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Decade of South Ethiopian Coffee Improvement Activities at Awada Coffee Research Center

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Abstract

Coffee improvement program of Ethiopia was aimed to develop widely adaptable and stable cultivars across all coffee growing regions of the country although there is a significant ecological variation that prevails between the major coffee growing regions. Assessing the feedback from users on the performance of released coffee cultivars, the national coffee research program realized the need to initiate coffee improvement programs for each coffee growing region that possessed specific coffee quality and fetch premium price in the world market. In effect, coffee improvement program was initiated for Awada Agricultural Research Center mandated to improve South Ethiopian coffee with the financial aid of the Government of Switzerland. To date about 580 arabica coffee accessions have been collected and maintained in the center in separate sets of collection and are under evaluation. Fourty-two (set I) and sixteen (set II) selections are under variety trials, twelve selections are in variety verification trial, five hybrids are under variety verification trial and four high yielding cultivars that possessed the typical quality of Yirgachefe or Sidama coffee types were released to coffee growers in the region. In this paper, coffee improvement activities, such as collection and evaluation of germplasm, variety development activities and genetic studies are reviewed.

Keywords: *Coffea arabica* L.; Genetic diversity analysis; Landraces; Hybrid varieties; Released cultivars; Hararge coffee; Yirgachefe coffee

Introduction

For more than two decades, Ethiopian coffee breeding program was aimed to search for improved coffee cultivars with wider adaptation to biotic and abiotic stresses and maintain stable yield across all coffee growing regions by concentrating the breeding program and source of germplasm only in the southwestern part of the country. However, this research direction has failed especially in providing cultivars that are suitable for the coffee growing areas of the Southern and eastern part of Ethiopia. In addition, these areas possess unique quality coffee types that are inherent only in the local varieties and land races of the respective locations. Hence, the national coffee research program initiated the Landrace Arabica Coffee Variety Development Strategy to establish coffee improvement programs for each coffee growing region that possesses specific coffee quality and fetch premium price in the world market [1]. To improve the yield as well as quality of South Ethiopian coffee, collection of germplasm accessions from the representative areas was undertaken. Consequently, screening of the germplasm accessions for economically important characters commenced and some promising cultivars were identified.

Literature Review

Coffee is the most important export crop of the south Ethiopian region with more than 46 percent share of the national market. It covers more than 185 000 ha of land in 50 Woredas (districts) among which 11 are high, 7 medium and 32 are low coffee producers. Garden coffee comprises 130,000 ha, semi forest 45,000 ha and forest coffee 10,000 ha. The semi forest and forest coffee production systems are pertinent to the western part of the region. In 2005, cropping season, the annual coffee production of the region was 131,000 tons out of which 100 302 tons were exported as 60 percent washed and 40 percent dry processed [2].

The average yield of coffee in the region is 500 kg/ha (for local or landrace cultivars) while that of the released coffee berry disease resistant cultivars is 800 kg/ha. Though the region is highly endowed with suitable environments, the productivity of coffee per unit area remains very low as compared to the world average. In Southeast Ethiopia (East and West Hararge zones) coffee was observed to grow as early as 850 AD [3]. In this area coffee is grown in homesteads under intensive management systems with an estimated average holding of less than 0.2 ha of land per family.

Planting space is very wide and the inter-row spaces are used for intercropping of various crops. The major coffee growing districts of Hararge zones such as Habro, Chercher, Wobera, Garamuleta, Harar Zuria, and Gursum are known for production of best quality coffee [3-6]. On the other hand, yield is reported to be generally low in this region due mainly to the low intensity and erratic rainfall distribution pattern, and also disease problems. In addition, lack of improved cultivars, unavailability of improved production technologies, physiological problems like die back and minimum or no use of agricultural inputs by small holder are also important factors for low coffee yield.

Awada Agricultural Research Sub-center is situated in the Tepid to cool semi-arid mid highland agro-ecology. It is located at 6°3'N of latitude and 38°E of longitude at an altitude of about 1740 m.a.s.l. The area has a semi-bimodal rainfall distribution characterized by double wet and dry seasons with an average precipitation of 1235 mm per annum (https://en.climate-data.org/africa/ethiopia/southern-nations/yirgalem-21940/). The belg (fall) starts in mid-February and extends up to mid-May (i.e., the wet season is from March to May) and the

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kiremt (winter=main rainy season) extends from June to September/ October (i.e., the wet season is from September to October).

The sub-center is mandated to run research activities on Southern Ethiopia coffee types in general and Sidama and Gedeo coffees in particular. Therefore, major emphasis has been given to the development and release of high yielding and disease resistant coffee cultivars that maintain the standard and/or known quality of such coffee types. Four improved cultivars (Angefa, Koti, Fayate and Odicha) were released to growers and twelve promising selections are in verification trial. To date more than 580 coffee accessions have been collected and conserved at the center and most have been characterized using the IPGRI [7] coffee descriptor.

Arabica coffee improvement activities at Awada Research Center

Collection, characterization and evaluation of South Ethiopian coffee germplasm accessions: The trials were laid out in three sets. In first set, the 206 accessions (collected in 1994, 1995 and previous Sidama coffee collections) along with 5 checks, hereafter referred this set as Batch I, were planted in 1997 with augmented design of four blocks and 10 trees per plot (2 m × 2 m spacing between plants, hence each plot had 36 m^2). Second set comprised of 56 accessions (collected in 1996) along with 5 checks, hereafter referred this set as Batch II, were planted in same way as per Batch I in 1998. While third set of 55 accessions (collected in 1997) and three checks, hereafter referred this set as Batch III, were planted in 1998 in RCB design with three replications and six trees per plot.

