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Review Article

The Indicators of Coffee (*Coffea arabica* L.) Genetic Variations and Achievements Made in Coffee Research in Case of Ethiopia: Review

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Abstract: Coffee (*Coffea arabica* L.) belongs to the genus *Coffea,* in the family of *Rubiaceae*. About 139 coffee species are known in this genus, whereas *Coffea arabica* L. and Coffea canephora are the two most widely cultivated species worldwide. *Coffee arabica* has its primary center of diversity in the highlands of southwest Ethiopia then disseminated to different world's continents by different agents. The objective of this review is to indicate the access of genetic variation among Ethiopian Arabica coffee germplasm for future breeding use. Morphological markers in coffee are vital to distinguish variation based on external observation differences, such as shoot character like: - color of the shoot tip, fruit and bean character, branch and stem character. So far, genetic variability study in coffee was conducted by many scholars coffee germplasm collected from different agro-ecologies. The availability of wide genetic variability among the indigenous coffee and the diverse agro-ecologies in the country provided immense possibilities to improve coffee for desirable agronomic and breeding interest traits. Moreover, outstanding achievements have been recorded in collecting 7130 germplasm accessions, generating basic information on the genetics aspects, and developing 44 improved varieties of which nine are F1 hybrids.

Keywords: Genetic Variation, Heterosis, Heritability, Land-Race Breeding Program

1. Introduction

Coffee (*Coffea arabica* L.) belongs to the genus *Coffea,* in the family of *Rubiaceae,* and around 139 species in this genus are known [1]. Among these species Arabica coffee is known to be well grown in tropical and subtropical regions of the world [2, 3]. Arabica coffee is allotetraploid species (2n=4x=44) [4]. Next to *Coffea arabica* L., *robusta coffee* is the second most cultivated species in the World coffee production.

More than one hundred twenty five million people in global coffee growing areas derive their income directly or indirectly from coffee products in the activities like: - cultivation, processing, trading, transportation and marketing [5, 6]. Arabica coffee is one of the global most valuable agricultural commodities which is around to two-thirds of the world coffee market [7] and ranks 2nd after oil in world trade. Ethiopia is the1st and 5th from Africa and World in coffee production, respectively [8]. The average national productivity is low and about 6.70 quintals/ha [9].

Various scholars explained the significance of coffee genetic resource in coffee variety improvement programs for high yield and resistance to pest attack [10]. Coffee materials in its center of origin were used as parental line; resulting in over 30% hetrotic productivity ranged from 9.6-120.3% higher over better parent [11]. Alemayehu and Merga indicated that from 1968 until 2017 about 6923 coffee genetic materials were collected and conserved at Jimma, Agaro, Gera, Wollega, Mettu, Awada and Teppi. However, 15% of the conserved coffee accessions died from conservation block. The reason might be due to climate change and adaptation problem of the genetic material, as they are forced to be grown outside their original environment [12].

Having this fact location specific coffee technology generation and promotion under diverse coffee growing agro

ecologies with different research projects has been the main breeding strategy of Jima Agricultural Research Center set a local landrace coffee breeding strategies with the goal of generating and promoting coffee technologies of specific origin coffee growing areas. As reviewed by Alemayehu, using crash program and local landrace coffee breeding program JARC has released 35 pure lines and seven hybrid coffee varieties for different coffee growing ecologies with the objectives of high yielding, pest resistance and acceptable quality profile [13]. Recently, two hybrid coffee varieties were released for Southern coffee growing areas of the country. Totally 44 coffee varieties were released in Ethiopia.

Despite immense effort and achievements made in technology generation, relative to other countries the production and productivity in center of origin is low and needs more improvement. Seyoum reported that the major contributing factors for such low yield in coffee are: - lack of improved coffee varieties [14], limited availability and adoption of improved coffee cultivars, lack of well characterized and distinctly variable breeding materials available for use. Therefore, to develop improved coffee variety, it is crucial to have well characterized genetic material which might be important for yield increase, successful exploring and utilizing of Arabica coffee genetic resources in coffee breeding.

