Chapter 9

New varieties for innovative agroforestry coffee systems

Benoit Bertrand, Jean-Christophe Breitler, Frédéric Georget, Éric Penot, Mélanie Bordeaux, Pierre Marraccini, Sophie Léran, Claudine Campa, Olivier Bonato, Luc Villain, Hervé Étienne

In the plant breeding industry (also known as the seed industry), the breeder applies specifications that are based on a productivist rationale which considers the environment as a production medium and cares little about the quantities of inputs to be used. Furthermore, this industry is not interested in tropical perennial crops (rubber, cocoa, coffee, coconut, etc.) that are mainly cultivated by small producers with little means, and which is thus economically unattractive. Varietal creation and seed production for these crops are sometimes carried out by professional or national organizations. As a result, the overall supply of new varieties in these agri-chains is extremely small and genetic progress is very limited. In a context of global warming and biodiversity loss, it is therefore necessary to create varieties that are more adapted and to reorient the selection criteria for tropical perennial crops.

In order to illustrate this need of revisiting breeding targets in a context of the agro-ecological transition, we present the example of new coffee varieties adapted to agroforestry systems.

Arabica coffee is mainly grown in Central America at elevations of 600 and 1200 m above sea level and in Peru (close to the Equator) at altitudes between 1000 and 1500 m. In these regions, this crop is cultivated mainly in agroforestry systems providing numerous ecosystem services, including biodiversity conservation, water cycling in watersheds, and carbon sequestration. At a socio-economic level, coffee cultivation is very labour-intensive and helps to arrest the rural exodus and illegal migration to the United States. The majority of the producers in these areas find it difficult to gain access to the so-called 'special' coffee market which is more remunerative.

The goal of this chapter is to show why productive and 'healthy' varieties are the cornerstone of the push to re-establish the profitability of coffee cultivation in the Central American countries, the Andean States and Mexico, in the low-lying areas that account for more than 90% of the Arabica coffee produced in El Salvador, Honduras and Nicaragua, 50-60% in Costa Rica, around 40% in Guatemala, over 50% in Chiapas in southern Mexico, and more than 80% in the latter country's northernmost cultivation areas, mainly located in the states of Veracruz and Oaxaca.

We will briefly recall the constraints and challenges of this form of coffee cultivation practised for the most part in agroforestry systems. We will describe breeding targets in the context of agroforestry and varieties that are most adapted and then discuss how to produce and disseminate these varieties.

The challenges to be met

An unsustainable form of coffee cultivation

The use of pesticides in agriculture, even in a reasoned manner, has environmental consequences. There are many such effects as the products resulting from the degradation of agrochemicals spread out widely and are likely to end up not only in various compartments of the environment (air, water, soil, etc.) but also in food. Coffee cultivated under full-sun conditions relies on chemical inputs: synthetic fertilizers, herbicides, fungicides and insecticides. Farmers are directly exposed to chemicals and the surrounding communities are also affected by residues that travel easily from one compartment to another where they accumulate.

The risk of biodiversity loss

The loss of biodiversity today, which is occurring at a rate that is 1000 times greater than the geological average, corresponds to the sixth mass planetary extinction since the appearance of life on Earth. Even though the disappearance of plant and animal species is part of the natural course of Earth's history, human activity is responsible for this accelerated rate of extinction. According to the theory of island biogeography (MacArthur and Wilson, 1967), which has formed the basis of research in conservation biology for the past 40 years, the reduction in available habitat results in a proportional loss in the number of species, and vice versa. As a result, an agricultural landscape with a large tree cover contains more forest species than a natural landscape without trees. The link between coffee cultivation and deforestation was highlighted by WWF (World Wide Fund for Nature, also known as World Wildlife Fund), which showed that of the 50 countries with the highest rates of deforestation, 37 are coffee producing countries.

Increased pressure from parasites

Different shading levels in coffee plantations influence the overall functionality of the food web, mainly through light intensity and relative humidity. Pest and disease pressures, as well as the impact of control agents (microflora and fauna), differ according to climate, altitude and soil type (Staver *et al.*, 2001). For example, outbreaks of rust (the main disease affecting coffee leaves and caused by *Hemileia vastatrix*) increase and intensify with climate change. Indeed, warmer temperatures affect both, the development of this fungus and the physiological state of the plant under environmental stress.

