Montagnon, C., Trouslot, P., Combes, M.-C., Berthaud, J., Noirot, M. & Hamon, S. 2003. Coffee (*Coffea canephora*). pp. 239–258, *in:* P. Hamon, M. Seguin, X. Perrier and J.-C. Glaszmann (editors). Genetic diversity of cultivated tropical crops. Collection Repères. CIRAD, Montpellier, France.

Engelmann, F., Jouve, L., Chabrillange, N., Anthony, F. & Charrier, A. 1993. Cold sensitivity of *in vitro* microcuttings of *Coffea arabica* and *C. canephora* during storage at various temperatures. Evolution of sugar, proline, MDA and ethylene production. pp. 67–72, *in:* Proceedings of the 15th International Scientific Colloquium on Coffee, Montpellier, France, 6–11 June 1993. ASIC, Montpellier, France.

Eskes, A.B. 1989. Identification, description and collection of coffee types in P.D.R. Yemen. Technical report [from IRCC/CIRAD to IBPGR] of the IBPGR/PDR Yemen Ministry of Agriculture/IRCC-CIRAD mission to Yemen PDR, 15 April–7 May 1989. IBPGR (now Bioversity International) internal report.

FAO [Food and Agriculture Organization of the United Nations]. 1998. State of the World's Plant Genetic Resources for Food and Agriculture. FAO, Rome. 510 p.

Fernie, L.M., Greathead, D.J., Meyer, F.G., Monaco, L.C. & Narasimhaswamy, R.L. 1968. FAO coffee mission to Ethiopia, 1964-65. FAO, Rome, Italy. 204 p.

Gole, T.W., Denich, M., Teketay, D. & Vlek, P.L.G. 2002. Human impacts on the *Coffea arabica* genepool in Ethiopia and the need for its *in situ* conservation. pp. 237–247 *in:* J.H.H. Engels, V.R. Rao, A.H.D. Brown and M.T. Jackson (editors). Managing Plant Genetic Diversity. CABI, Wallingford, UK, & IPGRI, Rome, Italy.

Guerreiro Filho, O., Medina Filho, H.P. & Carvalho, A. 1991. Fontes de resistência ao bicho mineiro, *Perileucoptera coffeella* em *Coffea* spp. Bragantia 50:45–55.

Guillaumet, J.-L. & Hallé, F. 1978. Echantillonnage du matériel récolté en Ethiopie. Bulletin IFCC 14:13–18.

Hamon, S., Anthony, F. & Le Pierrès, D. 1984. La variabilité génétique des caféiers spontanés de la section *Mozambicoffea* A. Chev. 1). Précisions sur deux espèces affines : *Coffea pseudozanguebariae* Bridson et *C. sp. A* Bridson. Adansonia 2:207–223.

Kushalappa, C.A. & Eskes, A.B. 1989. Advances in coffee rust research. Annual Review of Phytopathology 27:503–531.

Ky, C.L., Louarn, J., Dussert, S., Guyot, B., Hamon, S. & Noirot, M. 2001. Caffeine, trigonelline, chlorogenic acids and sucrose diversity in wild *Coffea arabica* L. and *C. canephora* P. accessions. Food Chemistry 75:223–230.

Lashermes, P., Combes, M.-C., Trouslot, P. & Charrier, A. 1997. Phylogenetic relationships of coffee tree species (*Coffea* L.) as inferred from ITS sequences of nuclear ribosomal DNA. Theoretical and Applied Genetics 94:947–955.

Le Pierrès, D. 1995. Etude des hybrides interspécifiques tétraploïdes de première génération entre *Coffea arabica* et les caféiers diploïdes. Doctoral thesis, Université Paris XI, Orsay, France.

Le Pierrès, D., Charmetant, P., Yapo, A., Leroy, T., Couturon, E., Bontemps, S. & Tehe, H. 1989. Les caféiers sauvages de Côte d'Ivoire et de Guinée : bilan des missions de prospection effectuées de 1984 à 1987. pp. 420–428 *in:* Proceedings of the 13th International Scientific Colloquium on Coffee. Paipa, Colombia, 21–25 August 1989. ASIC, Montpellier, France.

Leroy, J.-F. 1980. Evolution et taxogenèse chez les caféiers (*Coffea* L., *Psilanthus* Hook.f. et *Nostolachma* Durand). Hypothèse sur leur origine. Comptes Rendus de l'Académie des Sciences de Paris 291 (série D):593–596.

Louarn, J. 1992. La fertilité des hybrides interspécifiques et les relations génomiques entre caféiers diploïdes d'origine africaine (genre *Coffea* L. sous-genre *Coffea*). Doctoral thesis, Université Paris XI, Orsay, France.

Medina Filho, H.P., Carvalho, A. & Medina, D.M. 1977a. Germoplasma de *C. racemosa* e seu potencial no mehoramento do cafeeiro. Bragantia 36:43–46.

Medina Filho, H.P., Carvalho, A. & Medina, D.M. 1977b. Observações sobre la resistência do cafeeiro ao bicho mineiro. Bragantia 36:131–137.

Meyer, F.G. 1965. Notes on wild *Coffea arabica* from southwestern Ethiopia, with some historical considerations. Economic Botany 19:136–151.

