Genet Resour Crop Evol (2008) 55:1079–1093
DOI 10.1007/s10722-008-9361-7

REVIEW ARTICLE

Current status of coffee (*Coffea arabica* L.) genetic resources in Ethiopia: implications for conservation

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Received: 29 January 2008 / Accepted: 1 July 2008 / Published online: 29 July 2008

Abstract The aim of this article is to provide an overview of the current situation of coffee genetic resources that are dwindling at an alarming rate in Ethiopia, the centre of diversity of *Coffea arabica*. Firstly, we describe the coffee growing systems (forest coffee, semi-forest coffee, garden coffee and plantation coffee) and recent research on the genetic diversity of the coffee planting material associated with those systems. Whilst the maximum genetic diversity revealed by DNA-based markers is found in the forest coffees of the south-western highlands, the natural habitat of *C. arabica*, the taxonomy of coffee landraces is particularly rich in garden coffee systems located in ancient growing zones such as Harerge in eastern Ethiopia. After reviewing the factors involved in the genetic erosion of the Ethiopian genepool, we give an update on the status of coffee genetic resources conserved *ex situ* in the field genebank of the Jimma Agricultural Research Centre, with 4,780 accessions spread over 10 research stations located in the main production areas, and in the main genebank of the Institute of Biodiversity Conservation located in Choche (Limu) with 5,196 accessions conserved. Lastly, we mention the *in situ* conservation operations currently being implemented in Ethiopia. Improving our knowledge of the genetic structure of Ethiopian forest and garden coffee tree populations as well as genetic resources conserved *ex situ* will help to plan the future conservation strategy for that country. To this end, modern tools as DNA-based markers should be used to increase our understanding of coffee genetic diversity and it is proposed, with the support of the international scientific community and donor organizations, to undertake a concerted effort to rescue highly threatened Arabica coffee genetic resources in Ethiopia.

Keywords Centre of diversity · *Coffea arabica* · Cropping system · Genebank · Genetic erosion · Landrace

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Introduction

Coffee is the most valuable agricultural commodity in international trade and arabica coffee accounts for 66% of the world coffee market. Ethiopia is currently the third largest arabica coffee producer after Brazil and Colombia, with a production of 321,000 tonnes during the crop year commencing in 2006 (International

Coffee Organization 2007). During the same year, coffee accounted for about 35% of total exports of Ethiopia (IMF 2007), which has in previous decades been as high as 65%. In this country, coffee plays a central role in the incomes of more than one million coffee growing households and the livelihood of over 15 million people directly or indirectly depends on this commodity crop (LMC 2000).

Ethiopia holds a unique position in the world as *Coffea arabica* L. has its primary centre of diversity in the south-western highlands of the country. This fact is strongly substantiated by observations and publications of travellers and scientists (Vavilov 1935; Sylvain 1955; Meyer 1965) and, more recently, by several studies using DNA-based genetic markers (Lashermes et al. 1996; Anthony et al. 2002; Tesfaye et al. 2007).

Tewolde (1990) reported that some truly wild coffee populations can still be found in a few remote pockets of mountain rainforest, mainly in the south-western highlands, near Tepi, Gore (Illubabor), along Upper Didessa River (Wellega), and possibly in the Harenna Forest (Bale) in the south-east of the country (Tadesse and Nigatu 1996; Aga et al. 2003). To date it is still unclear whether the wild coffee of these regions is a remnant of the primeval forest flora or an escape of previous plantings. However, the largest proportion of coffee diversity existing in Ethiopia is being exploited by gathering or picking, in more or less managed forests, or grown in highly diversified cropping systems spread over different types of environments.

The existence of a varied range of Ethiopian origin coffees on the world market only partially reflects that diversity. For several decades, importers in industrialized countries have applied a green coffee classification based on geographical provenance and quality control prior to export from Ethiopia. Nine denominations are recognized in international trade, namely Limu, Jimma,[1] Gimbi, Sidamo, Yirgachefe, Illubabor, Harar, Tepi and Bebeka (Jobin 1992). More recently, some coffee roasters and retailers, in a policy of differentiating and adding value to their products, have resumed using many of these denominations for speciality coffees. In this regard, a recent dispute involved Starbucks, a giant American coffee distributor, and the Ethiopian government, which wanted to trademark the names of three famous coffee regions namely Sidamo, Yirgachefe and Harar (Gallu 2006). Starbucks was already using these names to sell high-priced coffee across the globe and had registered the name of Sidamo within the brand Shirkina Sidamo ('shirkina' in Amharinya language means to share or partnership). Eventually, on June 2007, Ethiopia and Starbucks signed a compromise agreement intended to give Ethiopian farmers a fairer share of the sale profits. The media coverage given to that event illustrates the economic importance of the Ethiopian coffees in that speciality food market segment.

