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Opinion paper

Conserving wild Arabica coffee: Emerging threats and opportunities

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ABSTRACT

Climate change and emerging pests and diseases are posing important challenges to global crop productivity, including that of Arabica coffee. The genetic basis of commercially used Arabica coffee cultivars is extremely narrow, and it is uncertain how much genetic diversity is present in *ex situ* collections. Conserving the wild Arabica coffee gene pool and its evolutionary potential present in the montane forests of SW Ethiopia is thus critically important for maintaining coffee yield and yield stability worldwide. Globally, coffee agroforestry helps to conserve forest cover and forest biodiversity that cannot persist in open agricultural landscapes, but the conservation of the wild Arabica coffee gene pool requires other priorities than those that are usually set for conserving forest biodiversity in mixed tropical landscapes. We show how forest loss and degradation, coffee management, in particular production intensification, and the introduction of cultivars, are threatening the genetic integrity of these wild populations. We propose an active land sparing approach based on strict land use zoning to conserve the genetic resources and the *in situ* evolutionary potential of Arabica coffee and discuss the major challenges including the development of access and benefit sharing mechanisms for ensuring long-term support to conservation.

1. Introduction

Coffee is grown in more than 70 countries across the tropics and the annual export value of coffee exceeds US$24 billion (FAO, 2015). The market demand for coffee is still rising, but climate change and emerging pest and diseases are posing important challenges to global coffee productivity (Läderach et al., 2010; Bunn et al., 2015). Outbreaks of coffee rust, coffee berry borer beetles and root nematodes have already reduced coffee yield and degraded coffee quality in coffee plantations around the world (Jaramillo et al., 2011; Avelino et al., 2015). The high susceptibility of commercial plantations to pests and diseases that seem to accompany global change and rising temperatures (Ghini et al., 2011), and the overall expected limited resilience of monocultures against environmental change in general (Lin, 2011), can be largely attributed to the very narrow genetic basis of the commercially used coffee cultivars (Anthony et al., 2001). These plants have a very limited potential to adapt, a feature shared with many other important crops (Fernie et al., 2006) including Cavendish banana, soybean, maize and cocoa. For Arabica coffee (*Coffea arabica* L.), accounting for 60% of all coffee produced globally and of higher organoleptic quality than the other commercially used coffee species *Coffea canephora* or 'Robusta' coffee, the narrow genetic basis is mainly related to major genetic bottlenecks during global dissemination of Arabica coffee. The plants that were originally introduced in Latin America and the Caribbean all descended from a few individuals that grew in Java, grown from seeds collected in Yemen, which in turn were the fruits of a few mother plants that most likely had their roots in the southwestern highlands of Ethiopia (Anthony et al., 2001). Given the very low genetic diversity of Arabica coffee cultivated worldwide, the extant wild gene pool of *C. arabica* in SW Ethiopia may prove to be essential to future-proof the global coffee economy and to secure the

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livelihood of millions of households that depend on Arabica coffee production or trade.

2. Wild Arabica coffee in Ethiopia

Wild *Coffea arabica* occurs as an understory shrub and has its center of diversity in the moist evergreen 'coffee forests' of southwestern Ethiopia (Anthony et al., 2001). Both wild populations and locally cultivated varieties (landraces) are still characterized by wide genotypic and phenotypic variability (Labouisse et al., 2008) and studies based on genotypic fingerprinting have provided evidence that Ethiopian wild provenances are genetically distinct from the most widely commercially used varieties *Typica, Bourbon* and *Caturra* (Anthony et al., 2001; Chaparro et al., 2004; Silvestrini et al., 2007; Tesfaye et al., 2014). The genes conserved in the Ethiopian wild gene pool are responsible for a number of desirable traits such as low caffeine content (Silvarolla et al., 2004), higher quality specialty grade (Berecha et al., 2014a) or resistance to root nematodes and coffee berry disease (Boisseau et al., 2009). These genes and genes related to other traits of wild coffee are essentially the genes needed to adapt coffee to changing climate and market demands. In these naturally regenerating populations, allele frequencies and gene combinations constantly change in a process of adaptation to external drivers, including climate change and disease pressure. Such evolutionary processes are lacking in *ex situ* collections of coffee (Schoen and Brown, 2001), including the collection of CATIE (*Centro Agronómico Tropical de Investigación y Enseñanza*) which includes c. 10,000 coffee trees, representing 1850 accessions, of which c. 600 accessions were collected in the Ethiopian center of Arabica coffee diversity (Anthony et al., 2007). In *ex situ* collections, coffee shrubs are kept outside their natural habitat under homogeneous environmental conditions and low disease pressure. Together with the typically clonal regeneration of the cultivars, this prevents adaptation of coffee collections to changing environments (Anthony et al., 2007). A dynamic, *in situ* conservation approach allowing natural regeneration and evolution is therefore the best way for conserving a coffee gene pool that is free to adapt to climate change and emerging pests and diseases, and that can be used to harness coffee cultivation worldwide in the face of such challenges (Sgrò et al., 2011; Sarrazin and Lecomte, 2016).