Recently new collections were added from four districts of Sidama Administrative Zone. Hundred and twenty coffee accessions collected from Dale and Aleta Wondo districts in 2005 were transplanted in the field at Awada in July 2006 in augmented design. Similarly, 100 coffee accessions collected from Bensa and Dara districts in 2006 were transplanted in the field at Awada in July 2007. Currently the seedlings are at required stage of growth. Batch I and II were managed in multiple stems as they were stumped due to the severe drought that occurred in 2000. Hence, yield data for 2000, 2001 and 2002 could not be obtained for these two batches.

Batch I had four years yield data (yield data for 2000, 2001 and 2002 not available because the trees were rejuvenated to recover the damage caused by the drought occurred in 2000 main season), Batch II had five years yield data and Batch III had seven years yield data. In batch I, average of four years yield data showed the top six high yielders were well above the best standard check (744) whereas, the top ten accessions performed better than the other four checks ranging from 17.29 to 26.30 q/ha of clean coffee (Table 1). Similarly, in batch II, the top three high yielders were well above the best standard check (744) whereas, the top ten accessions performed better than the other four checks (Table 2).

S No	Collection No	[b]Clean coffee yield in Qh^{-1}				Mean	% CBD (Visual)		Mean
		1999	2003	2004	2005		2003	2004	
1	85172	31.14 (28.28)	26.91 (31.07)	22.16 (15.69)	23.87 (25.50)	26.02 (25.14)	0.00	9.31	4.66
2	3883	22.21 (22.13)	12.92 (8.04)	39.55 (41.49)	9.71 (-1.84)	21.10 (17.45)	0.01	6.44	3.23
3	4083	19.79 (16.93)	19.91 (24.07)	24.91 (18.43)	16.35 (17.98)	20.24 (19.35)	0.00	0.03	0.02
4	39772	9.65 (9.57)	22.89 (18.01)	21.40 (23.34)	24.32 (12.77)	19.57 (15.92)	0.01	0.01	0.01
5	695	17.43 (19.11)	22.69 (24.25)	21.06 (20.90)	15.33 (19.67)	19.13 (20.98)	0.00	0.00	0.00
6	85171	20.89 (18.03)	19.23 (23.39)	25.97 (19.49)	6.07 (7.70)	18.04 (17.16)	2.14	10.72	6.43
7	85170	23.84 (20.98)	12.27 (16.43)	23.78 (17.30)	11.58 (13.21)	17.87 (16.98)	0.00	0.06	0.03
8	2783	13.97 (13.89)	13.88 (9.00)	38.42 (40.36)	3.89 (-7.66)	17.54 (13.90)	0.71	2.15	1.43
9	85298	13.22 (10.36)	10.00 (14.16)	40.91 (34.43)	5.37 (7.00)	17.38 (16.49)	0.00	0.02	0.01
10	2170	14.01 (13.93)	15.49 (10.61)	29.34 (31.28)	10.60 (-0.95)	17.36 (13.72)	0.01	0.31	0.16
LSD at	0.05	12.66	13.7	17.78	20.5	--	--	--	--
	0.01	17.75	19.21	24.93	28.75	--	--	--	--
Standard Checks									
1	74140	10.94	21.60	12.26	7.28	13.02	0.01	0.003	0.0065
2	7487	11.01	16.61	19.71	1.47	12.20	0.07	0.018	0.044
3	7440	13.09	18.96	13.61	3.94	12.40	0.03	0.007	0.0185
4	75227	9.82	21.56	20.31	7.76	14.86	0.02	0.005	0.0125
5	744	16.92	26.84	9.56	18.62	17.99	0.04	0.011	0.0255
F test		NS	NS	NS	NS	--	--	--	--

CV (%)	39.74	25.18	45.73	101.8	--	--	--	--

[b]Figures in parenthesis are adjusted values.

LSD values are used for comparison between un-replicated treatments and replicated treatments. Yield data for years 2000, 2001 and 2002 not available because the coffee trees were severely attacked by drought and thrips as a result they were deformed. Rejuvenation (stumping) was performed in year 2000 that caused three years delay in cherry yield.

Table 1: Mean yield and reaction to disease of the top ten high yielding accessions for batch I.