World arabica coffee production is largely based on using a very small number of cultivars: *C. arabica* var. *typica* Cramer, *C. arabica* var. bourbon (B. Rodr.) Choussy, and mutants or hybrids of those two varieties (Krug and Carvalho 1951). The low genetic diversity observed within those cultivars makes this crop particularly vulnerable to biotic and climatic hazards. It was in cognizant of this fact that plant material surveys and collections were undertaken in Ethiopia from the beginning of the 20th century (Sylvain 1958; Lejeune 1958; Meyer 1965; Charrier and Eskes 2004), which led to the establishment of valuable genebanks at several international research centres in Africa (Cameroon, Côte d'Ivoire, Ethiopia, Kenya, Madagascar, and Tanzania), America (Brazil, Costa Rica, and Colombia), and Asia (India and Indonesia) (Anthony et al. 2007b). The largest and most comprehensively documented collections were those carried out under the aegis of the FAO in 1964–1965 (Meyer et al. 1968) and by ORSTOM[2] in 1966 (Guillaumet and Hallé 1967). These collections have been used to assess the diversity of the Ethiopian coffee genepool by the analysis of phenotypic characters (Charrier 1978; Montagnon and Bouharmont 1996) or using DNA-genetic markers (Anthony et al. 2001; Silvestrini et al. 2007), to search for traits of agronomic interest, and to improve yield and quality by way of hybridization with the Typica and Bourbon cultivars (Eskes 1983; Anzueto et al. 2001; Bertrand et al. 2005, 2006).

In Ethiopia, conservation of coffee genetic resources is the mandate of the Institute of

[1] Traded grade Jimma 5 is a mix of basic qualities of various Ethiopian growing areas' sundried coffees.

[2] Office de la Recherche Scientifique et Technique Outre-Mer, France (now IRD, Institut de Recherche pour le Développement).

Biodiversity Conservation (IBC), and the Jimma Agricultural Research Centre (JARC), the latter being responsible for coordinating coffee research within the Ethiopian Institute of Agricultural Research (EIAR). In spite of the large number of accessions and the diversity they represent, the situation of genetic resources collected and conserved *ex situ* in Ethiopia is comparatively less well known by the scientific community than that of the international collections, except some brief overviews published around 10 years ago (FAO 1996; Bellachew 1997).

In this article, we paint a broad picture of Ethiopian coffee production systems, and focusing particularly on the nature and the genetic diversity of the coffee planting material exploited within those systems. We detail the main factors that are leading to the loss of genetic diversity. We describe how coffee genetic resources are currently conserved *ex situ* in field genebanks within Ethiopia. We also mention some *in situ* conservation initiatives being currently implemented in Ethiopia. Lastly we make a few suggestions for defining a global conservation strategy.

The coffee production systems in Ethiopia and genetic diversity of coffee germplasm in the different production systems

In Ethiopia, four major coffee production systems are commonly distinguished (Woldetsadik and Kebede 2000):

– *Forest coffee* system (Fig. 1a and b), which includes simple coffee gathering and forest production where coffee trees are simply protected and tended for convenient picking.
– *Semi-forest coffee* system (Fig. 1c), where farmers slash weeds, lianas and competing shrubs, thin forest trees and fill open spaces with local seedlings.

Both systems predominate in south-western Ethiopia and in Bale (Fig. 2). They account for 5 and 35% of national coffee production respectively (Petit 2006).

– *Garden coffee* system (Fig. 1d and e) is a further step in the cultivation process. Seedlings are taken from forest coffee plantations and transplanted closer to farmers' dwellings. In this system, coffee is grown in smallholdings under a few shade trees usually combined with other crops and fruit trees. The garden coffee system predominates in the south (Sidamo), in the west (Wellega) and in the east (Harerge and Arsi). Very small-scale coffee growing in the marginal zones of northern Ethiopia such as Gojam and Welo can also be included under this category. Garden coffee accounts for about 50% of national production.
– *Plantation coffee* system (Fig. 1f), where coffee is cultivated after land clearing with systematic soil preparation and seedling planting, and managed in order to maximize the volume of production and productivity. This sector includes a few large private and state farms mainly located in the south-west, as well as many smallholder plantations spread all over the coffee growing areas. It accounts for about 10% of national production.

As nowhere else in the world, these four systems exist in Ethiopia, along with intermediate or mixed situations. In addition, they are not isolated from each other. For instance, in forest coffee and semi-forest coffee systems, the coffee genotypes, often called 'wild coffee' in the literature, are directly derived from spontaneous coffee trees of the forest. In the garden coffee system, the planting material results from a complex process of transport, exchanges and selection by farmers, and adaptation to environments that are sometimes distant (in geographical and ecological terms) from its original habitat. This planting material is commonly referred to as landraces.[3] In the coffee plantation system, the planting material can be coffee landraces but, in most cases, it consists of a limited number of coffee lines selected by national research institutions. Around the beginning of the 1970s the advent and dramatic spread of coffee berry disease (CBD) caused by *Colletotrichum kahawae* resulted in a significant drop in Ethiopian coffee production. Consequently, an important breeding programme based on the selection of naturally

[3] A landrace may be defined as a set of populations (or clones) of a crop species developed and maintained by farmers and recognized by them as all belonging to the same entity (Guarino 1995). In general, a landrace is adapted to local environmental conditions and/or specific uses.