Coffee cultivation that is not very profitable

Coffee is often the only crop that provides income for farmers in the mountainous areas of Central America, Colombia and Peru. Collection networks for green coffee have been created even in the remotest locations to transport it to drying and sorting centres, and thence to ports for export to roasters who process and market the product.

The producer is, however, dependent on a price that is set elsewhere. He is aware of the volatility of world prices, and knows that the coffee he produces must stand out from cheaper coffees. He also realizes that if major producing countries such as Brazil or Vietnam – which practice intensive coffee cultivation systems that are highly dependent on pesticides and fertilizers – produce too much, the world price will collapse and the market price will no longer even cover his expenses. Producers can rarely resort to bank loans under such adverse conditions. In fact, national banks are of the opinion that factors such as price volatility, recurring epidemics like the series of rust crises since 2008 (McCook and Vandermeer, 2015; Avelino *et al.*, 2015), risks arising from climate change, and weak producer guarantees render the coffee cultivation sector a risky bet. Consequently, all they offer producers are loans at usurious interest rates (between 12% and 20% per annum).

Furthermore, in many coffee producing countries (with the notable exception of Colombia where the National Federation of Coffee Growers have given the production chain a robust structure), and to a lesser extent in Honduras and Costa Rica, the State does not play its regulatory role concerning credit and agricultural extension, seed supply, and research and innovation. Taxes collected from exports are only partially reinvested in the production chain. As for coffee varieties, the absence of a structured seed sector results in the production of poor quality seeds and plants, both in terms of genetics and horticulture. Non-standard varieties are often disseminated, and have a negative impact on productivity. At least 40 countries rely on innovation in other countries (Brazil, Colombia) for the creation of new varieties. The import of seeds from these countries is rarely facilitated by national governments. Varieties are therefore sometimes introduced illegally, with very poor traceability.

The creation of varieties adapted to agroforestry

Properly managed agroforestry systems make optimal use of biological and economic synergies, leading to sustainable land management and stable and localized income sources for stakeholders (essentially small farmers). It is understood that cultivation in shaded systems, such as agroforestry systems, reduces reliance on external inputs. Unfortunately, as observed for other crops, the productivity of coffee-based agroforestry systems is lower by 30% than that of full-sun systems (Vaast *et al.*, 2005). One reason for this situation is that varieties cultivated in such systems were bred for full-sun intensive systems, and are thus not adapted to agroforestry systems (Bertrand *et al.*, 2011; Van der Vossen *et al.*, 2015). Varietal improvement for intensive systems has provided growers with varieties that are unsuitable for growing under shade, while wild Arabica coffee is naturally tolerant to shade, and thus to agroforestry systems.

The BREEDCAFS project

The solutions which will be described here are currently being studied within the framework of a H2020 European project (2017-2021) called BREEDCAFS (BREEDding Coffee for Agroforestry Systems)[1]. Its goal is to establish a new breeding strategy to create coffee varieties with increased resistance and greater resilience to climate change in agroforestry systems. Coffee is seen here as a model perennial crop; most of the expected results and experience gained on coffee will serve as a basis to improve other tropical perennial crops such as cacao.

Using the new F_1 hybrids of *Coffea arabica* as a case study, the BREEDCAFS project designs and tests coffee varieties that are better adapted to low levels of inputs, to agroforestry systems and to climate change, while maintaining a robust defence system against biotic and abiotic stresses.

The project combines several mechanisms to compare hybrids to cultivated varieties and/or hybrids to their two parents in different scenarios that mimic global warming (increase in CO_2, increase in thermal regime, with or without shading, etc.), either in phytotrons under controlled conditions (in order to test the effects of temperature, light, drought, CO_2 and N_2, for example), as also in field trials, or in networks of plots at producers' locations. It is being implemented in eight countries: Nicaragua, Costa Rica, France (in French Guiana and in greenhouses in Montpellier), Cameroon, El Salvador, Vietnam, Portugal and Denmark. Roasters are involved in the improvement process as assessors of the beverage quality while the producers are involved in field measurements and profitability assessments. In Vietnam, Nicaragua and Cameroon the opinions of producers and roasters are taken into account via dialogue platforms.