S No	Collection No	[b]Clean Coffee Yield in Qh^{-1}			Mean	% CBD (visual)
		2003	2004	2005		2004
1	96/34	23.81 (23.92)	22.03 (23.95)	28.90 (24.31)	18.68 (18.04)	0.01
2	96/33	20.64 (22.26)	38.20 (36.16)	12.94 (16.25)	17.94 (18.67)	0.01
3	96/1	32.51 (32.62)	17.62 (19.54)	19.15 (14.56)	17.32 (16.68)	3.77
4	96/23	30.11 (31.73)	13.31 (11.27)	23.62 (26.93)	16.76 (17.48)	2.03
5	96/58	32.38 (29.83)	8.97 (10.74)	21.24 (21.13)	15.65 (15.43)	0.00
6	96/11	19.51 (19.62)	22.72 (24.64)	19.78 (15.19)	15.50 (14.86)	0.00
7	96/22	22.48 (24.10)	21.29 (19.26)	16.81 (20.12)	15.15 (15.87)	0.00
8	96/21	16.35 (17.97)	32.64 (30.60)	11.53 (14.84)	15.13 (15.85)	0.00
9	96/50	10.84 (12.46)	30.04 (28.01)	19.34 (22.65)	15.06 (15.78)	0.00
10	96/41	18.20 (19.02)	27.34 (25.68)	13.01 (14.40)	14.64 (14.77)	0.02
LSD at	0.05	6.84	14.14	10.52	--	--
	0.01	9.59	19.83	14.76	--	--
Standard Checks						
1	74140	13.37	10.22	18.62	14.07	0.006
2	7487	15.29	16.59	12.77	14.88	0.003
3	7440	14.85	12.64	12.14	13.21	0.003
4	75227	9.88	6.35	6.11	7.48	0.000
5	744	19.58	17.72	13.85	17.05	0.000
F test		HS	NS	HS	--	--
LSD at	0.05	6.85	--	6.29	--	--
	0.01	8.97	--	8.81	--	--
CV (%)		18.2	43.14	32.13	--	--

[b]Figures in parenthesis are adjusted values.

NS and HS are non-significant and highly significant respectively at P=0.05 and 0.01. LSD values are used for comparison between un-replicated treatments and replicated treatments. %CBD=percent coffee berry disease infection level.

Table 2: Mean yield and reaction to disease of the top ten high yielding accessions for batch II.

All the top ten high yielders performed better than the standard checks in batch III (Table 3). Most were free from coffee berry disease and coffee leaf rust under visual assessment score (scored from 0 to 100%; where zero is very resistant and 100% is completely susceptible); however, few accessions scored 3 to 8% infection level under field condition. The top six accessions from batch III and another 16 (those ranked from 7 to 22 based on mean yield data) transferred to multi-location varietal trial. Additional 15 to 20 promising accessions selected from batch I and II were promoted to variety trial in 2009.

S No	Collection No	Clean Coffee Yield in Qh^{-1}						CBD (%)				CLR (%)		
								ABT		Visual		Visual		
		2001	2002	2003	2004	2005	Mean	2003	2004	2003	2004	2001	2003	2004
1	974	9.34	18.49	24.67	40.2	11.02	20.74	0.72	3.76	0.13	0.01	3.89	17.99	4.78
2	9722	14.14	7.96	41.19	10.79	28.84	20.59	0.00	46.8	0.01	0.01	10.68	49.01	9.06
3	979	8.66	14.24	28.18	18.56	28.02	19.53	1.33	37.4	0.02	0.00	1.14	14.44	4.51
4	9718	13.02	12.08	25.41	20.36	23.41	18.86	0.00	54.2	2.23	0.00	14.11	35.77	8.17
5	971	13.32	7.93	25.46	27.34	19.56	18.72	0.00	7.09	0.01	0.01	15.44	48.89	22.39
6	9737	9.49	13.71	21.63	25.01	23.51	18.67	1.42	10.94	0.01	0.00	1.16	30.06	2
7	9738	5.84	10.31	23.34	32.12	17.89	17.9	3.04	12.55	0.02	0.01	1.02	16.43	12
8	9745	13.21	10.23	27.12	15.81	21.82	17.64	5.80	18.48	0.48	0.00	5.11	36.11	3.11
9	9714	14.39	5.10	33.62	11.37	22.77	17.45	2.67	28.1	0.02	0.00	4.67	37.17	2.68
10	975	10.31	11.83	26.52	17.16	20.35	17.24	4.18	5.60	0.04	0.00	1.02	14.66	4.78
Standard Checks														
1	744	5.18	5.03	20.55	23.5	31.09	17.07	1.23	6.99	0.01	0.00	0.92	13.14	1.85
2	75227	4.68	6.12	20.60	18.13	27.71	15.45	0.00	10.33	0.05	0.00	0.12	2.97	1.04
F test		HS	HS	HS	HS	HS	HS	--	--	--	--	--	--	--
LSD at	0.05	4.85	6.75	10.02	11.04	10.61	3.98	--	--	--	--	--	--	--
	0.01	6.41	8.93	13.25	14.59	14.03	5.24	--	--	--	--	--	--	--
CV (%)		30.89	49.88	29.57	43.38	40.28	39.11	--	--	--	--	--	--	--

HS are Highly significant at P=0.01, ABT=attached berry test (test for coffee berry disease by artificial inoculation while the young berries are still attached on the tree), CBD=coffee berry disease, CLR=coffee leaf rust.

Table 3: Mean yield and reaction to diseases of the top ten high yielding accessions for batch III.

Variety and verification trials of South Ethiopian coffee selections: Three independent experiments were conducted under this title. The first variety trial was established in two locations; Awada (mid altitude=1745 m) and Wonago (high altitude=1850 m), respectively, in 1997 and 1999. This trial consists of 42 Arabica coffee selections (collected from South Ethiopia in 1970, 1977, 1981 and 1985) and two standard cultivars used as checks. Amongst the 42 accessions, mean yield of the top ten accessions and the standard checks over four years are summarized in Tables 4 and 5.