To achieve the issue raised above, it is important to have a knowledge coffee morphology, that might attributes to hereditary traits of any plant species. Morphological markers in coffee are vital to distinguish variation based on phenotypic observation differences, like: - leaf size and shape, young and old leaf color, fruit character, branching habit, plant height and the length of internodes [15]. Moreover, a number of scholars reported the existence of coffee arabica genetic variation in Ethiopia through conducting a research using a different coffee geremplasm population: - on Amaro Kele coffee [16-18] on 26 Wollega coffee; [19] on 49 Limmu coffee accessions while the other scholar [20] on 81 Wollega coffee accessions. However, till now achievements of the general characterization using morphological marker is a base to design future coffee breeding program and improvement for desirable traits. The objective of this review is to indicate the access of genetic variation among Ethiopian Arabica coffee geremlasm for future breeding use.

2. Taxonomic and Genetics Base of Coffee Classification

The plant coffee belongs to the genus *Coffea* and family of *Rubiaceae*. The recent combination of morphological and molecular marker results indicated that Rubiceae (*Coffeaceae*) family is enlarged to encompass eleven genera [21]. These include *Argocoffeopsis, Belanophora, Calycosiphonia, Coffea L., Diplospora, Discospermum, Nostolachma, Psilanthus, Tricalysia, Sericanthe, and Xantonnea*. Among the 11 genera, the species of the genus *Coffea* is economically the most important. Up to date, about 124 species in this genus are known [3]. Guyot and his colic's reported coffee species in this genus increased to 139 species [1]. However, in terms of ecomic importance it was limited to only the three species namely: -*Coffea arabica* L., *C. Liberica* and *Coffea canephora* Pierre which belong to the subsection *Erythrocoffea* are economically significant [22, 23]. From the three species, *the former* is the most important and commercial species in the world [21, 24].

The basic chromosome number for the genus *Coffea* is x = 11. Arabica coffee is a tetraploid coffee species and self-fertile (over 95%) species of the genus *Coffea,* with chromosome number 2n = 4x = 44 [25]. Moreover, Arabica coffee is species a self-fertile species of the genus *Coffea* with over over 95%. *C. eugenioides* and *C. canephora are* the ancestor of Arabica coffee [4]. How many arabica coffee types are their based on genetic base? Two: - Typica and Bourbon. Anthony *and his/her colic's* reported that 1) Typica genetic base originated from Indonesia from a single plant cultivated in the Amsterdam botanical garden in the early 1715 [26]. 2) The Bourbon type genetic base originated from a few coffee trees that were introduced from Yemen to the Bourbon Island at about the same time as Typica. In general, *Coffee arabica* has its primary center of diversity in the highlands of southwest Ethiopia then disseminated to different world's countries by different agents.

3. Coffee Morphology and Reproductive Biology

Coffee Arabica is a small woody perennial tree that differ in plant morphology and ecological adaptations. The coffee plant height might reach up to five meters. The coffee plant has a dimorphic habit of branching in which vertical branches form horizontal branches bear the flowers and set fruits in clusters [27]. According to the review made by Alemayehu flowers of C. arabica with short corolla, long style and exerted stamen are typical of the genus Coffea [17]. Floral morphology of coffee might allow natural cross-pollination. However, arabica coffee is an autogamous which bear a fruit pollination [27, 28].

The flower part known as inflorescences develop and from a serial buds mainly on horizontal branches. Each inflorescence might carries up to five flowers. The flowers have a short pedicel and a rudimentary calyx as reviewed by Alemayehu [17]. The petals are fused and form corolla with five lobes. The pistil consists of an inferior ovary and a long style with two stigmatic lobes. The ovary is bilocular each with one anatropous ovule [27]. In coffee plant the flower initiation occurs were after rainy season period following by a dry period. The coffee flowering time is not more than three days after the majority of flowers opening on the first and the second day [27]. As soon as flower opening occurred early in the morning, the stigma will become ready and receptive. The pollen shedding will begin. Flowers dying will occur in one to two days after pollination. The coffee might contains two seeds per fruit.

What are Coffea Arabica propagation methods? 1) Seed, 2) cutting and 3) using tissue culture. Do think that there is a seed dormancy in coffee? The answer is no. the reason is coffee is a recalcitrant type therefore, seed viability is short lived and recommended to plant the seeds within two to four months after harvesting/seed preparation. Thus, storing the coffee seed for longer than five months might cause a loss of seed viability [29]. The propagation methods like: - cutting, grafting and tissue culture methods are applicable to coffee plant.

