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Arabica coffee (*Coffea arabica* L.) local landrace development strategy in its center of origin and diversity

Bayetta BELLACHEW[1] and LABOUISSE Jean-Pierre[2]

[1] Jimma Agricultural Research Center, Jimma, Ethiopia, P.O.Box 192, e-mail: bbellachew@yahoo.com [2] CIRAD, Montpellier, France

Abstract

Arabica coffee (*Coffea arabica* L.) breeding and selection methods applied everywhere to improve production, productivity and quality are generally the same. However, the application of these methods may vary from country to country depending on the amount of genetic variability available, ecological conditions and research focus or prevailing production constraints of the country. Ethiopia is the center of origin and diversity of arabica coffee. The country is ecologically very diverse and coffees grown under these environments are different in quality, disease resistance, yield potential and many other traits. Development of breeding strategy that fits to these conditions is of paramount importance to exploit all the available advantages. In the past, the interest was to develop varieties that have wider adaptation and distribute to all coffee growing areas. However, it was realized that distribution of such limited varieties to all coffee growing areas adulterates the typical quality of each specific locality or region, manifested poor adaptation and less preference by the local farmers compared to their respective local cultivars. A new breeding strategy, known as '*Local Coffee Landrace Development Program*', was designed to alleviate these problems. The new approach is aimed at development of varieties for each specific agro-ecology using the respective local landraces and this is elaborated in the text.

The collection of local landraces and the establishment of seven research centers (Jimma, Agaro, Gera, Tepi, Awada, Haru and Mechara) that represent different agro-ecological zones of the major coffee growing areas have greatly facilitated the implementation and effectiveness of the new program. Currently, landraces roughly amounting to 1900 accessions from Harerge, 350 from Sidamo, 590 from West Wollega, and 200 from Limmu have been collected and established at the research centers available in the respective areas. Systematic evaluation of some part of the accessions in a crash program resulted in the identification of over 26 promising selections for three agro-ecologies in five years, a quite short time. The selections were advanced to verification trial to confirm their performance before recommending for release as pure-line varieties for each agro-ecology. The implication of the new breeding strategy in promoting market oriented research and specialty coffee, the significance of hybrid development for increased yield and productivity and the focus of future breeding are discussed.

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1. Introduction

Arabica coffee (*Coffea arabica* L., Rubiaceae) originates from the South Western montane rainforests of Ethiopia where it has its center of genetic diversity and grows as an understorey (Sylvain, 1958; Tadesse et al., 2001; FAO, 1968). In Ethiopia, arabica coffee grows under very diverse agro-ecologies covering ranges of altitude (500m in the Gambella plain to 2600m in Wollo, Northern Ethiopia) (Bayetta, 1987; Mesfin et al., 1987), temperature (min. 8 – 15 ^{o}C, and max. 24 – 31^{o}C), rainfall (800 to 2000 mm) (ZEF and EARO, 2002), humidity (60 – 80 %), and soil types. The coffees grown under these diverse environments showed wide genetic variations within and between populations of different regions or environments for yield, quality disease resistance and other traits.

The availability of such genetic variations provides immense possibilities for improvement of the crop for any desirable traits of interest. On the other hand, the presence of such high environmental diversity, distinct variation in coffee quality within and between regions or localities (CTA, 1999) and location specificity of our improved varieties (Mesfin and bayetta, 1987) make the breeding program more complex. The coffees from Harerge, Limu, Sidamo, Yirgachefe, and Gimbi, for example, have distinctly different quality attributes and fetches premium price in the world market. The CBD resistant varieties originated from south western Ethiopia did not adapt to Harerge and many other areas and farmers were reluctant to grow them except in southwestern areas. There fore, it would be difficult to easily obtain varieties that have wider adaptation and at the same time maintain the typical quality of each particular area. This challenge was an impetus for the development of a new breeding strategy that alleviates these problems, best fits to the Ethiopian conditions and enables to exploit all the available advantages of ecological and genetic diversities. In effect, a new improvement strategy known as '*local landrace development program*' has been initiated and the objective of this report is to provide a brief account of this approach in relation to the conventional method.