Kinds of varieties for agroforestry: hybrids *vs* pure lines

Since *C. arabica* was introduced in Latin America from a very small number of plants, a genetic bottleneck has resulted (Anthony *et al.*, 2002). However, this low initial genetic diversity has given rise to varieties adapted to full-sun conditions, which has allowed their adoption in intensive cropping systems, mainly in Brazil, Colombia and Costa Rica. Nevertheless, the combination of these varieties with high-density crops (often mechanized) and systematic disease control methods has never been adopted in the rest of Latin America and Africa. Coffee plants in these areas continue to be grown under shade without any major technological improvements, with the result that yields are either stagnating, or even declining.

In 1990, CIRAD and its public and private research partners (CATIE[2], Icafé[3], ECOM Trading[4]) created F_1 hybrid varieties that were adapted to agroforestry systems by using a selection process based on cross-breeding of American pure line varieties and wild individuals from Ethiopia and Sudan (Photo 9.1) which were phylogenetically distant

1. www.breedcafs.eu.
2. The Tropical Agricultural Research and Higher Education Center, Turrialba, Costa Rica.
3. Central American Coffee Research Institutes.
4. Ecom Trading is a world leader in the commodities trading business.

(Van der Vossen *et al.*, 2015). It was thus possible to obtain hybrids that helped boost production by 30-60% in agroforestry systems without increasing fertilizer quantities (Bertrand *et al.*, 2011), and also improved aromatic quality (Bertrand *et al.*, 2006). The selection period for F_1 hybrids being significantly shorter than those of conventional pure line varieties (8 years as against 25 years) was also an argument in their favour.

Photo 9.1. F_1 hybrids of *C. arabica* planted in agroforestry systems (Matagalpa, Nicaragua).
© Benoît Bertrand/CIRAD.

The study of the responses of F_1 hybrids to multiple stresses (Photo 9.2) helped better understand of how heterosis (i.e. hybrid vigour) manifests itself in response to environmental constraints. Under shading, the photosynthetic efficiency of hybrids is not only higher than that of pure line varieties but is, in fact, much more stable and stronger (which is what is called homeostasis) under conditions of multiple abiotic stresses (Toniutti *et al.*, 2017, 2019). Homeostasis is actually one of the major components of heterosis in improved plants and in Arabica in particular (Bertrand *et al.*, 2011, 2015).

Since plants exhibit resistance levels to stress in proportion to the amount of energy they possess to cope with it (Kangasjärvi *et al.*, 2012; Ballaré, 2014), it is only logical that hybrids have better resistance to stress. Measurement of the chlorophyll fluorescence (a), by providing access to the functioning of Photosystem II and the electron transport chain, has proved to be an excellent marker of the health status of coffee plants, and is capable of predicting their health and their ability to resist rust. Conversely, the more the photosynthetic efficiency is affected, greater is the oxidative stress. This can be observed in pure line varieties that are less adapted to environmental constraints (Toniutti *et al.*, 2017, 2019).

Photo 9.2. Measurements of photosynthesis on hybrid varieties of *C. arabica* cultivated under shade simulating agroforestry conditions (Teocelo, Veracruz, Mexico). © Luc Villain/CIRAD.

Before the BREEDCAFS project, adaptation to future climatic constraints and low light intensities characteristic of agroforestry systems had never really been a breeding objective and homeostasis of hybrids was used to cultivate them in agroforestry (Figure 9.1). Significant progress in the adaptation of Arabica hybrids to agroforestry systems, and to biotic and abiotic stresses, seems all the more attainable as we can now rely on new tools (genomic, transcriptomic, metabolomic) and on genome sequencing (Denœud *et al.*, 2014).

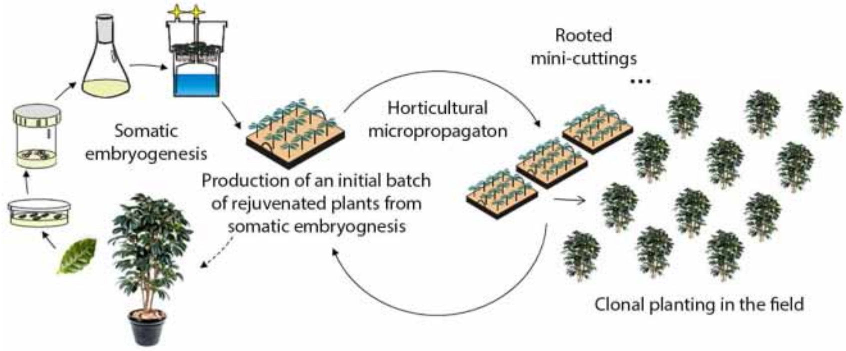

Figure 9.1. How hybrids are vegetatively propagated.