There is no need to use vegetative propagation method for pureline coffee varieties as such type of the cultivars are easily propagated by using direct seed multiplication methods. Therefore, it is not a mandatory to propagate coffee using vegetative propagation methods like cutting and grafting unless it is required to use a top working that might control soil born disease coffee wilt disease. However, it is a mandatory done vegetative propagation predominantly on the hybrid varieties as it is a must to maintained true-to-type in F1 hybrid coffee seeds. The other and the third propagation method in coffee is In-vitro methods that might be used for propagation by somatic embryogenesis. This multiplication method might enable to produce a great number of coffee plantlets. The disadvantage of tissue culture is/are requiring a sophisticated techniques that might use chemical media [29].

4. Coffee Genetic Variation

The genetic variability in any crop is the occurrence of differences among individual plant as a result of differences in their genetic composition and environmental source [30]). The other scholar defined genetic variation as the expression of character between two individuals that could be measured in a similar environment is identical [31]. The existence of genetic variation is important coffee improvement using either selection or hybridization [32]. Moreover, genetic variability is the precondition in variety improvement program of any crop [33].

A lead botanists and scientists; Mekuria and his colic's suggested that Ethiopia is not only the center of origin for coffee but it is also a center of diversification and dissemination of the coffee plant [34]. The study made many scholars using morphological and molecular marker indicated that the coffee populations from the southwestern part of Ethiopia shown high genetic variation. In the the south western Ethiopa forests like Yayo, Bonga and Harena (Eastern part of the country) are conducive for in-situ conservation of coffee germplasm for respective origin. For instance, the scholars [16, 17] observed a high genetic among Amaro Kele coffee accessions using morphological traits. Montagnon and Bouharmont also reported higher phenotypic diversity among the populations of *C. arabica* collected from Ethiopia as compared to cultivated populations of the species from around the world [35].

The variation among Ethiopian coffee population is higher than the coffee genetic materials from the other part a world. The reason for higher genetic diversity among Ethiopian coffee population might be the result of center of origin for the plant. The arabica coffee genetic variation among 58 Amaro coffee accessions were confirmed [16, 17]. The variations were also observed among 49 Limu accession [36]. Moreover, the other scholars reported the existence of genetic variation among 100 Haraghe coffee accessions [37, 38]. In general, the presence of genetic variation among Ethiopian coffee accessions originated from different agro-ecologies of the country for different characters were reported by many scholars as discussed above. Therefore, these are the evidences that could confirmed the presence of genetic variation among coffee plant population in Ethiopia.

5. Coffee Research Achievement

5.1. Germplasm Enhancement

In cognizant to the existence of broad genetic bases /wide genetic diversity/ of Arabica coffee in its center of origin, Ethiopia, several germplasm collection missions have so far been organized annually and made effective. The first genetic enhancement made by Jimma Agricultural Research Center were through germpasm collections. And the second was by using intra-hybridization program. Thus, in all the efforts made, the gremplasm enhancement program using a collection has resulted in assembling and conservation of 7130 accessions of which 1071 accessions. However, around 15 % were died in the field until 2014; might be due to coffee wilt disease (CWD), over bearing die-back and poor adaptation [12].

5.2. Coffee Variety Improvement

The implementation of the earlier crash program of coffee breeding department has resulted in releasing of 13 coffee berry disease (CBD) resistant pure-line varieties with a mean yield range of 1220 to 2300 kg of clean coffee ha^{-1} within five years. It was the first achievement of the national coffee breeding program and that played significant role in the coffee sector for production and productivity improvement as a result of coffee berry disease outbreak in around 1970. It is well known that coffee is cultivated over a wide range of agro ecologies in Ethiopia. Considerable progresses that focused on development of new varieties with improved yield, coffee disease resistance, overall quality and adaptation to diverse agro-ecologies was made following the long term conventional breeding approach. The implementation of this program has also resulted in release of additional five pure-line varieties were recommended for low-to-mid-altitude coffee growing areas of the country from the year 1997 to 2002. Moreover, by using the same breeding approach, four high-land and one mid-altitude coffee varieties were released for Southwest and South coffee producing areas, respectively, in the year 2006.

