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Progress in Arabica Coffee Breeding in Ethiopia: Achievements, Challenges and Prospects

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Abstract

Coffee belongs to the family *Rubiaceae*and the genus *Coffea*. Only two species, *Coffea arabica*L. and *Coffea canephora*Pierre, are economically important and widely cultivated in the world. *Coffea arabica*L. is believed to have originated in the highlands of south western Ethiopia where it has its center of genetic diversity. The availability of wider genetic variation among endogenous coffee types provide immense possibilities to improvement the crop for any desirable traits of breeding interest. In cognizant to this, coffee breeding program was initiated in1970's where Coffee Berry Disease (CBD) occurred in Ethiopia for the first time. Germplasm collection, selection and hybridization methods of breeding have been followed since the commencement of the breeding program. In effect, outstanding achievements have been recorded in assembling of 6721 accessions, generation of basic information on genetics of Arabica coffee and release of 40 improved varieties of which six are F1 hybrids. The details of the achievements, challenges and prospects are discussed in this paper.

Key words: coffee; Germplasm; collection; selection; hybridization; pure-line; hybrid; variety.

1. Introduction

Coffee belongs to the family *Rubiaceae*and the genus *Coffea* [1]. Earlier studies have indicated that the genus C*offea* consists of 90 to 100 species [2].

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However, recently [3] reported that 124 species have so far been identified in the genus. However, only two species, *Coffea arabica* L. and *Coffea canephora*Pierre are economically important and widely cultivated in the world. *Coffea arabica* L. is believed to have originated in the highlands of south western Ethiopia where it has its center of genetic diversity [4, 5]. In Ethiopia, Arabica coffee grows under very diverse agro-ecologies and wider ranges of altitudes, temperature, rainfall, humidity and soil types [6]. The coffees grown under these diverse environments showed wide genetic variations within and between populations of different regions 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 [5]. Coffee is by far Ethiopia's most important export crop which accounts the lion's share of the foreign exchange earnings of the country Furthermore, the livelihood of some 15 million people directly or indirectly depends on coffee [7, 8].

To exploit the potential genetic variability that the country is gifted for coffee research in Ethiopia was started in early 1968s at Jimma Agricultural Research Center (JARC) [9]. Even though some germplasm collection was made at the beginning as a starting material, strategically well designed coffee breeding program was initiated in1970's where Coffee Berry Disease (CBD) occurred in Ethiopia for the first time. Since then, efforts have been made to develop improved varieties with high yield, disease and insect pest resistant/tolerant and good overall quality. Outstanding results have been achieved from the coffee breeding program through implementation of different improvement strategies [9, 10, 11]. Therefore, the objective of this paper is to review the progress, achievements, challenges/gapes, and future prospects of coffee breeding program in Ethiopia.

2. Arabica Coffee Breeding Methods in Ethiopia

Similar Arabica coffee breeding principles and methods has been applied in different coffee growing countries around the world with the ultimate objectives of improved productivity and quality. However, the application of the methods may vary from country to country depending on the amount of genetic variability available, ecological conditions and prevailing production problems [10, 12]. In Ethiopia, pure-line selection and intra-specific hybridization methods of breeding are commonly used in the Arabica coffee breeding program, emphasizing on germplasm enhancement, development of improved varieties through selection for disease resistance and insect pest tolerance, high yield, quality and adaptation to diverse agro ecologies. Accordingly, outstanding achievements have been recorded that played significant role in the coffee production and productivity in the country [9, 13, 14,15].

3. Breeding for Disease Resistance

As a result of the outbreak of CBD in Ethiopia during the 1970s, well designed breeding program was initiated for the first time focusing on developing resistant varieties for the disease. As Ethiopia is the center of origin and genetic diversity of Arabica coffee, initial emphasis of the breeding program was to develop CBD resistant varieties within the shortest time possible through selection breeding from the natural population. Accordingly, a crash breeding program where different conventional breeding steps are conducted simultaneously was designed and launched in 1972/73. Efficient program had resulted in selection of 696 mother trees with less than

5% infection to CBD under the natural condition. Subsequent evaluation of the mother trees at their place of origin and the progenies at laboratory and experimental plots through artificial inoculation of the pathogen, 218 promising selections were identified of which 13 CBD resistant varieties were released (Table 2) within five years (1972-78) for the first time in the country. Considering the devastating nature of the disease and its occurrence in all major coffee producing regions of the country, seed multiplication and distribution to the farmers was carried out immediately after the release of the varieties [16, 17, 18]. The release of these varieties have played significant role in the coffee industry in the country and the varieties are still under production at diverse Agro ecologies without breaking of resistance to the disease.