2. Arabica coffee breeding methods in Ethiopia

Arabica coffee breeding principles and methods applied in different coffee growing countries and the overall objectives, improved productivity and quality, are generally similar. Van der Vossen (1985, 2001) distinguished four basic methods – pure-line selection, pedigree selection, hybridization (intraspecific F1 hybrids), and interspecific hybridization followed by backcrossing and pedigree selection. However, the application of these methods may vary from country to country depending on the amount of genetic variability available, ecological conditions and prevailing production problems. In Ethiopia, pure-line selection and intra-specific hybridization are commonly used.

2.1 Pure-line selection

The coffee breeding program in Ethiopia was initiated in 1969 with the local coffee collections made available by the French coffee collection mission (ORSTOM) to Ethiopia in 1966. Since then, a lot of experience had been gained and considerable improvement had been made in developing proper breeding methods and procedures that best suit to

Ethiopian conditions. Specifically, the pure-line variety development approach has been greatly improved.

2.1.1 The conventional approach (1969 – 1993) – In this approach, there were national and international collection programs. All the materials made available through local collections from different areas and introductions from abroad are first screened at one location, Jimma Agricultural Research Center (JARC) for yield, diseases, quality and other desirable agronomic traits. Materials that exhibited superior performance for yield and other characters are selected for advanced replicated multi-location trials in different parts of the country to test their adaptability and repeatability. The best selections are further verified in their respective areas of adaptation on a larger plot size under farmers condition. Selections that pass the final verification test are released as a new variety upon approval by Standing Committee on Coffee Research (SCCR). This process is so long particularly for perennial crops like coffee that it is known as 'long-term program'.

On the other hand, the outbreak of CBD in 1971 in Ethiopia had forced us to also develop short-term program and release CBD resistant cultivars in the shortest time possible. This program is sometimes known as 'crash program' and was developed by Robinson (1974). It was called 'crash' because the normal procedure was ruled out and multiple step-wise activities were simultaneously undertaken to shorten the period of selection. This crash program involves mother tree selection, testing of the mother trees *in situ* and the progenies in the nursery and field. Selections that exhibited high level of resistance during mother tree and seedling progeny testing are immediately established in a large progeny block in order to distribute seeds as soon as a selection passes the final test.

The conventional method of screening at one location reduces initial cost of selection and facilitates close supervision of the experimental field and effective data collection. On the other hand, this method had several drawbacks: (1) difficulty to develop a number of varieties that adapt to all environments, (2) low preference of the released varieties by the local farmers when released to all areas, (3) adulteration of the typical quality of specific and known areas by introducing improved varieties originated in other areas.

2.1.2 The new (modified) approach (since 1994) – Cognizant of the aforementioned drawbacks noted with the conventional approach and the environmental diversity of the major coffee growing areas, a new breeding strategy has been designed for the first time by Bayetta Bellachew, senior coffee breeder, while preparing ten-years development plan during the 'Derg' regime, earlier to 1991. This new selection and breeding strategy is known as **'***local landrace development program***'.** In this program, varieties are developed for each major agro-ecology or coffee growing area independently based on local landrace collections of the respective areas. The basic assumptions are that (1) local landraces have better adaptation in their areas of origin than cultivars introduced from other geographical and ecological origins, (2) farmers show more preference for local cultivars than those improved varieties introduced from other areas, (3) it is possible to maintain the typical quality of each locality and (4) it is market oriented in a sense that consumers preference

for a specific locality can be maintained and origin based diversity of specialty coffee can be produced.