With the emergence of demand for specialty coffee in the international market, quality was considered as a priority objective of the breeding program while maintaining all other desirable traits since 1990. Therefore, a new breeding strategy

known as 'local landrace variety development program' was designed and implemented to promote sustainable production of the distinct coffee types by origin maintaining inherent qualities of the specific localities for enhanced export market expansion. Rent less efforts were made to develop specialty coffee varieties for the most popular Ethiopian Arabica coffee land race origins that are branded and deserved international market recognition. Accordingly, a total of 12 specialty coffee varieties were released for; Hararghe, Sidama/yirgacheffe, Wollega and Limmu coffee growing regions between the years 2010 to 2018 (Table 1).

Hybrid coffee variety development program in Ethiopia started since 1978 with two main goals namely; to study inheritance of important agronomic traits and to develop hybrids that combine high yields, disease resistance, improved quality and other important characters. Since then, studies conducted on several experiments of crosses consistently show the presence of considerable amount of heterosis in crosses among indigenous cultivars and possibility to improve coffee yield in Ethiopia through hybrid variety development program. Eefficient implementation of the hybridization program had resulted in the development of nine hybrid coffee varieties. Accordingly, seven were for Southwestern and two were recommended Southern Ethiopia (Table 2).

Table 1. *Summary of pure-line coffee varieties.*

Variety Group	Number of Varieties	Year of Release	Yield Range (Qt/ha)	
			On station	On farm
CBD Resistant Varieties	13	1978-1981	12.2-23.8	6.0-10.0
Low and Mid-land Varieties	5	1997-2002	16.6-23.4	9.0-20.0
High-land Varieties	5	2006	16.4-23.5	15.2-16.2
Specialty Varieties/ Land-races	12	2006, 2010	11.9-20.4	7.2-16.2
Total	35			

Source: review made Alemayehu and Merga (12) and Benti [39]

Table 2. *Summary of hybrid coffee varieties in Ethiopia.*

No.	Variety Name	Year of release	Clean Coffee Yield Qt/ha			Attitude (m.a.s.l)	Some Suitable Region /areas /
			On station	On farm	Heterosis (%) in yield over best check		
1	Ababuna	1997	23.8	15.5	18	1500-1752	SW (Metu, Jima, Goma)
2	Melko CH2	1997	24.0	13.1	20	1500-1752	SW (Metu, Jima, Goma)
3	Gawe	2002	26.1	24.0	41	1500-1752	SW (Metu, Jima, Goma)
4	EIAR50-CH	2016	26.5	-	3.17	1000-1752	SW (Jima, Goma)
5	Melko Ibsitu	2016	24.9	-	42.5	1000-1752	SW (Jima, Goma)
6	Tepi-CH5	2016	23.4	-	42.5	1000-1752	SW (Tepi, Jima)
7	Gera-CH1	2018	23.0	22.5	-	1800-2100	SW (Gera, Jima)
8	Awada 1	2022	24.64	14.37	56.35	1550-1750	South (Sidama, Gedio)
9	Rori	2022	21.68	13.95	29.04	1550-1750	South (Sidama, Gedio)

Source: review made Alemayehu and Merga (12) and Benti [39]

6. Conclusion

In Ethiopia the geographic origin of coffee within its mother-land is good indication for the existence of genetic variation within and among a population. A number of scholars reported the significance of the Ethiopian coffee genetic materials in breeding programs for improved productivity and disease resistance. Variability is the occurrence of differences among individuals due to differences in their genetic composition and/or the environment in which they are raised. If the character expression of two individuals could be measured in an environment identical for both individuals, differences in expression might result from genetic control and therefore, the variation is called genetic variation.

The application of DNA-based molecular markers in the future breeding program is required to increase the efficiency and effectiveness of the coffee breeders as the conventional breeding approach in identifying divergent genotypes is a lengthy process. However, combined conventional breeding approaches and marker assisted selection would facilitate easy identification of divergent parental lines for crossing and establishment of core collections to avoid duplication accession in ex-situ conservation. Extensive collection of coffee genetic resources from unaddressed areas, and application of molecular breeding techniques such as marker-assisted selection and breeding for stress tolerance, among coffee plant population, would be the main focus areas of future coffee breeding programs.

Conflicts of Interest

The author declares that there is no conflict of interest.

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