4. Breeding for Overall Improvement of Arabica Coffee

After the release of the CBD resistant varieties the crush program was discontinued and the long term breeding strategy which is based up on the conventional step-wise breeding approach was designed and started to be implemented. The new breeding program was focused on breeding for overall improvement of economically and agronomicaly important characteristics of Arabica coffee [9, 12, 13]. This approach was mainly aimed at germplasm enhancement, variety development through selection & hybridization and genetic studies to generate basic information that would help for the subsequent breeding work.

4.1. Germplasm enhancement and characterization program

It is well known that progressive crop improvement requires easy access to intra and inter-specific genetic variation. Based on the experience developed during the implementation of the crash breeding program and the observations made on the existence of wider genetic variations among indigenous coffee types, collection and conservation of the genetic resources for subsequent breeding works became one of the priority areas of the breeding program.

In this regard, assembling of about 5820 Arabica coffee accusations from 1966 to 2005 have been achieved through the implementation of the long term ‘National and International coffee germplasm collection program’ designed during the initial improvement program as well as ‘local land race variety development strategy [12] designed at latter progress in the improvement program [14]. Continuous efforts, however, made to address coffee producing areas which were not covered in the previous collection programs and the increasing demand for improved local land race variety from farmers have resulted in collecting 1000 additional accessions since 2005 [19]. At present a total of 6721 indigenous and exotic coffee accessions are collected and conserved at field gene bank (Table 1). Large number of these accessions were evaluated for yield, disease and insect pest resistance/tolerance, overall quality and other traits of breeding interest while the remaining are currently under evaluation. Accordingly, large number of promising accessions were selected and utilized in the breeding program for variety development. Maintenance of all accessions including CBD resistant selections collected during the crash program and assembling new collections is still underway as a major coffee breeding activity in the center.

Furthermore, characterization study using morphological markers has confirmed the presence of high

phenotypic diversity among the accessions conserved in the gene bank indicating the possibility of exploiting heterosis breeding in the improvement program [20, 21, 22, 24]. Various studies beyond Ethiopia have also confirmed the presence of genetic diversity in Arabica coffee populations obtained from forest, semi forest and garden areas of different parts of the country using DNA based molecular markers [25, 26, 27, 28]. As far as detailed characterization and clustering of the coffee genetic resources is concerned, very little work has been done and therefore, it necessitate urgent need for well designed strategic morphological, molecular and biochemical characterization for future breeding objectives

Table 1: Summary of Arabica coffee germplasm collections maintained at field gene bank of JARC

Type of collection	Year of collection	Number of accessions
French mission collections and SN series	1966	73
CBD resistant selections	1973-1975	696
CBD resistant selections*	1981-1987	568
National coffee collections	1970-1990	554
National coffee collections**	2004-2009	941
Sub-total		**2832**
International coffee collection	1968-1984	190
Local landrace coffee collections***	1994-2013	3699
Total coffee genetic resource		**6721**

**:-selections after the discontinuation of the 1st crash-program*

***:- collected under the local landrace variety development program but planted outside their origin*

****:- Collections under local landrace variety development program and planted at their place of origin*

4.2 Improved Variety Development Program

The ultimate goal of coffee breeding program in any coffee producing countries is to develop improved varieties that can be used as a resource to increase yield, biotic & abiotic resistance and quality[10, 12].After the release of the CBD resistant varieties, the coffee breeding program was focused on genetics studies, yield improvement through development of varieties that combine high yield, disease and insect pest resistance/tolerance and improved quality. Hence, pure-line selection and intra-specific hybridization methods of breeding approach have been under implementation since the beginning of the program. Accordingly, remarkable achievements have been recorded that played significant role in the coffee industry [9, 13, 14, 15]. At present, strategically well designed pure line and hybrid variety development programs are in progress under the theme of 'Agro-ecology based and demand driven coffee technology generation and promotion' at JARC and its sub-centers in

collaboration with higher learning and regional research institutes.