2.1.2.1 Strategies for the implementation of Local Landrace Development Program:

Since the previous conventional approach largely focused on the development of widely adapted varieties, improved local varieties for each specific agro-ecologies are lacking in most of the coffee growing areas. This necessitated accomplishment of two major tasks : (a) designing of quick germplasm screening and selection methods in order to develop improved varieties using local landraces in the shortest time possible for the respective localities and (b) land acquisition and establishment of new sub-centers and renovation of existing ones in the major coffee growing areas, namely Sidamo, Wollega, Harerge and South Western (Kaffa, Jimma and Illubabor).

a) Germplasm screening and selection methods – A crash program (short-term) and long-term selection programs were developed in order to provide improved varieties in the shortest time possible and in the long-term, respectively.

The crash program –In this crash program, mother trees are selected from the forest or garden coffee for CBD resistance and other desirable traits and marked, the marked mother trees are evaluated *in situ* for one or two seasons for yield and CBD resistance. Simultaneously, seeds are collected for progeny testing for two seasons in glass house (seedling test) and in replicated field trials (Table 1). The plan was to collect enough and reliable data within five years in order to identify CBD resistant materials with good yield, quality and growth performance that can be recommended for release. The varieties released on the fifth year can be multiplied through tissue culture for immediate distribution to growers, but establishment of seed orchard should commence simultaneously for sustainable and cheaper distribution of seeds.

The long term program – under normal process, the long term plan in coffee takes a minimum of 15 years if variety trial and verification trials are merged. However, if the screening (9 years), variety trial (6 years) and verification trial (5 – 6 years) are separately carried out in that order, the duration will prolong up to 20 years to release a pure-line variety. Considering the present situation where improved local varieties for different coffee growing areas are lacking, a **modified long term program** has been designed to shorten the duration and release local varieties for each locality in a relatively shorter period. In this program, it is designed to make the first screening in five years and advance the selections to verification trial but still continuing data collection on the original plot as well (Table 2). In doing so, six years yield data from the original plot and two years yield data from the verification plot shall be obtained in eight years. This will provide sufficient and reliable data on yield, disease resistance, quality and other parameters to select the best variety for release.

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Table1. Strategy for the crash program designed to release CBD resistant selections within five years

Year	Activities	
	Mother tree	Progeny
1	Mother trees selection, evaluation for CBD (visual,ABT,ST) and yield estimation	Seed sowing
2	Evaluation: ▸ CBD – visual$_2$, ABT$_2$, ST$_2$ ▸ Yield est.$_2$	Transplanting and field management
3	–	Field management
4	–	Evaluation - Yield (1st crop), CBD
5	–	• Evaluation - Yield (2nd crop), CBD, growth, quality • Data summarization and variety release

ABT=attached berry test, ST=seedling test, CBD=coffee berry disease

Table 2. Strategy designed to implement the modified long-term program in eight years.

Year	Activities	
	Original plot	Verification plot
1	Germplasm collection and Planting	-
2	Maintenance	-
3	Recording (year 1)	-
4	Recording (year 2)	-
5	Recording and selection (year 3)	Multi-location planting in large replicated plots
6	Recording (year 4)	Maintenance
7	Recording (year 5)	Recording (year 1)
8	Recording (year 6)	Recording (year 2)

Note: Recording refers to collection of data for yield, major diseases, growth characters, quality and related observations

The other interesting advantage of the modified long-term program is that three important step-wise operations are simultaneously conducted – verification, local adaptation or variety trial and seed orchard establishment. In effect, 10 – 15 best and promising selections are planted in three replications over two or three locations in large progeny plots of 150 trees per plot within each agro-ecology to accommodate the three activities in one trial.

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b) Establishment of research centers in different agro-ecologies – The availability of research centers in each of the major agro-ecologies is the most important factor to implement the local landrace development strategy. Therefore, it was deemed necessary to renovate the existing sub-stations and establish new sub-centers in order to represent the major coffee growing areas or agro-ecologies. Different externally funded projects have been initiated at different times to materialize the proposed plan. The fund raised through Ethio-Swiss Coffee Research Project (ESCORP) financed by Switzerland government and third and fourth coffee improvement projects (CIP III, CIP IV) both financed by European commission (EC) has enabled to establish new sub-centers namely Awada in the South (Sidamo) in 1997, Haru in western Wollega in 1998 and Mechara in Harerge in 2005, respectively. Today there are five coffee research sub-centers and four testing sites established across the major coffee growing areas all representing different agro-ecology (Table 3).

