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Research Article

Genetic Variability of Coffee (*Coffea arabica* L.) Germplasm in Biennial Bearing and Its Influence on Selection Efficiency

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Arabica coffee is a perennial cash crop and highly affected by biennial bearing which disturbs farmers' annual income and world's coffee industries. Developing nonbiennial bearing variety is prominent in addition to applying field management practices. This study was conducted from 2012 to 2020 in southwestern Ethiopia at Tepi and Gera to test the extent of genetic variability among Arabic coffee germplasm in biennial bearing and understand the influences of bienniality on advanced selection. The pooled analysis of variance revealed handiness of genetic variability in yield and biennial bearing. The moderate genotypic coefficient of variation (10–20%), heritability (30–50%), and high genetic advance as percentage of the mean (>20%) were manifested in yield and biennial bearing. Response to selection and selection efficiency were negatively affected by biennial bearing. Early selection excluded 30–40% of the top high yielders from advanced selection. Selection at four harvesting seasons revealed 90% and more selection efficiency. Thus, one has to be conscious of the alternate bearing nature of lines during advanced selection. Both T43/11 and T51/11 were among the top high yielders and showed low biennial bearing at Gera and Tepi. T33/11, T49/11, T55/11, and T61/11 showed very low biennial bearing at both locations. These are promising lines and could be recommended for further biennial bearing improvement breeding programs.

1. Introduction

Coffee is a perennial cash crop that belongs to the family Rubiaceae and the genus Coffea which consists of 124 species [1]. Among these species, *Coffea arabica* L. and *Coffea canephora* P. are the dominant species in the world coffee market. Arabica coffee contributes 65% of worlds' coffee production, and 35% contributed from Canephora production. The former is tetraploid ($4x = 2n$) and self-pollinated, and the latter is diploid ($2x = 2n$) and self-incompatible species.

Among the headache in perennial crop production, bienniality is an alarming issue. Many fruit trees and other horticultural crops such as mango, apple, pear, apricot, and avocado are highly affected by bienniality [2–4]. Also, Arabica coffee is one of the horticultural crops that are affected by biennial bearing. Thus, the *Coffea arabica* L. yield is fluctuating or higher one year and lower the next [5, 6]; this of course affects farmers' annual incomes. The fluctuation of coffee yield results in food security problem, especially in developing countries such as Ethiopia. The producers' off and on harvesting and supply affect the total coffee production and demand in the world market. This has become a bottleneck for world's coffee industries today.

The biennial bearing nature in yield performance affects selection efficiency in coffee; this is due to its negative effect on yield accumulated over years [2, 7]. Moreover, bienniality causes heterogeneity growth variable and temporal correlation pattern over multiple harvesting seasons; this fluctuation in coffee yield makes the process of selecting the best performing progenies/lines difficult. Finally, this may lead to wrong conclusions for any gauge of variance components and selection of promising lines that exhibit biennial bearing nature.

Despite enormous agronomic management practices applied to alleviate biennial bearing in Arabica coffee,

Table 1: Description of experimental sites.

Locations	Annual rainfall (mm)	Annual temp. (°C) Min.	Max.	Altitude (m. a.s.l)	Latitude	Longitude	Distance from JARC (km)
Gera	1878.9	10.4	24.4	1940	7 0 7′0″N	360 00′00″E	74
Tepi	1678	16	30	1200	7° 30′00″ N	35° 18′ 00″E	267

reducing it to the required level became still difficult for cost users to steadily generate the annual income from coffee production. Thus, developing regular bearing variety which can regulate the undesirable traits of heavy and light bearing is more economical. It is well known that regular bearing/nonbiennial cultivars are preferred to biennial bearing cultivars [8]. This cultivar helps farmers get stable annual income, stable world coffee industries, and reduce the gap between supply and demand in the world coffee markets [9].