4.2.1 Pure line variety development program

The common breeding steps such as screening, variety trial/adaptation test at different locations, verification of the promising selections, variety release and seed multiplication are followed in pureline coffee variety development breeding program in Ethiopia until 1994 [9, 13, 14]. All the accessions collected under the national and international coffee collection program were critically evaluated for varying number of years at each breeding steps. Major consideration is given to the most economically desirable traits of breeding interest such as yield, disease (CBD, CLR) and insect pest resistance/tolerance and good quality attributes.

At the beginning the pure-line variety development program was mainly focused on releasing of varieties adaptable to different (low to high alt.) agro-ecologies of all coffee producing regions regardless of their geographic origin. With this effort, from 1978 - 2006 a total of 23 varieties including CBD resistant varieties developed during the crush breeding program (Table 2), have been released and distributed for production at low to high altitude areas where coffee is predominantly produced in Ethiopia [14, 29]. However, in cognizant of the long time required to develop improved coffee varieties through the conventional breeding approach and the ever increasing demand for quality and traceability, the coffee breeding program was focused in developing improved varieties for areas previously known in the international coffee market for producing coffee with unique flavor. Accordingly, 'Local landrace variety development breeding strategy', as the detail is described by [11], was designed and under implementation since 1994.

Table 2: Summary of pure-line coffee varieties released from coffee breeding program in Ethiopia

Year of release	**Number of varieties**	**Clean coffee yield (kg/ha)**	**Area of recommendation***
1978-1981	13	1220-1970	Low to high
1997	3	1660-1940	Low to medium
2002	2	2140-2540	Low to medium
2006	5	1540-2350	Medium to high
2010	11**	1190-2120	Medium to high
Total	**34**	**11.9-25.4**	**Low to high**

** Different coffee producing areas with altitude range (masl); low (1000-1500), mid (above 1500-1750), high (above 1750)*

*** Local land race varieties released for three major coffee producing areas*

As indicated in table 1, large number of Arabica coffee germplasm accessions were collected from each area as prioritized in the strategy and planted for evaluation at research sub-centers established at respective areas. After critical field and laboratory evaluation for yield, diseases and quality, 11 new local land race varieties (Table 2), were released for Hararge , Sidam/yirgacheffe and Wollega coffee producing areas in 2010 [30]. In addition, large number of promising selections promoted from different batches of collections originated from these areas

are also under evaluation of which about 60 selection are at final verification stage at different trial sites [19]. The upcoming varieties released from these selections would have significant role in broadening of the genetic base of the improved varieties.

4.2.2 Hybrid coffee variety development program

In Ethiopia, right after the release of CBD resistant varieties, coffee hybridization program was started in 1978. The main objectives were to study genetics of coffee to generate basic information for subsequent breeding strategy and develop hybrid varieties with better characters over the pure lines released through selection. Different sets of experiments made of single crosses between parental lines selected for desirable characters such as yield, resistance to CBD and CLR, quality and vigor were initiated that would enable to achieve the desired objectives simultaneously. Partial to complete dominance of the susceptible alleles over the resistance alleles (Table 3), involvement of a maximum of two to five recessive genes in controlling resistance to coffee berry disease, lack of cytoplasmic inheritance, presence of considerable amount heterosis, importance of both additive and non-additive gene actions in controlling inheritance of CBD and the expression of yield and some yield related growth characters and importance of morphological variation or difference in geographic origin in expression of heterosis were among the major achievements of the early genetics studies in coffee breeding program in Ethiopia [9, 15, 31, 32, 33,15].

Table 3: Hybrid and parental mean susceptibility to CBD under field and laboratory conditions and fouryears mean yield of fresh cherry in g/tree at Gera (CBD prone area)

Crosses	CBD infection		Yield (gm/tree)
	Lab.(1-5 class)/2yrs	Field (%)/3yrs	
R x R (1)	1.9	6.1	5287
R x I (2)	2.6	23.8	4409
R x S (6)	4.2	81.0	1205
I x S (3)	4.1	83.2	1033
S x S (3)	4.4	91.7	630
Rp_1	1.3	2.8	4429
Rp_2	1.5	7.7	4266
Ip	2.2	18.4	2523
Sp_1	4.5	95	106
Sp_2	4.3	97.9	197
Sp_3	4.2	85.1	169