Table3. Coffee Research Sub-centers and testing sites established in the major coffee producing areas.

Research Center	Year established	Altitude (m.a.s.l)	Land holding (hectare)	Location (zone, region)
Main center - Jimma	1967	1753	183	Jimma, Oromia
Sub-centers				
• Gera	1974	1900	166	Illubabor, Oromia
• Tepi	1976	1200	40	Bench-Maji, Southern
• Awada	1997	1740	31	Sidama, Southern
• Haru	1998	1750	69	West Wollega, Oromia
• Mechara	2005	1800	50	West Harerge, Oromia
Testing sites				
• Agaro	1973	1630	15	Illubabor, Oromia
• Mettu	1974	1550	32	Mettu, Oromia
• Mugi	1973	1553	27	West Wollega, Oromia
Wonago	1974	1850	10	Gedeo, Southern

2.1.2.2 Progress in local landrace development program

i) Germplasm collection and maintenance – The long-term national and international coffee germplasm collection program was launched in 1970. Collections were made using random and with major emphasis targeted or pointed collection methods in order to capture as many genetic variability as possible and also to capture desirable genotypes *per se* for immediate breeding work, respectively. So far about 5127 accessions have been collected from different coffee growing areas of the country and maintained at Jimma and its sub-centers, but some (approximately 200 – 300) of them have died from poor establishment,

overbearing die-back and diseases (Table 4). In the international collection program about 190 material which includes 28 rust differentials, 6 diploid species and 156 known international arabica varieties have been introduced. The introduction from abroad ad been discontinued since 1984 because of poor performance of the varieties compared to the locals and death of most of them from poor adaptation and disease problems except that variety Geisha and Catimor lines did well at lower altitudes of Bebeka and Tepi.

Table4. Germplasm collection and maintenance

Maintenance and testing site	No of accessions	Duration of collection	Remark
Jimma	802	1970 – 1990	Collections from various areas
	190	1969 – 1984	Introduced arabica varieties, some diploid species and rust differentials from abroad
	172	2004	Bale landrace collections
Jimma, Mechara	1863	1998 – 2002	Harerge coffee landrace collections
Gera	973	1973 – 1982	CBD resistant mother trees from south western ethiopia
Awada	499	1994 – 2005	Sidamo coffee landrace collections
Haru	591	1998 – 2001	Wellega coffee landrace collections
Agaro	187	2001 - 2005	Limmu coffee landrace collections
Total	5317		

ii) Germplasm Evaluation and Variety Release – Once the genetic variability (germplam) is at hand, the next step is to evaluate the germplasm for yield, quality, disease resistance and other desirable traits in a series of trials (screening, variety trials and final verification test) over years to come up with a new variety. At present, there are 22 pure-line varieties that have been released through the conventional approach (Table 5). The release of varieties through the new approach, local landrace development program, is at early stage. However, because of the envisaged 'crash' and 'modified long-term' programs, one variety has been released for Sidamo area (Gedeo and Sidama zones) and a number of promising selections are under verification for Sidamo, Wollega, Limmu and Harerge coffee growing areas.

2.2 Hybridization: Intraspecific F_1 hybridization

Hybridization is a means of aggregating two or more desirable traits in to a single plant. However, while making crosses, it is necessary to know that the desirable traits from different parent sources are dominant over the accompanying contrasting undesirable traits in order to exploit the advantage of F_1 heterosis. In Ethiopia, sets of crosses have been

made between different elite local cultivars to study heterosis for yield, components of yield and resistance to CBD, the most important traits of breeding interest.

From the hybridization program, it has been learnt that there is considerable and consistent degree of heterosis in crosses among elite local cultivars that can be exploited in commercial production as noted in different sets of crosses and under different locations (Table 6). These results were the base to determine a proper breeding method that follow development of pure-line varieties followed by further improvement of the productivity and growth of the elite cultivars through intra-specific hybridization for each agro-ecology. So far three heterotic hybrids with good yield, quality and moderate resistance to CBD have been released.