Coffee species respond differently to bienniality effects; the production of *Conilon robusta* is relatively less affected by biennial production change [10]. However, relative to robusta types, Arabica is highly affected by bienniality [10]. The difference between these two species implies that bienniality in coffee can not only be controlled by genes but also by environmental factors and field management practices. Variability in biennial bearing is reported for some fruit trees; the biennial bearing of stone fruits such as mango, olive, and plum varies from cultivar to cultivar [11]. Also, variability reported among apple and pear genotypes is in biennial nature [2, 12]. Additionally, Guitton et al. [13] confirmed that the gene related to hormone is more responsible for biennial bearing than flower related gene in apple. In the field, variability is observed among Ethiopian Arabica coffee germplasm in biennial bearing. However, so far, no well-planned and designed implementation has been conducted for studying genetic variability among these coffee germplasm in biennial bearing and its effect on advanced selection. Thus, this study was designed with the main objectives to evaluate the response of Arabica coffee to biennial bearing and identify the biennial bearing effects on selection efficiency.

2. Materials and Methodology

2.1. Description of the Study Area. The experiment was conducted at the Tepi Agricultural Research Center and the Gera Agricultural Research Subcenter of the Jimma Agricultural Research Center. The metrological, temperature, and rainfall information of the areas are clearly indicated in Table 1.

2.2. Materials, Field Management, and Design. About 87 coffee accessions which were collected from Tepi and its surrounding were field established with five checks at Tepi in June 2012 and with six checks at Gera in June 2013 (Table 2). Augmented design was used at both testing sites. Six coffee trees were planted per plot with the spacing of 2 m × 2 m between plants and rows. The field managements of the experiments such as shade and fertilizer application were applied according to Endale et al. [14].

2.3. Methods and Data Recoded. Red cherry of coffee yield data was selectively picked and recorded per plot in gram. All coffee berries are not changed to red cherry at the same time. After red cherry is completely harvested, the leftover dry and green coffee fruits were collected separately and recorded in gram which were later changed to red cherry using 2.26 and 1.04 conversion factors, respectively [15]. The mean of red cherry was computed by dividing the total amount of red cherry in gram per plot for the total number of bearing coffee trees per plot. Then, the mean of red cherry was converted to clean coffee yield in $\mathrm{Qha^{-1}}$, multiplying red cherry by 0.00417 (conversion factor). Finally, the yield data in $\mathrm{Qha^{-1}}$ were converted to $\mathrm{kg{\cdot}ha^{-1}}$ which is the SI unit for weight.

2.4. Data Analysis. Five and four years of clean coffee yield data were analyzed for Tepi and Gera locations, respectively. All collected data were subjected to R-software (version 4.3) for statistical analysis. Data uniformity was tested using the Shapiro–Wilk test; earlier, combined data analysis homogeneity variance was tested using the F-max method.

The alternate or biennial bearing of coffee germplasm has been characterized with several descriptive statistics [16] and the mean relative difference index as Hoblyn et al. [17]. $I = 1/n - 1\ (|y_t - y_{t-1}|/y_t + y_{t-1} + |y_{t+1} - y_{t-2}|/y_{t+1} + y_{t-2} + \ldots + y_{t+1} - y_t/y_{t+1} + y_t)$, where y_t is the t^{th} observed yield in an ordered series of size n, $|y_t - y_{t-1}|$ is the absolute value of the difference in yield between two successive years t and $t-1$, and $y_t + y_{t-1}$ is the sum of the yields over these two years and then standardized over the total number of years in the time series, n, minus one. I varies between 0 and 1, with $I = 0$ representing no alternate bearing behavior and $I = 1$ corresponding to strict alternate bearing behavior.

Relative percentage of biennial bearing (RP): it was calculated according to Morettini [18] and Singh [19] as follows. RP = difference between two successive crops x100/sum of the two successive crops. It is obvious that the index RP can vary between 0, in the case of a regular bearing pattern, and 100, in the case of a pronounced biennial bearing pattern.

For per year phenotypic analysis, the following linear model is utilized: $Y_{ijk} = \mu + g_i + b_k + \varepsilon_{ik}$, where y_{ik} is the phenotypic value for the genotype i and the block k, μ is the population mean, b_k is the effect of the kth block, g_i is the random effect of the ith genotype, and ε_{ik} is the random effect of residual.

Table 2: Descriptions of the study materials.