Period	Programme	Selection of F_1 hybrids	Material, selection stages	Selection targets	Expected results
1990-2017	IICA-CIRAD-CATIE-Promecafe, CIRAD-Ecom programmes	Phenotypic selection on F_1 hybrids	American varieties × Ethiopian varieties (wild or traditional cultivars)	Resistance to rust, cup quality, high productivity	
2017-2021	BREEDCAFS, European Union H2020 project	Assisted selection of F_1 hybrids with biomarkers	Identification of robust markers (allelic, epigenetic, metabolic, molecular) for prediction of breeding lines and early evaluation of F_1 hybrids	Adaptation to agroforestry systems and climate change, resistance to diseases, cup quality and high productivity	Early predictors of performance of F_1 hybrids
			Validation of markers with a large population of hybrids and parents grown in agroforestry systems		Prediction of the best parents in a large panel of genotypes
2019 -	New model of international governance to be found (private and public partners)	Selection based on new 'omic' tools for predicting heterosis and adaptation to agroforestry	Evaluation and selection of BREEDCAFS F_1 hybrids	Adapted to agroforestry systems and climate change	Worldwide distribution and accessible by all coffee growers. Varieties adapted to agroforestry and climate change

Figure 9.2. Towards a new selection strategy for F_1 hybrids of *C. arabica*.

Figure 9.2 schematically shows the changes proposed by the H2020 BREEDCAFS project during the hybrid breeding process. The goal is to evolve from a phenotypic selection to a genome-based selection. *Coffea arabica* is a polyploid species with reduced genetic diversity. BREEDCAFS offers software for the analysis of polymorphisms of polyploid species. This software will be used for detecting markers, and can also be easily adapted for the analysis of epigenetic data. Variations in (epi) genetic markers between reciprocal F_1 hybrids and their parents cultivated under various environmental conditions are sought and linked to the ideotypes identified in experimental and field trials. These data are used to predict genotype-phenotype-environment interactions for expected complex traits.

Improving selection tools and methods

The goal of BREEDCAFS is to move from an exclusively phenotypic breeding of hybrids to a breeding assisted by genomic and transcriptomic tools (Figure 9.3).

Figure 9.3. Implementation of a horticultural vegetative propagation process using rooted mini-cuttings from rejuvenated plantlets of *C. arabica* derived from somatic embryogenesis.

a: 15-week rejuvenated plants obtained by somatic embryogenesis and planted in plastic boxes
b: Plantlet cuttings from somatic embryogenesis
c: Planting of mini-cuttings in honeycomb plates
d: Rooted mini-cuttings obtained after 6 weeks of acclimation in the greenhouse
e: 8-week rooted mini-cuttings with horticultural substrate lumps
f: 8-week rooted mini-cuttings with bare roots
g: Rooted mini-cuttings after 3 months of hardening in the nursery
h: Rooted mini-cuttings after 6 months in the nursery and ready for transfer to the field plot.

Using transcriptomic and transgenic approaches, candidate genes involved in drought tolerance in *Coffea canephora* and *C. arabica* have been identified (Marraccini *et al.*, 2012; Mofatto *et al.*, 2016; Alves *et al.*, 2017, 2018; Torres *et al.*, 2019). By coupling the phenotypic, ecophysiological, transcriptomic and biochemical approaches, the detection of biosynthetic pathways that are over- or under-expressed during adaptation phenomena (primary or secondary metabolic genes, photosynthesis, photoprotection, volatile green coffee compounds) will help reveal marker genes that can be used in the selection. In addition, a more traditional approach to finding genomic selection tools is also being implemented.

Box 9.1. The transcriptomic approach to coffee breeding

The environment is used as a source of variation to identify correlations between gene expression and growth characteristics (QTT or Quantitative Traits Transcripts) linked to shading adaptation. The use of environmental variations to identify QTTs has been proposed by Passador-Gurgel *et al.* (2007), in the case of the resistance of drosophila to nicotine, and applied by Joët *et al.* (2009) to determine the accumulation of chlorogenic acids in coffee seeds. This method is based on the principle that the environment is a powerful factor that modulates gene expression levels and thus allows the detection of QTT correlated to the measured character. This approach is suitable for an allopolyploid plant with little polymorphism.