S No	Accessions	Clean coffee in Qh^{-1}					CBD visual (%)		CLR visual[a]	
		1999	2003	2004	2005	Combined Mean (03-05)	2000	2004	Mean	2003
1	1377	19.34	21.45	22.59	23.19	22.41	1.49	0.003	0.747	9.2
2	2081	21.35	16.06	38.39	12.18	22.21	4.87	0.638	2.754	4.75
3	85188	19.29	24.36	27.24	13.26	21.62	8.93	0.381	4.653	19.85
4	3677	15.91	26.68	19.24	18.39	21.43	8.04	0.628	4.332	26.85
5	2970	12.19	23.53	25.42	14.98	21.31	10.16	0.003	5.081	13.4
6	85245	10.48	22.76	20.65	19.81	21.07	7.03	0.005	3.518	3.61
7	85180	17.90	23.43	18.15	20.31	20.63	0.48	0.000	0.238	10.3

8	2181	17.48	21.44	23.01	16.84	20.43	13.85	0.388	7.120	17.65
9	3070	12.62	28.59	21.33	10.19	20.03	33.26	2.625	17.94	14.35
10	85257	16.39	22.35	15.01	20.34	19.23	0.38	0.006	0.191	22.35
Standard Checks										
1	75227	6.73	24.28	26.75	26.00	25.68	0.18	0.009	0.09	0.39 (3.49)
2	744	12.67	19.18	10.25	31.61	20.35	0.24	0.003	0.12	5.11 (12.22)
F test		HS	HS	HS	HS	HS	--	--	--	--
LSD at	0.05	4.64	4.61	7.7	6.12	3.59	--	--	--	--
	0.01	6.13	6.09	10.16	8.08	4.73	--	--	--	--
CV (%)		24.22	19.28	31.71	34.33	28.49	--	--	--	--
[a]Figures in parenthesis are transformed value, HS: Highly significant at P=0.01.										

Table 4: Mean yield and reaction to diseases of the top ten high yielding accessions at Awada.

S No	Collection No.	Clean Coffee Yield in Qh^{-1}						CBD (%)			[a]CLR Visual (%)
								ABT	Visual		
		2001	2002	2003	2004	2005	Combined Mean	2004	2003	2004	2003
1	85259	5.36	9.98	28.29	11.11	20.98	15.14	14.07	5.07	3.56	1.39
2	85238	8.55	9.53	23.4	10.2	15.39	13.41	57.83	0.073	0.64	3.26
3	3670	6.8	10.54	24.94	12.27	11.69	13.25	40.34	3.87	3.89	4
4	85294	6.53	9.69	25.87	11.98	10.98	13.01	68.19	1.45	1.09	9.66
5	85232	6.5	5.05	20.42	12.69	14.38	11.81	37.73	9.2	8.89	1.86
6	1870	4.98	4.54	23.22	10.63	15.33	11.74	49.94	2.38	1.63	14.55
7	1377	6.21	7.21	18.84	12.62	12.46	11.47	31.03	0.11	2.39	2.27
8	85257	6.11	6.07	25.47	7.93	10.24	11.16	9.5	0.47	0.26	4.2
9	2077	7.17	5.96	21.27	11.95	9.3	11.13	41.02	9.91	12.76	8.15
10	85296	7.15	7.84	21.86	7.85	10.64	11.07	48.08	28.18	7.17	9.08
Standard Checks											
1	744	6.24	11.09	28.82	10.34	20.64	15.43	12.3	0.12	0.01	0.81
2	75227	4.7	7.78	16.9	10.13	14.95	10.89	3.54	0.01	0.3	0.48
F test		HS	HS	HS	HS	HS	HS	--	--	--	--
LSD at	0.05	3.36	3.2	6.22	4.68	5.54	2.1	--	--	--	--
	0.01	4.45	3.99	8.22	6.18	7.32	2.76	--	--	--	--
CV (%)		45.39	41.55	27.67	38.91	40.19	37.53	--	--	--	--
[a]Figures in parenthesis are transformed values, HS: Highly significant at P=0.01.											

Table 5: Mean yield and reaction to diseases of the top ten high yielding accessions at Wonago.

At Awada, combined analysis over four years showed that none of the top ten accessions did better than the best check (75227). Similarly, at Wonago, combined analysis over five years indicated that none of the accessions out yielded the best check (744) though four of the top ten selections were significantly better than 75227. Landraces of Ethiopian coffee performed differently at different locations indicating location specific adaptation [8].

The second trial i.e., verification of Sidama coffee selections comprising 14 accessions including two standard cultivars, was established at two locations in an RCB design of three replications, spacing of 1.5 m × 2 m and plot size of 75 and 66 trees at Konga and Korkie demonstration sites, respectively in 2004. The first cherry yield was harvested in 2007 (Table 6). Clean coffee yield and CBD infestation was recorded higher in Konga than Korkie. However, six selections, namely, 974, 1377, 9744, 979, 85292 and 971 performed better than the best check, 75227 at both locations.