Montagnon, C. & Leroy, T. 1993. Résultats récents sur la résistance de *Coffea canephora* à la sécheresse, à la rouille orangée et au scolyte des branchettes en Côte d'Ivoire. pp. 309-317 *in:* Proceedings of the 15th International Scientific Colloquium on Coffee, Montpellier, France, 6–11 June 1993. ASIC, Montpellier, France.

de Namur, C., Couturon, E., Sita, P. & Anthony, F. 1987. Résultats d'une mission de prospection des caféiers sauvages du Congo. pp. 397-404 *in:* Proceedings of the 12th International Scientific Colloquium on Coffee, Montreux, Switzerland, 29 June–3 July 1989. ASIC, Montpellier, France.

Ornano (d'), M., Chassevent, F. & Pougneaud, S. 1965. Composition et caractéristiques chimiques de *Coffeae* sauvages de Madagascar. pp. 131-144 *in:* Proceedings of the 2nd International Colloquium on Green Coffee Chemistry, Paris, France, 3–7 May 1965. ASIC, Montpellier, France.

Prakash, N.S., Combes, M.-C., Dussert, S., Naveen, S. & Lashermes, P. 2005. Analysis of genetic diversity in Indian robusta genepool (*Coffea canephora*) in comparison with a representative core collection using SSRs and AFLPs. Genetic Resources and Crop Evolution 52:333–343.

Rodrígues, C.J. Jr. 1980. Resistance to *Hemileia vastatrix* Berk. & Br. of some *Mozambicoffea* coffee species. pp. 663–665 *in:* Proceedings of the 9th International Scientific Colloquium on Coffee, London, UK, 16–20 June 1980. ASIC, Montpellier, France.

Rodrígues C.J. Jr., Bettencourt, A.J. & Rijo, L. 1975. Races of the pathogen and resistance to coffee rust. Annual Review of Phytopathology 13:49–70.

Rodrígues C.J. Jr., Várzea, V.M. & Medeiros, E.F. 1992. Evidence for the existence of physiological races of *Colletotrichum coffeanum* Noack *sensu* Hindorf. Kenya Coffee 57:1417–1420.

Smith, R.F. 1985. A history of coffee. pp. 1–12 *in:* M.N. Clifford and K. Willson (editors). Coffee botany, biochemistry and production of beans and beverage. Croom Helm, London. UK.

Sonké, B. & Stoffelen, P. 2004. Une nouvelle espèce de *Coffea* L. (Rubiaceae) du Cameroun, avec quelques notes sur ses affinitiés avec les espèces voisines. Adansonia 26:153–160.

Stoffelen, P. 1998. *Coffea* and *Psilanthus* (Rubiaceae) in tropical Africa: a systematic and palynological study, including a revision of the West and Central African species. Doctoral thesis, Katholieke Universiteit Leuven, Leuven, Belgium.

Stoffelen, P., Robbrecht, E. & Smets, E. 1996. *Coffea* (Rubiaceae) in Cameroon: a new species and a nomen recognized as species. Belgian Journal of Botany 129:71–76.

Stoffelen, P., Cheek, M., Bridson, D. & Robbrecht, E. 1997a. A new species of *Coffea* (Rubiaceae) and notes on Mount Kupe (Cameroon). Kew Bulletin 52:989–994.

Stoffelen, P., Robbrecht, E. & Smets, E. 1997b. Adapted to the rain forest floor: a remarkable new dwarf *Coffea* (Rubiaceae) from lower Guinea (tropical Africa). Taxon 46:37–47.

Stoffelen, P., Robbrecht, E. & Smets, E. 1999. A new species of *Coffea* (Rubiaceae) from central Africa, with notes on tentative other taxa. Systematics and Geography of Plants 69:119–124.

Stoffelen, P., Noirot, M., Couturon, E. & Anthony, F. [2006]. *Coffea anthonyi* Stoff. *sp. nov.*, a self-compatible Central African coffee species, closely related to an ancestor of *C. arabica* L. Submitted to *Taxon*.

Stoffelen, P., Noirot, M., Couturon, E. & Anthony, F. 2007. A new caffeine-free coffee species in the deep rain forest of Cameroon. Botanical Journal of the Linnean Society, in press.

Thomas, A.S. 1942. The wild arabica coffee on the Boma Plateau, Anglo-Egyptian Sudan. Empire Journal of Experimental Agriculture 10:207–212.

Van der Graaf, N. 1981. Selection of Arabica coffee types resistant to Coffee Berry Disease in Ethiopia. Mededelingen Landbouwhogescholan, Wageningen, The Netherlands.

van der Vossen, H.A.M. 2001. Coffee breeding and selection: review of achievements and challenges. Ref. A001 *in:* Proceedings (CD-ROM) of the 19th International Scientific Colloquium on Coffee, Trieste, Italy, 14–18 May 2001. ASIC, Montpellier, France.

van der Vossen, H.A.M. & Walyaro, D.J. 1980. Breeding for resistance to Coffee Berry Disease in *Coffea arabica* L. II. Inheritance of the resistance. Euphytica 29:777–791.

White, F. 1983. The vegetation of Africa. A descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa. UNESCO, Paris, France.

de Wildeman, E. 1901. Les caféiers. Veuve Monnom, Bruxelles, Belgium.

Anthony François, Dussert Stéphane, Dulloo E. (2007)

Coffee genetic resources. In : Engelmann Florent (ed.), Dulloo M.E. (ed.), Astorga C. (ed.), Dussert Stéphane (ed.), Anthony François (ed.). Conserving coffee genetic resources : complementary strategies for ex situ conservation of coffee (*Coffea arabica* L.) genetic resources : a case study in CATIE, Costa Rica

Rome (ITA) ; Paris : Biodiversity International ; IRD, 12-22

ISBN 978-92-9043-752-9