The adoption of varieties by producers

In an agri-chain characterized by strong conservatism, what are the reasons that can convince producers to adopt new varieties?

An increase in productivity can be a motivation because it is necessary in agroforestry systems. This requires more productive varieties that are different from those currently used. We have been witness to a massive varietal change over a period spanning less than a decade. This change has taken place in the context of the great rust crisis (McCook and Vandermeer, 2015), by making use of the 'Catimors', 'Sarchimors' and 'Castillo' introgressed pure line varieties, which are reputed to be strongly resistant to leaf rust. Unfortunately, the disease is overcoming the resistance of these varieties. The search for new resistance genes has not been successful for many years, except in Colombia. Consequently, producers will be left with only two choices in the near future: either resort to a solution of a systematic and expensive phytosanitary umbrella based on fungicides that pose a danger to the environment; or use an intermediate solution by planting hybrid varieties, which are also sensitive, but are more tolerant and resilient (Toniutti *et al.*, 2018, 2019). Rust outbreaks can be controlled with copper treatments (approved in organic farming) on these susceptible hybrid varieties.

Certain conditions must be satisfied for a successful renewal of coffee plantations with hybrid varieties. We review them here.

Organization and guarantees of a seed chain

Once a coffee variety has been created by breeders, we must be able to reproduce it on a large scale in a consistent manner, and be able to provide it to producers at an affordable price (Bertrand *et al.*, 2012; Figure 9.4).

In Costa Rica, Honduras, Colombia and Brazil, for example, State agencies or cooperatives distribute seeds (beans) of pure line varieties of very good germinal quality, and a varietal purity of 90-95%, at a subsidized rate of US$ 8/kg, or about US$ 15/ha.

In other countries, coffee growers rely on non-certified seed producers, which puts them at risk in terms of varietal purity (very heterogeneous seeds due to mixtures and cross-pollination), of highly variable germination depending on the batch, of poor productivity, and of uncertain coffee quality, which can sometimes be well below the standard.

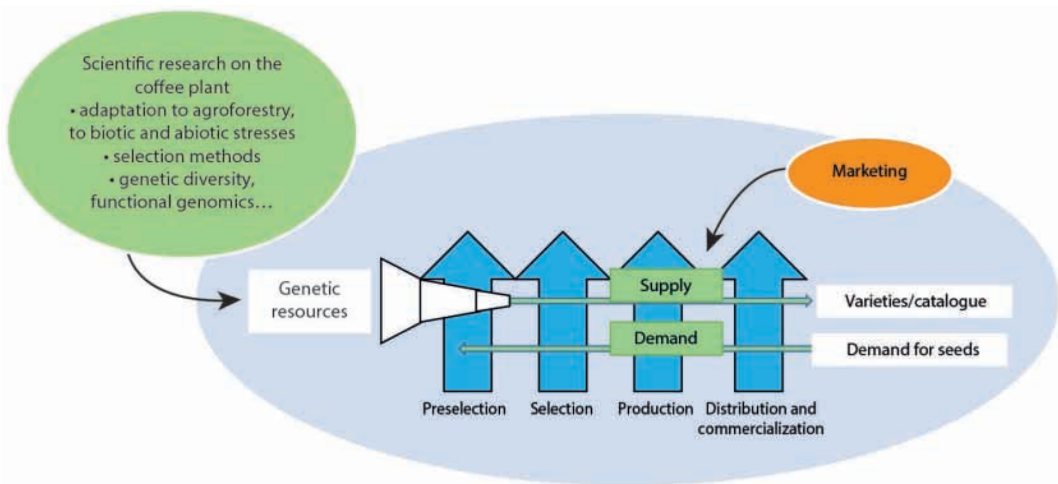

Figure 9.4. Varietal creation process of *C. arabica* for adaptation to agroforestry and climate change. It can basically be broken down into research in plant science, conservation and utilization of genetic resources, followed by stages of pre-selection, selection (with a necessary step of multi-local field validation), seed production and marketing.

The BREEDCAFS project assumes that, in a context of climate change, the best varieties for agroforestry systems are F_1 hybrids of *C. arabica*. The dissemination of these F_1 clones, however, poses new commercial and logistical problems. These varieties, which are propagated by vegetative propagation (and not by seeds), must be delivered in the form of developed plants, at the lowest possible price, to small producers, who often live in remote and mountainous areas.