S No	Selections	Clean coffee yield in q/ha	
		Korkie	Konga
1	85238	2.29	4.85
2	9718	4.45	4.93
3	85237	3.45	4.63
4	974	3.63	5.68
5	1377	5.22	5.75
6	9744	4.17	5.56
7	744*	1.28	4.33
8	979	3.18	8.35
9	9722	2.07	6.97
10	85294	5.61	5.04
11	85259	1.21	2.15
12	85257*	2.28	4.99
13	971	3.41	8.43
14	75227	1.30	2.58

Selections 744 and 75227 were standard checks (released CBD resistant cultivars)

Table 6: Mean coffee bean yield of the twelve selections and two standard checks.

The third trial was undertaken in two sets: i.e., Set I and Set II at three locations, viz., Awada, Wonago and Kumato. In Set I, seedlings of 16 selections and 2 standard checks were transplanted in August 2006 while; Set II was established in 2009. The seedlings were well established in the fields of the 3 locations.

Coffee hybrid variety development activity: Several reports have described heterosis in *coffea arabica* with average up to 30% hybrid F_1 cultivars [9-13]. In an effort to develop high yielding, CBD resistant coffee hybrids that possess the standard quality of Sidama and Gedeo coffee in the mid and high altitudes of the south, a hybridization program was initiated in 1996. Through series of observations made since 1998 for yield, CBD resistance and quality of the crosses, it was possible to identify more than eight hybrids superior over the standard checks for the traits considered. Moreover, a maximum over parent heterosis of 31% for yield was obtained (four years average data) for the 15 hybrids studied (Tables 7 and 8).

S No	Hybrids	^{b}Clean coffee yield in Qh^{-1}					
		2003	2004	2005	Combined Mean	% Hetrosis	
						OMP	OBP
1	744 × 1681	34.78	39.44	31.04	35.08	59.85	50.17
2	1377 × 1681	29.41	45.15	20.41	31.66	36.17	35.53
3	75227 × 1681	24.77	48.08	18.19	30.34	62.12	29.88
4	744 × 2077	29.74	18.58	40.55	29.63	52.54	44.32
5	7440 × 75227	35.85	11.12	40.89	29.29	89.09	81.73
6	7440 × 1681	27.82	32.84	25.07	28.57	41.89	22.3
7	7440 × 1377	30.01	17.34	37.71	28.35	41.57	22.35
8	75227 × 1377	27.61	24.04	32.94	28.2	51.57	21.87
9	7440 × 2077	26.18	25.98	32.15	28.11	59.58	53.44
10	744 × 1377	29.75	16.81	35.58	27.38	25.40	18.32
11	75227 × 2077	22.61	34.05	23.78	26.82	65.61	46.4
12	2077 × 1681	20.66	40.85	14.69	25.40	21.88	8.73
13	1377 × 2077	23.41	21.31	28.93	24.55	18.43	6.09
14	744 × 7440	26.70	9.12	36.73	24.18	29.17	17.78

15	744 × 75227	25.00	14.65	26.02	21.89	26.53	6.62
Parents							
16	744	18.71	12.68	30.21	20.53	--	--
17	7440	19.19	9.03	22.51	16.91	--	--
18	75227	10.45	18.50	13.26	14.07	--	--
19	1377	22.89	18.71	27.81	23.14	--	--
20	2077	13.36	23.07	18.54	18.32	--	--
21	1681	20.19	36.03	13.86	23.36	--	--
F test		HS	HS	HS	HS	--	--
LSD at	0.05	7.77	10.19	12.47	5.85	--	--
	0.01	10.33	13.55	16.6	7.72	--	--
CV (%)		22.2	29.25	32.01	28.45	--	--
HS: Highly significant at P=0.01; OMP: heterosis over mid-parent; OBP: heterosis over better parent							

Table 7: Mean yield of hybrids between south Ethiopian and southwest Ethiopian coffee genotypes at Awada.

Of these fifteen hybrids, five (744 × 1377; 7440 × 2077; 75227 × 1377; 75227 × 2077; 75227 × 1681) were promoted to verification trial to confirm the repeatability of their performance across locations and years. Evidence showed that there is a wide variation in environmental conditions within the southern coffee growing areas (Sidama and Gedeo Zones) by the presence of G × E interaction [14,15]. Therefore, the adaptability of these hybrids should be tested across locations with larger plots to verify their response to yield, major coffee diseases and other important characters.

S No	Hybrids	Clean Coffee Yield in Qh^{-1}									CBD Visual (%)	CLR Visual[a] (%)
		2000	2001	2002	2003	2004	2005	Combined Mean	Hetrosis (%)		2003	2003
									OMP	OBP		
1	75227 × 1377	4.76	15.28	21.63	28.82	20.79	34.81	21.02	65.38	51.77	3.81	3.81 (10.75)
2	75227 × 1681	5.65	12.47	23.45	28.54	27.74	26.46	20.72	99.81	79.08	2.21	2.21 (8.38)
3	7440 × 2077	7.52	8.32	28.21	16.78	36.61	19.27	19.45	163.91	48.13	2.52	2.52 (8.38)
4	744 × 1681	4.53	8.48	23.52	24.53	26.74	24.16	18.66	69.25	44.88	0.23	0.225 (2.5)
5	75227 × 2077	5.26	12.15	23.85	20.60	25.21	24.81	18.64	182.85	61.11	0.16	0.16 (1.11)
6	744 × 2077	6.08	11.60	24.49	15.80	27.21	25.98	18.53	155.76	43.87	1.10	1.21 (5.93)
7	7440 × 75227	6.59	8.66	26.85	22.58	22.09	21.44	18.03	45.99	37.32	0.96	0.96 (5.38)
8	744 × 1377	5.03	8.48	19.37	23.69	21.81	26.97	17.56	31.39	26.79	0.46	0.46 (3.01)
9	7440 × 1681	1.05	11.81	20.92	25.69	23.93	20.04	17.24	54.62	31.30	1.13	1.13 (4.66)
10	744 × 75227	4.68	9.11	21.08	18.43	22.94	24.56	16.80	37.42	30.43	1.71	1.71 (7.32)
11	7440 × 1377	0.85	9.02	17.77	20.36	20.55	26.47	15.84	17.42	14.37	2.13	2.13 (8.29)
12	1377 × 2077	3.64	10.18	20.42	14.69	26.39	18.29	15.60	101.81	12.64	0.34	0.335 (2.99)
13	744 × 7440	2.75	6.90	16.74	16.55	20.01	22.9	14.31	165.49	8.99	1.15	1.15 (5.54)
14	2077 × 1681	3.14	5.76	10.34	20.71	19.73	19.27	13.16	1.19	43.51	1.46	1.46 (6.75)