Fig. 1 Views of the main coffee production systems. (**a**) coffee forest near Gera in Limu; (**b**) forest coffee in Keffa; (**c**) semi-forest coffee in Limu; (**d**) garden coffee in Harerge; (**e**) garden coffee in Sidamo; (**f**) plantation coffee in Tepi

resistant genotypes from farmers' fields and forest or semi-forest areas was launched (Robinson 1974; Van der Graaff 1981; Bellachew et al. 2000). In 2006, 23 pure resistant lines were available for distribution. A large number of promising landrace selections are currently being evaluated for disease resistance, yield

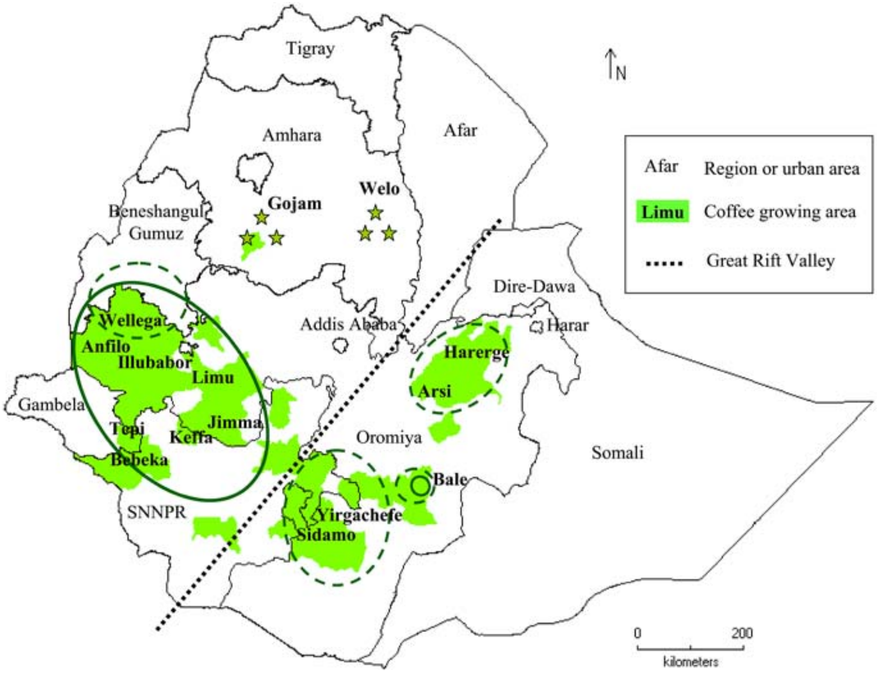


Fig. 2 Administrative map of Ethiopia showing the main coffee growing areas. The plain circles represent original habitat of *Coffea arabica*. The dashed circles represent secondary areas of cultivation. The stars represent marginal areas of cultivation. The main coffee growing areas (in green/dark grey) correspond to the *woredas* with more than 500 ha planted with coffee, according to 2001/2002 agricultural census (CACC 2003)

and organoleptic qualities in Sidamo, Wellega, Limu and Harerge (Bellachew and Labouisse 2007).

Average yield increases gradually when moving from the forest coffee system to the plantation coffee system. Coffee yield never exceeds 200 kg ha^{-1} year^{-1} for forest coffee and 400 kg ha^{-1} year^{-1} for semi-forest coffee (Woldetsadik and Kebede 2000). In the area of Bonga, in Keffa zone, Schmitt (2006) recorded very low yields, around 15 kg ha^{-1} year^{-1} for forest coffee and 35 kg ha^{-1} year^{-1} for semi-forest coffee. For garden coffee, the yield is very variable, ranging from 200 to 700 kg ha^{-1} year^{-1} depending on agricultural practices and the occurrence of CBD. Yield in plantation coffee varies between 450 and 750 kg ha^{-1} year^{-1} (Woldetsadik and Kebede 2000) although the average potential of selected lines is 1,700 kg ha^{-1} year^{-1} under optimum growing conditions (Bellachew and Labouisse 2007).

In the traditional production systems of Ethiopia, coffee trees exhibit a large phenotypic diversity, which has long been observed by travellers and scientists. On the basis of botanical observations, Sylvain (1955) proposed to classified Ethiopian coffees in 13 main types in relation with their cultivation areas. Charrier (1978) analysed morphological data gathered from samples collected by ORSTOM and emphasize their high variability compared to commercial cultivars such as Bourbon and Typica. Montagnon and Bouharmont (1996) analysed morphological and agronomical data of 148 samples collected by Lejeune (1958) and ORSTOM mission. They observed a clear structure within the species with the identification of two main phenotypic groups. Most of the coffee samples collected in the south-west fell into the first group, the samples from the south (Sidamo) and the east (Harerge) into the second one.

Coffea arabica species is characterized by a low molecular polymorphism, which is attributable to its allotetraploid origin, reproductive biology and evolution (Lashermes et al. 2000). However recent studies based on the use of genetic markers demonstrated that the genetic diversity observed in the traditional Ethiopian coffee planting material is large compared with the diversity detected in commercial cultivars (Lashermes et al. 1996). Moreover, within Ethiopian planting material, differences in level of genetic diversity are found according to the cropping systems from which the coffee plants were collected. Anthony et al. (2001), using random amplified polymorphic markers (RAPD), studied 88 accessions collected by FAO and ORSTOM in forests and gardens of Ethiopia and conserved at the Centro Agronómico Tropical de Investigación y Enseñanza

(CATIE) in Costa Rica. He found higher genetic diversity in coffee trees from the south-west (Keffa and Illubabor) compared to coffee trees collected from gardens in the east (Harerge) and in the south (Sidamo). In addition, he demonstrated that genetic distances were low between coffee trees that originated from these three geographical areas. These results support the hypothesis that southern and eastern coffee trees were not selected from forest coffee growing locally, but introduced from the south-west of the country. Tesfaye et al. (2007) analysed 300 coffee samples collected from several forests and farms using Inter Simple Sequence Repeat (ISSR) markers and the results point to lower genetic distances between individuals from coffee landraces taken in the gardens compared to individuals taken from forest production systems.