The lack of a seed chain for F_1 hybrid clones (described above) is even more serious since no State or private organization (apart from the CIRAD/ECOM alliance on Arabica) is currently disseminating these new varieties. It should also be noted that, until recently, the production cost of a ready-to-be-planted F_1 hybrid plant (US$ 0.70-0.80) was much higher than that of seed-grown seedlings (US$ 0.15-0.20), which has greatly limited their dissemination.

To sum up, there are four major stumbling blocks to the dissemination of F_1 hybrids:
- the high plant cost;
- the logistical problems in reaching small producers;
- the need for certification of the plant production chain;
- the lack of financial means of small producers.

Horticultural solutions to lower the cost of F_1 seeds

The general idea is to professionalize the coffee seed sector so that clones of F_1 hybrids can be produced in large quantities (several tens of millions each year), with 100% traceability, an excellent horticultural quality and following a well-defined technical itinerary (high-tech greenhouses and certified nurseries using inert substrates).

The CIRAD/ECOM alliance produces a few hundreds of thousands of F_1 hybrids each year using somatic embryogenesis (Etienne *et al.*, 2012, 2016, 2018; Bobadilla-Landey *et al.*, 2013). The recent development of the propagation of horticultural rooted mini cuttings (Georget *et al.*, 2017) has increased the number of plants produced from a somatic embryo (by a factor greater than 10), and thus cut the cost of producing a hybrid plant by half, as compared to a plant directly derived from a somatic embryo. With the CIRAD/ECOM alliance having shown the way with this production model, we believe that this technology to produce hybrid F_1 plants of *C. arabica* can be replicated by the horticulture industry, as is the case with other plants (ornamental plants, fruit trees, forest trees, etc.). This would lead to plants being offered at competitive rates (US$ 0.40-0.50/plant), given the high productivity of these clones.

Seed cooperatives for remote areas

Given that remoteness and distance can make industrialization unviable, we have developed the technique of mini cuttings in rural areas (Etienne *et al.*, 2018). We have set up seed cooperative networks on the pattern of farmers' seed systems, which are especially adapted to reproduction from seeds. The horticultural technique of rooted mini cuttings is thus transferred to women's cooperatives in order to:
- reduce the production cost of mini cuttings;
- reduce inequalities between men and women;
- promote access to F_1 hybrids and popularize their use.

This experiment was set up as part of the BREEDCAFS project in three very different contexts: those of Vietnam, Cameroon and Nicaragua[5].

Starting from a small number of initial explants from a certified seed producer and renewed every year, the women's cooperatives take up the reproduction of mini cuttings, and their marketing to producers in the area. The cooperatives also undertake to pay a royalty every year in order to acknowledge the rights of the breeder.

Seed certification: a guarantee for the industry

This process has been initiated since 2003 by the CIRAD/ECOM alliance in Nicaragua, Mexico and Costa Rica. The industry is fully cognisant of the value of this

5. http://www.snv.org/update/press-release-project-breedcafs-nicaragua-advances (retrieved 4 May 2019).

approach and has created and financed, since 2015, the World Coffee Research (WCR) not-for-profit organization. Programmes were set up to verify varieties and production nurseries, e.g. the 'WCR Verified programme'[6]. This is the first global standard for coffee plants to ensure that producers of coffee seeds or clones of *C. arabica* F_1 hybrids, and associated nurseries, produce healthy and genetically pure plants.

A fair price for a supply guaranteed in terms of quantity and quality

In times of a price crisis, or when production costs are too high, or when the terms of trade are too unfair, small producers adopt non-investment strategies that have a significant and long-lasting impacts on yields and quality. At the same time, medium-sized producers who have taken usurious bank loans are ruined and sometimes even abandon their farms. Thus, uncertain terms of trade, price volatility and low productivity undermine the modernization of the coffee agri-chain and contribute to its loss of competitiveness. This eventually results in the undermining of the entire value chain. The best example is Mexico, a leading economy but whose coffee sector, mostly comprising of agroforestry systems, is arguably one of the least productive and least profitable in the world.