3. Imminent threats to wild Arabica coffee

Globally, coffee agroforestry helps to conserve forest cover and forest biodiversity that cannot persist in open agricultural landscapes (Tscharntke et al., 2011). Also in Ethiopia, extensive coffee production systems including semi-forest coffee and homegarden coffee have been demonstrated to support the conservation of forest cover (Aerts et al., 2011; Hylander et al., 2013) and associated components of forest biodiversity (Gove et al., 2008; Hylander and Nemomissa, 2008; Tadesse et al., 2014a; Buechley et al., 2015) in landscapes that in the absence of coffee would be entirely converted to open crop- and grazing land (Tadesse et al., 2014b). Nevertheless, the conservation of the wild Arabica coffee gene pool requires other priorities than those that are usually set for conserving forest biodiversity in mixed tropical landscapes, such as the conservation of small forest patches, isolated trees and hedgerows (Muñoz et al., 2013). Like cultivated Arabica coffee elsewhere, also wild Arabica coffee is susceptible to climate change, and a bioclimatic model for *C. arabica* predicts a 38 to 90% reduction of the suitable area within its native range by 2080 (Davis et al., 2012). However, multiple direct threats to the *in situ* conservation are currently more imminent. First, ongoing loss and fragmentation of natural coffee forests (Tadesse et al., 2014a,b) are directly threatening wild coffee populations and the genetic

Fig. 1. Coffee forest in SW Ethiopia. This part of the Belete-Gera National Forest Priority Area harbored an undisturbed, wild population of *Coffea arabica* in 2008 (A). The same stand was re-photographed in 2014 (B). The tallest canopy trees have been cut and the diverse understory vegetation has been replaced by a mixture of transplanted wild *C. arabica* seedlings and acquired *C. arabica* cultivars.

diversity present. In the core area of coffee diversity, we continue to observe the fast replacement of natural coffee forest harboring wild coffee populations by intensively managed coffee plantations (Fig. 1). Decreased coffee population size and increased spatial isolation may cause inbreeding at the expense of local fitness and associated disease resistance and productivity (Jump and Peñuelas, 2006). In addition, increased genetic drift in small and fragmented populations compromises the ability to cope with changing environmental pressures due to the loss of (cryptic) beneficial genetic variation (Honnay and Jacquemyn, 2007). Second, coffee forest management intensification leads to degradation and simplification of forest structure and plant communities (Fig. 1B; Senbeta and Denich, 2006; Schmitt et al., 2009; Hundera et al., 2013). The meticulous harvesting of coffee berries, transplanting of coffee seedlings and frequent slashing of the understory vegetation disturb the natural regeneration process and the age structure of the coffee populations (and other tree species) (Berecha et al., 2014b; Hundera et al., 2015) and inhibit the process of natural selection in response to environmental change (Jump et al., 2009). The biotic and structural homogenization also results in a forest hosting less diverse pollinator communities (Samnegård et al., 2014; Berecha et al., 2015). This has been linked to decreased pollen dispersal and reduced outcrossing in wild Arabica coffee populations (Berecha et al., 2014b), likely negatively affecting extant genetic diversity through inbreeding. Third, the widespread introduction of locally improved cultivars resistant to coffee berry disease into natural forests since the 1970s is threatening the genetic integrity of the remaining wild coffee populations, which already show signs of admixture with these cultivars (Aerts et al., 2013). All these threats can strongly interfere with the evolutionary trajectories underlying genetic diversity and adaptive potential. Especially in fragmented and homogenized forest landscapes, where gene flow and hence the exchange of (adaptive) alleles is hampered, small population sizes can quickly result in depleted adaptive genetic diversity (Bijlsma and Loeschcke, 2011). To conserve the genetic diversity required for long term adaptive responses, management of the forests and the coffee populations therein should aim at supporting the evolutionary processes governing genetic diversity (Sgrò et al., 2011). Thus, the most important challenge involves the conservation of adequate effective population sizes and gene flow dynamics in the face of ongoing forest loss and degradation (Bacles and Jump, 2011).