15	1377 × 1681	0.21	5.55	14.50	16.18	21.76	18.85	12.84	11.56	-7.29	0.86	0.86 (4.51)
Parents												
16	744	3.10	5.73	12.46	19.66	15.52	20.83	12.88	--	--	0.40	0.4 (3.58)
17	7440	3.82	8.65	17.84	14.20	19.27	15.05	13.13	--	--	1.06	1.06 (5.42)
18	75227	2.20	7.58	14.19	15.02	11.74	18.70	11.57	--	--	0.51	0.51 (3.44)
19	1377	3.34	8.44	14.26	21.13	14.67	21.24	13.85	--	--	1.72	4.72 (11.73)
20	2077	0.21	0.11	0.55	2.79	4.11	1.89	1.61	--	--	12.50	12.5 (20.7)
21	1681	2.54	5.99	6.70	11.67	16.15	12.00	9.17	--	--	0.66	0.66 (3.45)
F test		HS	HS	HS	HS	HS	HS	HS	--	--	--	--
LSD at	0.05	2.93	4.55	7.32	8.68	9.25	10.26	3.06	--	--	--	--
	0.01	3.90	6.05	9.74	11.54	12.3	13.64	4.03	--	--	--	--
CV (%)		56.57	37.19	28.67	32.33	30.87	34.3	35.31	--	--	--	--

Table 8: Mean yield and reaction to diseases of crosses in set B at Wonago.

The Released South Ethiopian Coffee Cultivars

Angefa (Breeder's reference: Selection 1377)

Awada Agricultural Research Center (AARC) has released an improved cultivar named "Angefa" in 2006; which was high yielder and well adapted to Sidama and Gedeo coffee growing areas. This cultivar represents the local coffee types with resistant to coffee berry disease [14].

Angefa is highly preferred by coffee farmers of Sidama and Gedeo Zones for its high vigor, yield advantage and quality characters. Currently Awada Agricultural Research Center is the only source of seed for this cultivar and the demand for this cultivar in the country is very high. Angefa was initially collected from Quoti Kebele of Wonago district in Gedeo Zone of South Ethiopian region. It can be described as follows; it has an open type of growth habit, bronze leaf tip color, can grow at an altitude range of 1700 to 2000 m. The rainfall requirement of this cultivar is well above 1200 mm per annum. It grows best in Nitosol type of soil with the application of 125 kg DAP and 81 kg of Urea fertilizers per hectare. It can give 11 to 17 quintals of clean coffee per hectare on farmers' field. It requires 50% shade using common shade trees like Milletia, Cordia, Albizia, Sesbania and Acasia species. A spacing of 2 m × 2 m is the best recommended practice. Angefa is resistant to CBD and moderately resistant to CLR under field conditions both at Yirgalem and Wonago areas. It is also characterized by Yirga Chefe type of cup test with best raw and roast quality.

Odicha (Breeder's reference: Selection 974)

Odicha was released in 2010 by AARC for mid altitude (1740-1850 m) coffee growing areas of Sidama and Gedeo zones of Southern Nations and Nationalities and Peoples Region (SNNPR). It is characterized by high cherry yield potential and moderately resistant to coffee berry disease and highly resistant to coffee leaf rust under field and seedling evaluation test. Odicha is well adapted to the region even in marginal areas like Korke and has vigorous growth (with strong and tough stem and branches) and highly acceptable cup quality. It is medium open in growth habit which has very attractive appearance with manageable height and canopy diameter. This cultivar has an open type of growth habit with strong and stiff stem. The branches are very dense and uniformly distributed on the tree and are horizontally spreading. The leaves are long and medium wide. Both matured and young (leaf tips) leaves are green in color. Matured and ripe cherries are medium round sized and red in color.

Odicha represents both the typical quality profiles of Sidama and Yirgachefe coffee types which are spicy at Awada and floral at Konga. The cultivar has good and acceptable raw and cup quality profile under appropriate and recommended processing method. It has comparable overall quality standard and typical flavor profile than the standard checks. Cultivar Odicha has revealed regular bearing habit within the acceptable range.