Note:- *R = resistant, I = Intermediate, S = susceptible, P = parent; Numbers in bracket indicates number of crosses; class 1= resistant, 5= susceptible.* ***Source:*** *extrapolated from [34].*

Furthermore, evaluation of the selected promising F1 hybrids identified from the initial hybridization program at

different locations over several years had resulted in release of the first three hybrid varieties that combine high yield, moderate resistance to (CBD & CLR) and acceptable quality in 1997 and 2002 for production at medium altitude coffee growing areas of the country [15]. On the bases of the information obtained from the genetics study and the continuous efforts made to bring about improvement in coffee yield had also resulted in release of additional three new hybrid verities (Table 4), in 2016 that are recommended for production at low and medium altitude coffee growing areas [19].

Table 4: List of released varieties from hybrid variety development breeding program inEthiopia

No	Variety name	Year of release	Yield(kg/ha)	Production area*
1	Ababuna	1997	2,380	1500-1752
2	Melko CH2	1997	2,400	1500-1752
3	Gawe	2002	2,610	1500-1752
4	EIAR50-CH	2016	2,650	1000-1752
5	Melko-Ibsitu	2016	2,490	1000-1752
6	Tepi-CH5	2016	2,340	1000-1752

Note: 1000-1752 and 1500-1752 represents low to medium and medium altitude areas of coffee producing regions of the country, respectively.

Similarly, hybrid variety development for higher altitude (areas with high CBD pressure) is currently under final stage of breeding. The program is still under progress focusing on quality improvement. In effect, elite parental lines were identified and crossing has been made to develop hybrid variety for Limu, Harerghe and Wolega coffee producing regions as part of local landrace variety development program [19].

In general, early findings in hybridization study laid a significant foundation for the subsequent breeding program in the development of hybrid coffee variety in Ethiopia. The results so far achieved also indicated the possibility of improving the productivity of the crop both by developing pure line and hybrid coffee varieties for different coffee growing regions of Ethiopia having diverse coffee types, agro-ecologies and quality profiles.

5. Challenges and opportunities

Reduction in suitable land for Arabica coffee growth [34] due to shifting of the domain of adaptation recommended for varieties so far released, abiotic stress, increased temperature, changes in dynamics of diseases and pests attacking the crop, change in rain fall in terms of amount and distribution etc, due to prevailing climate change [3] are among the major challenges of the breeding program. Coffee genetic erosion due deforestation and replacement of local landraces by improved varieties is another area of challenge that the current breeding program needs to focus on. Ever increasing demand from farmers for hybrid varieties is also another challenge as the seed multiplication is solely dependent on hand pollination and to lesser extent by clonal propagation by cutting due to delay in protocol optimization for mass multiplication by using tissue

culture. The enormous genetic diversity available in the country as well as diverse agro-ecologies where coffee can be produced among others can be considered as an opportunity for the sustainability of the breeding program.

6. Conclusions

The coffee breeding program have resulted in remarkable achievements by developing 40 Arabica coffee varieties out of which six are F1 hybrids that are currently under production at diverse agro-ecologies of the country. The release of these varieties have contributed to increasing production and productivity of coffee at national level as well as in reduction of productions costs such as expenditure for chemical purchase for controlling major fungal diseases commonly attacking the crop. Conservation of the gerrmplasm though not large enough to represent the available diversity, would also serve as an immediate source of breeding material in the future breeding program. However, it is vital to strengthen the national coffee germplasm collection program to ensure sustainability of the program. On the other hand, solely dependent of the breeding program on the conventional breeding approach need to be supplemented with the modern molecular breeding techniques such as marker assisted selection and use of DNA markers to characterize the available genetic pool of the crop. Similarly, biochemical compounds diversity analysis should be taken in to consideration to determine those compounds attributing to quality variations of coffee from different geographic origins. In the face of the predicted climate change, designing of breeding strategies addressing the expected challenges would enable to bring about sustainable development of the coffee sector in Ethiopia and beyond. The total number of coffee germplasm accessions indicated in this paper does not include some collections made by Etiopian Inistitute of Biodeversity and regional research research inistitutes and coserved at their respective field gene bank that would inclrease the total number conservaed at national level. Therefore, it could be considered as a limitation of this review work.

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