The diversity of Ethiopian coffee trees can also be analysed with the help of ethnobotanical data (Eyzaguirre 2001). For several centuries, coffee has played an important role in Ethiopian folk culture. It is generally believed that the current manner of making coffee—an infusion of ground roasted beans—came to Ethiopia from Arabia. However, travellers in Ethiopia have reported very diverse ways of preparing the brew, using boiled pulp, leaves or husk with the addition of milk, or roasted and flavoured with salt, butter or spices such as cardamom or cloves (Pankhurst 1997). Original agricultural practices are found in gardens, particularly in marginal ecologies such as in Harerge where coffee trees can be seen growing on constructed terraces with gravity irrigation. In this area, farmers maximize the use of ecological niches and the diversity existing within the species by selecting and multiplying the genotypes that they consider to be the most adapted to their local growing conditions. In each garden, farmers distinguish between and give different names to the coffee types, mainly based on morphological criteria (size and colour of leaves or fruits), but also depending on the origin of the plant (geographical origin or name of a farmer). For instance, Bellachew (1987), in a set of 592 samples collected in Harerge in 1986, listed 17 vernacular names of coffee landraces, of which 12 principal names were widely represented in that zone. Using the JARC database, we listed 57 single names or combinations of those single names, in addition to the principal 12 names, in a set of 1,013 samples collected in the same zone in 1998. Only 54 of the 1,013 coffee trees, i.e. 5.3%, could not be named by the farmers during the collecting time. In a set of 359 samples collected the same year in Wellega in western Ethiopia, we listed 10 names of which only 4 names involved large numbers of trees, and 61% of the coffee trees were not named. In Limu (south-western Ethiopia), out of 101 samples collected in 2001 and 2003, only 7 names were found, and 69% of the coffee trees were not designated a name. In the light of these observations, it is possible to put forward the hypothesis that the rich coffee landrace taxonomy observed in Harerge is the result of old and intensive cultivation practices[4] and stronger cultural links between farmers and coffee plants than in the west and the south-west. However, it is interesting to note that the richness of this landrace taxonomy does not reflect the extent of genetic diversity (as revealed by DNA-based markers) as well as phenotypic diversity of coffee planting material, which is the highest in the forest and semi-forest production systems located in the south-western part of the country.

Genetic erosion and contributing factors in Ethiopian coffee germplasm

Among the factors that contribute to the erosion of coffee genetic diversity in Ethiopia, the more noticeable is deforestation. Forty year ago, during FAO mission, Meyer already observed that "seven-eights of the forest cover of Ethiopia has vanished, leaving only a fragment in the southern and south-western provinces still in semi-pristine condition" (Meyer et al. 1968). About 16% of the Ethiopia land area was estimated to have been covered by high forest in the early 1950s, which declined to 3.6% in the early 1980s and further down to 2.7% in 1989 (EFAP 1994). In south-west Ethiopia, approximately 38% of the highland plateau was covered by 1,158,000 ha of closed high forest at the beginning of the 1970s, and, by 1997, only 556,700 ha were left, resulting in a loss of 52% of the natural coffee habitat in less than 30 years (Gole et al. 2002).

Ethiopia has a population of 77.4 million inhabitants, and a population growth rate of 2.4% (United

[4] According to Aregay (1988), there is evidence of coffee cultivation on a large scale in the Harerge region since the 16th century, while such development occurred only in the later 18th century in south-western Ethiopia.

Nations 2007). This population growth results in increasing land pressure and conversion of forest to farmland. The situation is also being exacerbated by population migration policies and government settlement programs for food security reasons. In 1997, Ethiopia has defined its own environment policy and conservation strategy, emphasizing the need to conserve, develop and utilize forest resources in a sustainable manner (EPA 1997); however, according to Gole et al. (2002), "the absence of respective government organs to implement the national conservation and environmental policy at regional level makes impractical the realization of such policy".

In some areas, the interest of farmers in coffee growing decreased in the past recent years due to economic, climatic or agronomic factors, leading to partial abandoning of coffee trees in forests or gardens. Very low prices paid to farmers, particularly during the 'price crisis' between 1999 and 2004, resulted in the drop of producers' revenues (Osorio 2002) and shifting to food crops or to the more lucrative khat[5] cultivation after uprooting coffee plants (Gole et al. 2002). With global climate change, some marginal coffee areas suffer from prolonged dry periods; this favours the cultivation of khat more resistant to drought than coffee. Low yields, particularly in highly CBD-proned areas, do not encourage farmers to exploit and conserve forest coffee populations and landraces, which are mostly not resistant to CBD. There is also very little incentive to conserve remnants of forest with very low yields and poor quality of forest coffee. The incidence of coffee wilt disease or tracheomycosis caused by *Gibberella xylarioides,* which slowly but surely destroys coffee plants, is also increasing in the country, mainly in the garden coffee systems (Girma et al. 2001).

An example of area particularly affected by coffee genetic erosion is Harerge in the eastern part of the country. This area suffers from recurrent droughts and, since the last half century, khat growing has been reported to compete with coffee (Brooke 1960). Harerge coffee is susceptible to different diseases and insect pests. It is severely attacked by coffee leaf rust (*Hemileia vastatrix*) and since the 1970s by CBD, resulting in harvest losses estimated between 70 and 100% (Bellachew 1987). Harerge coffee trees also suffer from die-back due to poor management practices and inadequate shade and mulch. As a result, severe defoliation is frequently encountered and yields are very low (Bellachew 1987, Labouisse personal observations 2005). On the other hand, Harerge coffee—marketed under the name Harar—fetches premium prices on the world market due to its specific cup taste profile: a typical mocha flavour, with chocolate notes, in a medium-dense body and a mild, soft acidity with light fruitiness. For these reasons, the rescue and conservation of the remaining Harerge coffee planting material are considered a priority. At the same time, within that genepool, there is a need to select landraces adapted to the Harerge ecology, resistant to diseases and reasonably productive in order to improve crop profitability.