The fair-trade solution was successfully applied to small coffee growers in Mexico (Van der Hoff, 2010). This solution was then adopted for many commodities around the world. However, it is now clear – despite significant impacts on producers' living standards – that fair trade is not enough for an in-depth modernization of coffee cultivation. In addition, this solution is available only for small producers (less than 5 ha). We believe that the real challenge is to increase farm profitability. This not only requires a per-hectare increase in productivity, but also an increase in the value derived from the product.

Varietal innovation to ensure the profitability of agroforestry coffee systems

The variety as a tool for traceability and differentiation

The basis of this concept is that the variety and the coffee it produces become a tool for traceability, and an instrument of differentiation because of its relative novelty. Indeed, since there are very few varieties[7], any new one not only introduces new characteristics of resistance, productivity, and cup quality, but also a unique genetic heritage that modern genetic marking techniques are able to identify, not only in green coffee but also in roasted coffee (Morel *et al.*, 2012). The ability to trace the product through the entire agri-chain, including up to the stage of roasted coffee, is a unique tool to guarantee the origin, practices and, possibly, maintain the rarity of the product, which will ensure a demand for it from buyers who wish to offer something new to consumers.

6. https://worldcoffeeresearch.org/work/seed-and-nursery-verification-program (retrieved 4 May 2019).
7. https://varieties.worldcoffeeresearch.org.

The 'Business driven' agroforestry cluster: a new integrative approach

The general idea behind this approach is to promote the creation of clusters. A cluster is a group of producers in a given territory who come together to produce coffee that is compliant with environmental and agronomic standards and is 100% traceable. Quality levels and quantity to be produced are set according to the coffee company' requirements, which, in return, commits to a minimum price. Agroforestry clusters comply with strict specifications concerning the planting of shade trees (number, diversity per hectare), with associated environmental services, on a given terroir. They promote as much direct trading as possible to offer a consistent product that corresponds to the standards required at the end of the agri-chain by the industrial roaster which markets the product according to its high quality standards. The set of environmentally responsible practices, the terroir, the practices of a more equitable trade, and the sensory qualities specific to the variety, possibly improved by post-harvest processing, result in the creation of a coffee that is not only high in quality, but is also distinctive.

The 'Business driven' agroforestry cluster is thus: a terroir + agroforestry practices (UTZ and/or Rainforest certified) + fully mastered post-harvest processing + a certification + 100% traceability.

A prototype cluster of 1350 ha[8] was set up in Nicaragua around the 'Marsellesa' variety (a CIRAD-ECOM variety) to produce an exceptional coffee for industry (Nespresso's Master Origin Nicaragua capsules). The concept is applicable across countries. This model is intended to be replicated on new terroirs, for projects of 1000 to 2000 ha and a minimum annual production of 2500 tonnes of coffee, the minimum amount necessary to justify the investments necessary.

Perspectives

The development of sustainable and profitable agroforestry systems for coffee cultivation involves the selection and adoption by planters of new hybrid Arabica varieties adapted to low light conditions characteristic of agroforestry. This requires a better understanding of molecular processes that underpin a better adaptation to shading, in order to redefine selection targets, and create specific tools and methods. The example of *C. arabica* can be used by other agri-chains to offer varieties that are better adapted to agroecology. This is the case for the majority of tropical perennial crops. However, because of future climatic and epidemic challenges, and also to differentiate itself, and preserve biodiversity, it is necessary to not only create new varieties continuously, but also to produce them, market them and encourage their adoption by producers and industry alike.

For coffee, the research community, coffee companies and producers have collectively started to find solutions. While these solutions are still not perfect, they represent

8. https://www.moringapartnership.com/cafetalera-nica-france and https://www.oikocredit.coop/what-we-do/partners/partner-detail/46387/nicafrance-nicaragua-outgrower-holdings (retrieved on 15 April 2019).

significant progress. Finally, governance rules proposed for the coffee agri-chain must respect the rights of the countries that own the genetic resources (notably Ethiopia, Côte d'Ivoire, Central African Republic, Gabon, Cameroon, Angola, Democratic Republic of the Congo).

The BREEDCAFS project also aims to study the conditions required for the emergence of a seed industry for coffee-based agroforestry systems, while proposing rules governing the ethics and common governance for the conservation and access to genetic resources, and the creation and dissemination of varieties. This example of research into comprehensive governance of an agri-chain should inspire similar initiatives for other tropical perennial species.

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