Fayate (Breeder's reference: Selection 971)

Fayate was also released in 2010 by AARC for mid altitude (1740-1850 m) coffee growing areas of Sidama and Gedeo zones of SNNPR. Fayate is highly resistant to CBD and better performed in highland areas like Wonago and Konga (Yirgachefe). In addition, selection 971 is resistant to CWD under greenhouse conditions; hence this selection can be preferably promoted to areas where CWD infestation is severe.

Fayate is characterized by high potential for cherry yield with highly consistent bearing habit that is unlike to most cultivars of arabica coffee. It is resistant to coffee berry disease both at visual and attached berry test evaluations. It is characterized by open type of growth habit with strong and stiff stem. The branches are open and uniform across the tree. The type of branching habit is horizontal and spreading. Matured leaves are narrow, short in size and green in color. The leaf tips (shoot tips) are also green colored. It has round and medium sized cherries that become red when ripe.

Fayate represents the typical quality profile of Sidama coffee types which is characteristically known as spicy. It has good and acceptable raw and cup quality profile under appropriate and recommended processing method. The cultivar produces very acceptable export standard bean size grading. Generally, Fayate has comparable overall quality standard with the checks and typical flavor profile than the standard checks (744 and 75227). Fayate expressed a fairly regular bearing habit.

Koti (Breeder's reference: Selection 85257)

Cultivar Koti was also released in 2010 by AARC for mid altitude (1740-1850 m) coffee growing areas of Sidama and Gedeo zones of SNNPR. Like Fayate, Koti is also highly resistant to CBD and better performed in highland areas like Wonago and Konga (Yirgachefe). Koti is characterized by an average potential for yield with fairly consistent bearing habit. Its medium vigor (manageable height and medium canopy) can be an advantage for close spaced planting which is preferred by smallholder farmers. It also meets the standard quality (Yirgachefe and/or Sidama type) of cup test.

This cultivar can be expressed by thin and flexible stem along with open type of growth habit. Branches are shallowly (openly) distributed uniformly from bottom to top. The orientation of branches is horizontal and spreading. Leaf tips are bronze while matured leaves are dark green in color and broad and long in size. The matured and ripe cherries are red colored, small sized and round shaped. In addition, the cherries possess persistent calyx that is a morphological marker for resistance to coffee berry disease.

Genetic Studies

Since Ethiopia is the primary center of origin and genetic diversity for *C. arabica*, there is high genetic variability for yield and yield components, disease and pest resistance, and other traits. Systematic studies conducted on genetic diversity analyses of Ethiopian coffee germplasm using morphological characters confirmed the prevalence of enormous variation for economically important traits. Cluster and principal component analyses conducted on 100 Hararge coffee germplasm accessions collected from 16 districts of East and West Hararge Administrative Zones with four standard checks using 14 quantitative characters produced six clusters. The number of accessions per cluster ranged from five in cluster VI to 44 in cluster III. Moreover, the first four principal components explained 78.5 per cent of the total variation prevalent within the germplasm accessions out of which 38.5 percent was explained by the first principal component. Similarly, a field experiment conducted on evaluation of 41 south Ethiopian coffee accessions with two standard checks of the southwest Ethiopian origin using seven morphological agronomic characters, average of three years data on severity of CBD and CLR infestations and clean coffee produced nine clusters. The number of accessions per cluster ranged from one in cluster IX to 13 in cluster II. Further, the first four principal components explained 82.63 percent of the total variation prevalent within the germplasm accessions out of which 32.52 percent was explained by the first principal component.

Several workers have estimated the extent of genetic diversity present from the different sources of arabica coffee germplasm collections. For instance, a study by Catter [16] on second progeny arabica coffee collections of Ethiopian origin indicated the prevalence of high level of variability in morphological, agronomic and biochemical characteristics. The genetic diversity analysis conducted by Lashermes et al. [17] by employing RAPD markers on cultivated and sub-spontaneous accessions of arabica coffee confirmed the narrow genetic base of commercial cultivars (3 typica and 3 bourbon types). On the other hand, they reported the existence of large genetic diversity within the sub-spontaneous material, which consisted of 11 samples representing the different coffee growing areas in Ethiopia. Further, they have suggested the prevalence of an east-west differentiation in the Ethiopian coffee germplasm. Similarly, Montagnon and Bouharmont [18] characterized 148 arabica coffee accessions for phenotype diversity under field condition. They have evaluated the accessions using eighteen different morphological and agronomic traits by employing multivariate analysis and identified two main groups in the coffee accessions. According to them, accessions of group I have a more erect branching habit, narrower leaves, and were more resistant to coffee leaf rust and coffee berry disease than accessions of group II. They further opined that group I mostly contained Ethiopian arabica coffee accessions whereas group II contained commonly cultivated varieties throughout the world.

Genetic diversity analysis was conducted at Wonago Agricultural Research Sub-Station on 41 South Ethiopian coffee selections collected from six Woredas of Gedeo, Sidama, and Wolayta zones along with two released coffee berry disease (CBD) resistant cultivars. The ANOVA showed a highly significant difference among the genotypes for the seven morphological agronomic characters and yield. The findings of this study indicate the presence of wide variations among Southeast Ethiopian landrace coffee populations.