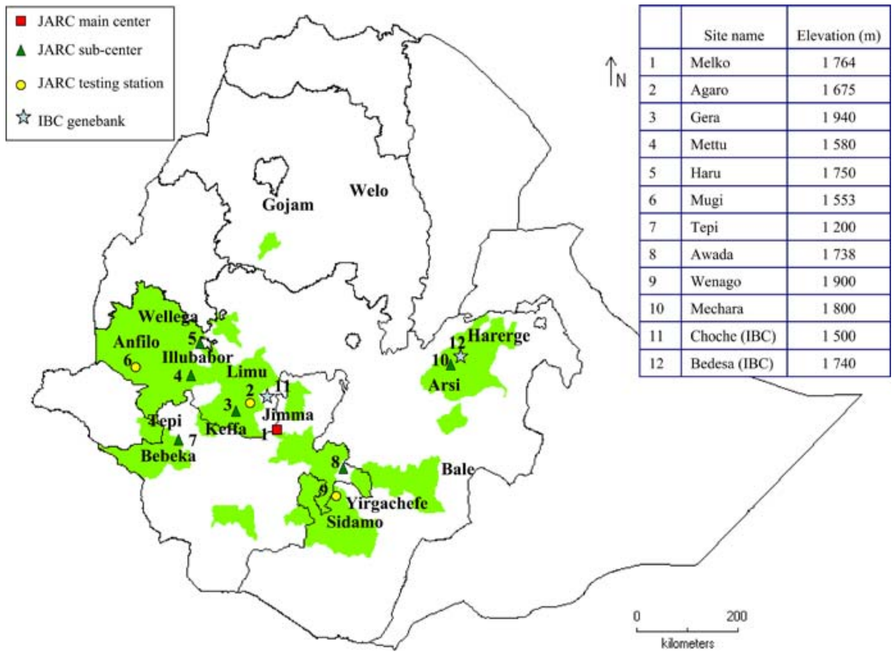
Another factor affecting genetic diversity is the replacement of local landraces by few improved varieties with a narrower genetic base. Although Ameha (1991) reported that 25,000–35,000 ha of semi-forest coffee had been replaced by CBD-resistant cultivars, leading to at least a 10% loss of the original genepool, the impact of such action is difficult to quantify. However, it is obvious that the search for greater profitability at all levels in the supply chain is encouraging the use of few varieties with better yields and quality traits. This trend is amplified by the recent involvement, with government encouragement, of wealthy investors in more intense cultivation methods, mainly in the south-west, in or near forest areas (Kotecha personal observations 2004–2007).

Ex situ conservation of coffee genetic resources within Ethiopia

In Ethiopia, the first deliberate attempt to conserve *C. arabica* genetic resources was the planting between 1954 and 1956 at the Jimma Agricultural and Technical School of different types of coffee trees selected by Sylvain (1955). Yield data were recorded for several years, but the collection was not conserved. Ten years later, out of the 621 samples collected by the FAO in 1964–1965, 433 were entrusted to the same institution (Meyer et al. 1968)

[5] Khat (*Catha edulis* Forsk.) is a shrub of which the fresh young leaves and tender shoots are chewed for their stimulant effect. The World Health Organization classifies khat as a drug of abuse that can produce moderate psychic dependence. Khat is consumed locally or exported, mainly to Djibouti, Yemen, and Somalia.

Fig. 3 Map of Ethiopia showing the location of the conservation sites of JARC and IBC



	Site name	Elevation (m)
1	Melko	1 764
2	Agaro	1 675
3	Gera	1 940
4	Mettu	1 580
5	Haru	1 750
6	Mugi	1 553
7	Tepi	1 200
8	Awada	1 738
9	Wenago	1 900
10	Mechara	1 800
11	Choche (IBC)	1 500
12	Bedesa (IBC)	1 740

but the seedlings were not planted (Mesfin Ameha ca. 1979 unpublished). It was only after the creation of the Jimma Research Station (now the Jimma Agricultural Research Centre) in 1967 that systematic and organized coffee research and germplasm collecting started at the national level. The collection arising from the ORSTOM mission at the end of 1966 was successfully established at the Melko station near Jimma and called the 'French Collection'. Since that date, 47 other collecting missions have been conducted over the last 40 years by JARC researchers within Ethiopia and, in total, 5,537 samples have been collected (Labouisse 2006).

Currently, the conservation of genetic resources is ensured in the form of living collections at the main JARC centre near Jimma and at 9 other sub-centres or testing sites, which are mostly located in the main coffee producing zones under different agro-ecological conditions (Fig. 3). The JARC genebank comprises 3 types of collections, not exclusive from each other: collections geared towards the search for traits immediately usable in the breeding programme, such as CBD resistance; those intended to capture the genetic diversity existing in the different agroecologies of Ethiopia; and lastly those designed to rescue coffee tree populations threatened by erosion. In December 2006, the total number of accessions conserved at JARC was about 4,780, of which 4,593 were collected within Ethiopia[6] over the last 40 years, 81 are internationally known *C. arabica* varieties introduced from other countries, 78 are off-types or mutants identified in the JARC genebank or trials, 7 are duplicated accession numbers, and the remaining 21 are of unknown origin (Labouisse 2006). The landraces collected from gardens and homestead farms alone amount to 80% of the total germplasm conserved.