In the national coffee breeding program, one of the major challenges was the outbreak of CBD in 1971. A selection program for resistance was developed and it was so successful because of the proper strategy developed and availability of high genetic diversity in the population. In the case of breeding for resistance to the disease, as in any other breeding program for disease resistance, the primary step was to study the mode of inheritance of resistance to the disease and determine the best method of breeding. In effect, crosses were made between resistant, intermediate and susceptible parents using six-parents diallel cross in the F_1 (Mesfin and Bayetta, 1984) and F_2 (Bayetta, 2001) generations.

Table 5. Varieties released and those in pipe-line for different agro-ecology

Variety	Target areas and year released	No of Varieties	Yield (qt/ha)	
			Res. plot	Farmers field
Pure-lines released	All coffee growing areas,1978 – 81	13	12 – 20	8 – 10
	Low and mid-alt., SW Ethiopia, 1997 – 2002	5	18 – 21	9 – 15
	High altitude CBD prone areas of SW Ethiopia, 2005	4	15 – 23	15 – 17
	Gedeo and Sidama zones, Southern Ethiopia	1	20	16.0
Pure-lines in pipe-line	Sidamo, S. Ethioipia	12	Under simultaneous variety and verification trials plus seed garden establishment	
	West Wollega, W. ETH	14		
	Harerge, E. Ethiopia	14		
	Harerge (Crash)	82	Under simultaneous mother tree and progeny tests	
	Limu area, SW Ethiopia (crash)	197		
2. Hybrids	SW Ethiopia, 1997 – 2002	3	24 – 26	15 – 24
Total		26		

In both generations, mean grade susceptibilities of the crosses resistant x susceptible and moderately resistant x susceptible showed significantly higher levels of susceptibility over the mid-parent values and negative, but non-significant differences compared to their susceptible parents. The result indicated that there was partial to complete dominance of the susceptible alleles over the resistance alleles in the population studied and that the favorable character, resistance, was controlled by recessive allele(s) of the relevant gene(s). Based on this information a breeding strategy that follows selection for resistant and high or medium yielding cultivars and intra-specific crosses among the cultivars for further improvement of yield and growth characters was designed and implemented.

Table 6. The expression of heterosis in different sets of crosses among elite indigenous cultivars

Set	Breeding objective & traits observed	Better parent heterosis (%)		F_1s & parents (No)
		Range	Mean of F_1s	
I (1978)*	Test for hybrid vigor			10 (5)+
	• Yield	-8 – 60	17.4	
	• Stem girth	-2 – 12	5.0	
	• Length of 1st pr.br.	-2 – 10	2.4	
II (1989)	Heterosis & parental diversity			15 (6)
	• Fresh yield	9.0 – 70.8	53.0	
	• Clean yield	9.6 – 90.5	57.5	
	• Girth	-2.4 – 16	10.2	
	• Length of 1st pr.br.	-3.2 – 15.3	4.0	
	• Plant height	-4.9 – 13.9	2.3	
III (1995)	Test Sidamo x SW crosses			10 (5)
	• Yield	-7.9 – 79.1	35.1	
IV (1996)	Yield & quality improvement			15 (6)
	Yield – Jimma	0.1 – 42.7	18.3	
	– Mettu	14.1 – 57.3	32.7	
	– Tepi	38.2 – 103.8	74.3	

*, + Figures in parenthesis indicate the year the experiment was initiated and number of parents employed, respectively

2.3 *In vitro* breeding

The main interest in the breeding program here was to assist the conventional breeding program in reducing the long cycles in coffee breeding and to multiply true-to-type F_1 hybrids for distribution to growers. However, this program was at its very early stage and not well developed in trained human power and facilities. Currently, only tissue culture protocol optimization is under way even though screening for disease resistance at callus level, germplasm characterization (fingerprinting), and identification of markers for important traits are in the plan.

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