The cluster analysis grouped the 41 south Ethiopian coffee selections and the two southwest Ethiopian origin CBD resistant cultivar in to nine clusters suggesting the prevalence of wide phenotypic variations in the coffee populations. The number of genotypes per cluster varied from one in cluster IX to 13 in cluster II. Relatively low mean yield and higher scores of both CBD and CLR infestations characterized cluster IX that contains only one selection from Yirgachefe district.

The intra and inter-cluster distance (D^2) analysis showed a highly significant ($p<0.01$) difference among clusters. The smallest inter-cluster distance (18.6) was observed between clusters VI and VII while the highest (134.7) was between clusters V and VIII. In most of the cases, the genotypes among the clusters were significantly ($p<0.001$) divergent from each other. Considering the intra-cluster (within cluster) distance, no significant genetic dissimilarity was detected (data not shown).

Similarly, genetic diversity analysis was conducted at Awada Agricultural Research Sub-Center on 100 coffee accessions collected from 16 districts of East and West Hararge Administrative Zones along with 4 released coffee berry disease (CBD) resistant cultivars originated from Southwest Ethiopia [19]. Data on 14 morphological agronomic characters was obtained on the 104 genotypes. The ANOVA showed a highly significant difference among the genotypes for all the 14 characters considered in the study suggesting the presence of high variability among the accessions and good chance to improve Hararge coffee accessions through selection and breeding.

The cluster analysis grouped the 104 coffee germplasm accessions into 6 clusters [19]. The size of cluster varies from five accessions in cluster V to 44 accessions in cluster III. Clusters I, II, and IV contained accessions mainly from the Western Hararge districts whereas clusters III and V had almost equal number of accessions from both east as well as West Hararge districts. The five accessions in cluster VI were from the two districts of West Hararge out of which four originated from Kuni and one from Chiro District. Three cultivars (75227, 74165 and 74140) used as checks were grouped in cluster I, where middle to high altitude accessions from Western Hararge districts were most frequent.

The check, F-59 was grouped in cluster II, confirming the fact that this cultivar was distinctly different from the rest standard checks in morphology and geographical origin. It was evident that the accessions from Eastern Hararge districts showed close similarity as 58.5 per cent of the germplasm accessions from this region were grouped in cluster III. Similarly, more than 65 per cent of the germplasm accessions from Darolabu, Mesela and Tulo Districts of Western Hararge were concentrated in cluster III. The germplasm accessions of Girawa, Bedeno, Kuni, Chiro, Mesela and Habro Districts were found distributed in four different clusters, which suggested that the germplasm accessions from these districts were relatively more variable.

The cluster analyses conducted at two locations i.e., South and Southeast Ethiopia failed to clearly show relatedness of the selections due to geographical origin. There was overlapping of clustering patterns in respect of all Woredas, which could be explained as lack of differentiation among Woredas arising partly due to gene flow [20-23]. In light of the results obtained from the principal component analyses, it may be possible to deduce that more than half (53%) of the variation obtained in the south Ethiopian coffee was primarily due to number of stem nodes, primary branches, and plant height. Similarly, length of the longest primary branch, stem diameter, average length of primary branches, total number of internodes per plant and total number of primary branches per plant were the five important characters that contributed most to the total variation in the first principal component. This perhaps emphasized the significance of these characters to the appraisal of genetic diversity in the south and southeast Ethiopian landrace coffee populations [24-26].

Discussion and Conclusion

Overlapping of the clustering patterns of the accessions from different districts of both locations indicated lack of differentiation among districts to a certain extent. Moreover, germplasm accessions from western Hararge districts were relatively more variable in their clustering patterns as compared to eastern Hararge districts. Based on this, it can be inferred that western Hararge could serve as a potential source of variability for Hararge coffee. Similarly, selections from Gedeo Zone were more divergent than selections of Sidama Zone though relatively greater number of selections were considered from Gedeo Zone.

The significant inter-cluster distances suggested that there is a high opportunity for obtaining transgressive segregates and maximize heterosis by crossing germplasm accessions of these clusters. Therefore, the grouping of accessions by multivariate methods could be of considerable practical value to the coffee breeders so that representative accessions could be chosen from such clusters for hybridization programs. Moreover, the quantitative characters vis-à-vis number of stem nodes, primary branches, plant height, length of the longest primary branch and stem diameter could be used as a selection criterion for improving the productivity of the crop since they represent the lion's share in the variability of the coffee crop.

Gaps and Challenges

The number of germplasm accessions for the South Ethiopian coffee were limited and germplasm collections from the Southeast Ethiopia (Hararge zones) were appraised at pre-bearing stage only. However, it is necessary that the expression of different characters need to be studied. Further, molecular techniques may be very useful for germplasm characterization that may provide immense potential for the development of improved varieties from the local landraces for the area.

Future Directions

The studies brought out that Gedeo Zone and Western Hararge appeared to be the target areas for future intensive germplasm exploration endeavors of both locations. At the same time, evaluation and maintenance of germplasm collections for yield, quality and disease resistance must continue to provide improved cultivars for coffee growers of both regions in the shortest time possible to minimize the risk of losing smallholder coffee orchards challenged by the severe competition with chat (*Catha edulis*) especially in the Hararge coffee growing districts.

Genetic diversity analysis using molecular techniques should be conducted on those germplasm accessions so as to confirm the results obtained and avoid duplications of accessions or genotypes. Moreover, molecular markers shorten the lengthy conventional breeding scheme through the use of marker-assisted selections.

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