In 2006, we constructed a computerized database under Microsoft® Access software and recorded the main passport data for all the JARC accessions (Labouisse et al. 2007). Use of that database provides a general picture of the regions and zones already surveyed in Ethiopia (Table 1). The elevation of the collection sites varies from 540 m (Gambela region) to 2,300 m (Amhara region) but 82% of the collected samples was found between 1,500 and 1,900 m. The JARC genebank is of prime value in that the major coffee producing regions are all well represented in the collections, the number of accessions is large and the morphological diversity is high (Fig. 4). The field design consists of 6–10 trees planted per accession, with two replicates in some cases. Observations focus on morphological characteristics, yield and resistance

[6] In this figure, we include five accessions from Eritrea, formerly a province of Ethiopia, now an independent country.

Table 1 Number of accessions (N) collected in Ethiopia and Eritrea, currently conserved in JARC genebank and grouped by collecting place (administrative divisions of the Federal State of Ethiopia)

Country	Region	Zone	N
Ethiopia	Amhara	Agew Awi	4
Ethiopia	Amhara	North Shewa	1
Ethiopia	Amhara	North Welo	12
Ethiopia	Amhara	South Welo	10
Ethiopia	Amhara	West Gojam	2
Ethiopia	Gambella	Godere	4
Ethiopia	Gambella	Zone 2	30
Ethiopia	Harar	Harar/Hundene	36
Ethiopia	Oromiya	Unknown	7
Ethiopia	Oromiya	Bale	192
Ethiopia	Oromiya	Borena	42
Ethiopia	Oromiya	East Harerge	980
Ethiopia	Oromiya	East Wellega	3
Ethiopia	Oromiya	Illubabor	237
Ethiopia	Oromiya	Jimma	617
Ethiopia	Oromiya	West Harerge	901
Ethiopia	Oromiya	West Wellega	667
Ethiopia	SNNPR[a]	Unknown	1
Ethiopia	SNNPR[a]	Amaro South West	37
Ethiopia	SNNPR[a]	Bench Maji	111
Ethiopia	SNNPR[a]	Dawro	13
Ethiopia	SNNPR[a]	Gamo Gofa	1
Ethiopia	SNNPR[a]	Gedeo	333
Ethiopia	SNNPR[a]	Hadiya	1
Ethiopia	SNNPR[a]	Keffa	198
Ethiopia	SNNPR[a]	Sheka	37
Ethiopia	SNNPR[a]	Sidama	64
Ethiopia	SNNPR[a]	South Omo	5
Ethiopia	SNNPR[a]	Welayita	25
Ethiopia	Somali	Jijiga	1
Ethiopia	Tigray	Central Tigray	4
Ethiopia	Tigray	East Tigray	1
Ethiopia	Tigray	South Tigray	1
Ethiopia	Tigray	West Tigray	4
Ethiopia	Addis Ababa		4
Ethiopia	Unknown		2
Eritrea			5
Total			4,593

[a] SNNPR is the abbreviation of Southern Nations, Nationalities, and People's Region

to diseases (mainly CBD). Using NIRS (Near Infra Red Spectroscopy) technology (Guyot et al. 1993; Bertrand et al. 2006), JARC is currently screening its entire genebank for identification of genotypes with very low or zero caffeine content, a characteristic with commercial development potential, by making use of cultivars giving a naturally decaffeinated product. However, two main weak points of JARC genebank should be mentioned: there has not yet been any systematic evaluation of genetic diversity by tools such as DNA-based genetic markers, and there are no security back-up collections established.

Indeed, the field genebanks are not immune from genetic erosion. For instance, Anthony et al. (2007a) estimated accession losses in the *C. arabica* collection established at CATIE in Costa Rica to be 3.6% over 10 years, i.e. an erosion rate of 0.4% per year. The plant material conserved in the field is subject to risks of total loss or erosion at varying speeds due to adverse environmental conditions, lethal diseases such as coffee wilt disease, die-back,[7] fires, wars and civil strife,[8] as well as poor management due to budgetary problems. In the JARC collections, when comparing the number of accessions listed in the introduction records and current numbers, we estimated the erosion rate at 21% over 40 years, i.e. approximately 0.6% per year.

In addition to *ex situ* conservation by JARC, there is also a large field genebank established and managed by the IBC. It is located in Choche (Limu) and, in 2006, contained 5,196 accessions maintained under indigenous trees shade covering an area of 40 ha (Tadesse Woldemariam Gole personal communication 2006). This genebank is mainly geared towards the conservation of diversity of 'wild coffee'. It consists of samples collected at random from forests or semi-forests and some accessions are duplicates of JARC collections. IBC maintains another small coffee field genebank in Bedesa (West Harerge) with coffee samples collected in Harerge area. A systematic evaluation of genetic and

[7] Die-back: A phenomenon of physiological decline which can culminate in tree death, due to a nutritional imbalance, exacerbated by inadequate cultural practices (absence of shade, lack of fertilizers, etc.) or a lack of adaptation to the pedo-climatic conditions of the conservation site.