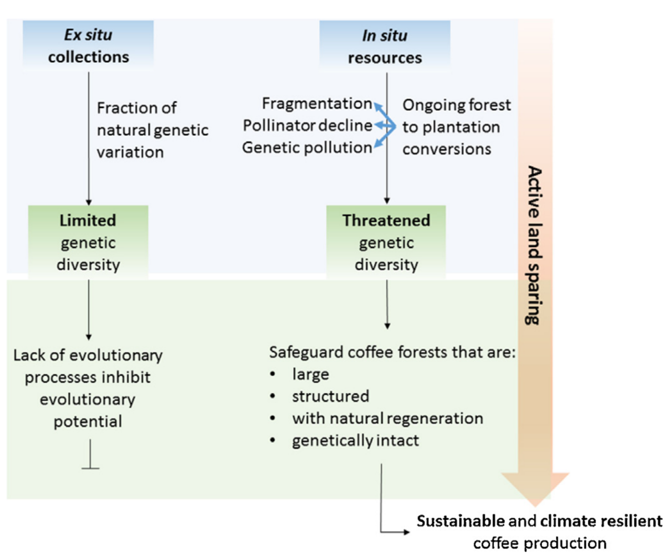

Fig. 2. Major threats to *ex situ* and *in situ* genetic diversity of *Coffea arabica*. Strict forest reserves are needed to secure conservation of *in situ* coffee genetic resources and their evolutionary potential.

4. Conservation approaches for wild Arabica coffee

Given the multiple challenges related to safeguarding the evolutionary processes and the adaptive potential of the wild coffee gene pool, the establishment of strict wild coffee forest reserves, free from active coffee farming, is urgently needed (Fig. 2). Not to compromise the interests and livelihoods of the local coffee farmers and the coffee production goals set by the government as part of its poverty and hunger reduction strategy, this would basically require the combination of land sparing and land sharing approaches (Phalan et al., 2011) where (i) the management in the most strongly degraded coffee forests is optimized aiming at increasing coffee yield; (ii) the management in less degraded coffee forests is optimized for biodiversity conservation and the provisioning of ecosystem services, and (iii) large tracts of natural coffee forests are not taken into production to conserve wild coffee populations. Given the currently observed fast conversion of natural forest into plantation-like coffee forest (Fig. 1), the conservation of the last remaining natural forests is imperative and providing detailed actual maps of their distribution as a first step is an absolute priority.

To avoid that local yield increase and profit encourage agricultural expansion into protected areas rather than the opposite, Phalan et al. (2016) have recently proposed a range of active land-sparing mechanisms that may be successfully applied to the Ethiopian wild coffee case. Strict land use zoning in combination with directed yield increasing measures is needed to successfully and permanently separate coffee production areas from coffee forest reserves. Production could be boosted, for example, through technical advice on forest, soil and disease management, and through improvement of the roads and other infrastructure in the coffee production chain. Standards and certification schemes rewarding groups of farmers with additional benefits in terms of access to production resources, to technical advice to increase coffee production and perhaps to price premiums, when conserving the strict coffee forest reserves, are likely to increase the success of such a land sparing approach. Monitoring, in particular by use of remote sensing, may be helpful to demonstrate success of the land use zoning and to identify problems so that these can be addressed early if they emerge. The designation of Yayu, Sheka and Kaffa, three coffee forests in the southwest of Ethiopia, as UNESCO biosphere reserves, is certainly an important step forward to the implementation of such an active land sparing approach in Ethiopia. The cores of these forests are proposed to be placed under land sparing management, while land sharing is practiced in the forest edges and in the other parts of the landscape (which covers more than 1 million hectares over the three reserves, see online interactive map).

An important hurdle for the sustainable exploitation of the wild coffee gene pool is the danger that these genetic resources are not used to the benefit of the Ethiopian people, in particular the Ethiopian farmers and government bodies who face the costs and burden of wild coffee gene pool conservation. The UN Convention on Biological Diversity (CBD) and Nagoya Protocol provide opportunities to develop specialized access and benefit sharing (ABS) instruments. Given the global importance of the coffee industry, a specialized ABS scheme for Arabica coffee could generate substantial funds for long-term support to the conservation of coffee genetic resources in return for fair access to the genetic resource (Richerzhagen and Virchow, 2007). Together with funds derived from coffee certification schemes (Wiersum et al., 2012; Takahashi and Todo, 2014) or policy mechanisms such as

REDD+ (as in Yayu forest, see *e.g.* Phalan et al., 2013), this fund could become instrumental in supporting local forest managers and coffee smallholder farmers to implement a combination of land sparing (reserve) and land sharing (biodiversity-friendly) conservation strategies (Fischer et al., 2008) and to conserve the unique biodiversity of Ethiopia's last remaining coffee forests.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2016.12.023.

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