[8] In 1998, the Mechara research station in Harerge was totally destroyed during civil strife, leading to the definitive loss of a collection of 592 accessions collected in 1986 in that zone of high genetic erosion. The station has been re-established in 2005.

Fig. 4 An example of morphological variability within Ethiopian coffee germplasm. Two genotypes, one tall and one semi-dwarf, planted at the same time in JARC genebank

phenotypic characters would be useful to assess the value of both IBC genebanks.

Complementary conservation methods

In situ conservation of genetic resources is a conservation approach that is acknowledged as being complementary to *ex situ* conservation (Maxted et al. 1997; Dulloo et al. 1998) and its implementation for Ethiopian coffee has long been considered as a national urgency (Tewolde 1990; Paulos and Demil 2000). Up to now, emphasis has been placed on the conservation of a few, more or less degraded, remnants of forest areas under development projects funded by international agencies.

In 1998, three sites, namely Kontir-Berhan in Bench-Maji zone (ca. 20,000 ha), Boginda-Yeba in Keffa (5,500 ha) and Geba-Dogi River in Illubabor (18,600 ha), had been identified for forest coffee conservation in the framework of Coffee Improvement Project Phase IV (CIP IV) funded by the European Union, but this project can claim very few concrete results mainly due to lack of efficient management and coordination between the institutional partners (Westlake and Rosskamp 2005). The forest conservation component of CIP IV has been recently redesigned with IBC as the main implementing institution and an emphasis put on a better coordination with other projects involved in the forestry sector in Ethiopia.

For several years, most of these projects have been developing a participatory forest management strategy. Many activities are currently being carried out in forest coffee areas by FARM-Africa and SOS-Sahel in the forests of Bonga (Keffa zone), GTZ[9] in the forests of Adaba-Dodola (Bale zone), Japan International Cooperation Agency (JICA) and the Agriculture and Rural Development Bureau of the Oromiya Regional in the Belete-Gera Forest (Jimma zone), and Non Timber Forest Products (NTFP) research and development project funded by European Union in Mahsa Forest, Sheka zone, south-west Ethiopia (NFTP 2005, PFMP 2006, JICA 2007). More recently the FARM-Africa/SOS Sahel Bale Eco-Region Sustainable Management Programme started in the Bale Massif. These integrated projects are mainly oriented towards the social and economic well being of the communities dependent on the natural resources of the forest, through the promotion of participative forest management and non timber products exploitation such as coffee, honey and spices. In order to gain more income out of these products, the projects focus on sustainable harvesting and marketing. However very little information is available on the real impact of these operations on the preservation of the whole ecosystem and

[9] Deutsche Gesellschaft für Technische Zusammenarbeit GmbH, Germany.

consequently on the conservation of forest coffee trees populations.

The project entitled 'Conservation and use of the wild populations of *Coffea arabica* in the montane rainforests in Ethiopia' or CoCE, coordinated by ZEF[10] with IBC, Addis Ababa University and JARC as main partners, is more oriented towards research topics. Phase I of the project was implemented from 2002 to 2006 and was divided in six sub-projects covering issues on coffee habitat botanical diversity, coffee genetics and genomics, coffee eco-physiology, coffee pathology, socio-economics and institutions (ZEF 2007). For conservation, the project is promoting the model of biosphere reserves along the lines of the UNESCO Man and the Biosphere Programme (Gole 2003; Schmitt 2006). The implementation of *in situ* genebanks with areas reflecting the broad genetic diversity of natural populations is the objective of the CoCE phase II project (2006–2009). But the application of such a model is still far off. The cost of such an initiative is high and its justification goes well beyond the conservation of the *Coffea arabica* species, since such a conservation method embraces all organisms (micro-organisms, plants, animals, etc.) contained within a given ecosystem, including activities of humans. In that regard, participatory forest management is just the first step towards a biosphere reserve.

In addition to the conservation of coffee forests, it also seems important to develop some on-farm conservation methods for landraces in the coffee-based garden systems. Unlike cereals and several horticultural species, whose cultivation has been an established fact for some thousands of years, the coffee trees found in the garden systems of Ethiopia can be considered as only partially domesticated plants, which still maintain many of the traits and characteristics found in the wild populations. When placed under ecological conditions similar to their original habitat, young coffee trees exhibit weedy tendencies. As revealed by the diversity of landrace names and phenotypes, and in spite of the breeding system of *C. arabica,* garden coffee germplasm usually consists of heterogeneous mixtures of genotypes and is an important reservoir of diversity, although to a lesser extent than forest coffee. In addition, the existing landraces offer the advantage of being adapted to their *terroirs.*[11] Lastly, the expression of their agronomic traits, such as productivity, resistance to diseases and abiotic stress, such as drought, is easier to observe in gardens than in a forest environment, making it possible to identify individuals that can immediately be incorporated into a genetic improvement programme of landraces. To our knowledge, the on-farm conservation initiatives undertaken in Ethiopia have so far only involved domesticated plants, predominantly landraces of cereal or legume crops (Worede 1997; Tesfahun 2000) and little concerted action can be found for coffee in this domain.

In general, the sustainability of *in situ*/on-farm conservation systems seems to be guaranteed only if farmers can earn a large enough benefit from the whole agroforestry system or garden system. Since currently harvested forest coffee qualities are quite mediocre, due consideration for their improvement is a prerequisite to obtain premium prices by commercialization for export. Only then, it will become possible to consider product labelling which could take several forms (environmental certification, Protected Designation of Origin, etc.) in order to increase its value on the market by providing consumers some form of assurance of quality and provenance and better incomes to farmers who produce such coffees. Kotecha (2008) mentioned similar commercialisation with coffee eco-tourism and, in degraded forest areas, regenerative agroforestry initiatives with forest coffee planting material established under newly planted indigenous shade trees. The advantages along with the conditions required for such a system of geographical indication to be adopted in Ethiopia have been reviewed by Roussel and Verdeaux (2007). They reported that a significant increase in the income levels generated by the certification label would presumably make it worthwhile for farmers to continue conserving the diversity of species and landraces in their gardens. However, such assumptions have yet to be validated, particularly if there is no increase of crop productivity while more care is

[10] Zentrum für Entwicklungsforschung (Center for Development Research) of the University of Bonn, Germany.

[11] French word commonly applied to vineyards, a *terroir* is characterized by a physical environment, cultural practices, harvesting and processing methods that contribute to the originality of its production and give a unique character to its product.

needed to improve the quality. The project Ethiopian Home Gardens, implemented by the Ethiopian Environment Protection Authority (EPA) with French funding and technical assistance, is currently promoting the use of such geographical indication system.

Some proposals for a global conservation strategy

A recent study by Hein and Gatzweiler (2006) considered the potential economic value of forest coffee genepool, related to the potential benefits it could bring through the breeding of new varieties for pest and disease resistance, low caffeine content and improved yield, to 1,458 million US$. According to the same authors, this value estimate is prone to considerable uncertainty due to the numerous assumptions on which this value is based. Actually, our current inadequate knowledge of the degree and structure of the diversity existing in the forests and gardens of Ethiopia makes it impossible to estimate the potential value of the Ethiopian coffee genepool. With at least one thousand *Coffea arabica* distinct accessions conserved in genebanks out of Ethiopia, most of them in the hands of competing producing countries, the value of the advantages that foreign producers would gain from further access to Ethiopia's coffee genotypes remains uncertain (Westlake and Rosskamp 2005). More studies are required on coffee trees populations to determine the local abundance, the self-fertilization rate, the population age structure, the degree of kinship between individuals, the phenotypic diversity (morphology, resistance to diseases), and the genetic polymorphism. Such studies have been undertaken on wild populations of *Coffea canephora* Pierre and *Coffea liberica* Hiern (Berthaud 1986) but much remains to be done on *Coffea arabica,* in both its forest habitat and in the gardens. This will help to determine the optimum size of the populations to be maintained for *in situ*/on-farm conservation, and to define an appropriate sampling strategy (number and location of sampling sites, number of individual plants sampled at a site, etc.) for *ex situ* conservation (Brown and Marshall 1995).

As regards *in situ* conservation policy, there is a need to review the lessons from the past and current forest management projects in Ethiopia and in other countries. This was the main objective of the workshop entitled 'Policies to increase forest cover in Ethiopia' organized in September 2007 by the Environmental Economics Policy Forum for Ethiopia (Bane et al. 2008). Among many recommendations, the participants stressed the need to clarify land use in forest areas and forest property rights, to organise a better coordination between federal and regional institutions as well as with non-governmental organizations involved in participatory forest management projects, and to set up clear directives and detailed guidelines for a new forest policy.

Much work also remains to be done to assess the diversity existing in the collections currently conserved *ex situ* by JARC and IBC. An enormous quantity of characterisation data has been gathered during the past 40 years in coffee genebanks and JARC trials, but the use of DNA-based genetic markers will overcome the environmental effect on most of the quantitative traits. The analysis of both phenotypic and genetic data will help to guide the collecting strategy for the future, fill gaps in the collections, rationalise field genebank conservation through the creation of security back-up collections or for renewal operations, and guide hybridization programmes by searching for heterotic groups. Implementing such a genotyping programme on all the JARC and IBC collections may seem difficult to envisage now, due to the costs involved, but progress in molecular biology techniques will probably overcome this limitation in the medium term. Thereafter, it will become possible to define a core collection for priority preservation. Such core collection could be maintained in the form of living trees or possibly by cryopreservation (Dussert et al. 2007).

Ethiopia stands out through the diversity of its *terroirs* and the unique richness of coffee genetic diversity. The latter is under-exploited, inadequately understood, and increasingly under threat of erosion. There is no doubt that urgent measures are necessary, mainly from the federal government and the regions, to slow down the process of forest degradation. It is clear that the country on its own does not have the resources necessary to maximize the conservation potential. The world community should contribute to this by providing technical and financial assistance. A systematic assessment of the coffee genetic resources conserved *ex situ* and a better knowledge of the genetic structure of the populations existing in the different forest or farming systems will help to define a comprehensive conservation strategy for the future.

To that end, provided that an effective system of plant variety protection is set up in a transparent manner, a strong initiative should be undertaken without delay by Ethiopia, for example in the framework of the International Coffee Genome Network[12] (ICGN), in order to mobilize the research potential of the international community involved in the coffee sector for the benefit of everyone.

Acknowledgements This work was made possible thanks to the support of the Coffee Improvement Project (Phase IV) funded by the European Union. The main partners of this project are the Ministry of Agriculture and Rural Development of Ethiopia, JARC, IBC, BDPA (Bureau pour le Développement de la Production Agricole, France) and CIRAD (French Agricultural Research Centre for International Development).

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[12] ICGN is committed to advancing genomic research through international partnerships for sustainable coffee production (ICGN 2008).

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