No.	Accession code	Region	Zone	Woreda	Specific location	Altitude (m)	Acc. no.	No.	Acc. code	Region	Zone	Woreda	Specific location	Altitude (m)	Acc. no.
1	T01 and 05/11	SNNPS	Bench Maji	Bero	Bolt	1650 and 1651, resp.	2	22	T54/11	SNNPS	Bench Maji	Sheko	Shimi	1250	1
2	T02/11	SNNPS	Bench Maji	Bero	Kuldak	1629	1	23	T55 and 56/11	SNNPS	Bench Maji	Sheko	Burayta	1215	2
3	T03 and 04/11	SNNPS	Bench Maji	Bero	Kuldak	1680	2	24	T57 and 58/11	SNNPS	Bench Maji	Sheko	Burayta	1300 and 1450, resp.	2
4	T06/11	SNNPS	Bench Maji	Bero	Keraft	1708	1	25	T59 and 60/11	SNNPS	Bench Maji	Sheko	Tigre Mejenger	1250	2
5	T0709/11	SNNPS	Bench Maji	Bero	Garo	1698, 1711, and 1718, resp.	3	26	T61/11	SNNPS	Bench Maji	Sheko	Tigre Mejenger	1260	1
6	T10/11	SNNPS	Bench Maji	Bero	Nonek	1676	1	27	T62/11	SNNPS	Bench Maji	Sheko	Dara	1290	1
7	T11/11	SNNPS	Bench Maji	Bero	Gelet	1667	1	28	T63/11	SNNPS	Bench Maji	Sheko	Behal Ayibera	1260	1
8	T12 and 13/11	SNNPS	Bench Maji	Bero	Boyek	1620 and 1601, resp.	2	29	T64 and 65/11	SNNPS	Bench Maji	Sheko	Sanka	1220 and 1250, resp.	2
9	T14 and 15/11	SNNPS	Bench Maji	Bero	Banjat	1656 and 1664, resp.	2	30	T66 and 67/11	SNNPS	Sheka	Anderacha	CheChele	1500 and 1520, resp.	2
10	T16, 17, 20, and 21/11	SNNPS	Bench Maji	Merit-Shasha	Gelglit	1441, 1443, 1440, and 1444, resp.	4	31	T68 and 69/11	SNNPS	Sheka	Anderacha	CheChele	1510	2
11	T18 and 19/11	SNNPS	Bench Maji	Merit-Shasha	Chibil	1449 and 1438, resp.	2	32	T70 and 71/11	SNNPS	Sheka	Anderacha	CheChele	1550 and 1590, resp.	2
12	T2227/11	SNNPS	Bench Maji	Merit-Shasha	Bushururu	1532, 1594, 1590, 1605, 1611, and 1606, resp.	6	33	T72 and 73/11	SNNPS	Sheka	Anderacha	Genet	1650	2
13	T2831/11	SNNPS	Bench Maji	Merit-Shasha	Betekilu	1930, 1910, 1900, and 1870, resp.	4	34	T74 and 75/11	SNNPS	Sheka	Anderacha	Unit farm 01	1800	2
14	T32 and 33/11	SNNPS	Bench Maji	Merit-Shasha	Barach	1950 and 1900, resp.	2	35	T76 and 79/11	SNNPS	Sheka	Anderacha	Opa	1850 and 1820, resp.	2
15	T34 and 35/11	SNNPS	Bench Maji	Merit-Shasha	Geisha	1975	2	36	T77 and 78/11	SNNPS	Sheka	Anderacha	Opa	1810	2
16	T36/11	SNNPS	Bench Maji	Merit-Shasha	Jongach	1537	1	37	T80 and 81/11	SNNPS	Sheka	Anderacha	Utti	1900	2
17	T37 and 38/11	SNNPS	Bench Maji	Merit-Shasha	Kesibere	1573 and 1555, resp.	2	38	T82 and 83/11	SNNPS	Sheka	Anderacha	Gumbi Kachi	1970	2
18	T3944/11	SNNPS	Bench Maji	Sheko	Adinko	1098, 1067, 1066, 1067, 1049, and 1050, resp.	6	39	T84 and 85/11	SNNPS	Sheka	Anderacha	Gumbi Kachi	1980	2
19	T4547/11	SNNPS	Bench Maji	Sheko	Kentseb	1310, 1335, and 1338, resp.	3	40	T86/11	SNNPS	Sheka	Anderacha	Gumbi Kachi	1890	1
20	T48/11	SNNPS	Bench Maji	Sheko	Mosqude Zuria	1293	1	41	T87 and 88/11	SNNPS	Sheka	Anderacha	Gebbi	2000 and 1990, resp.	2
21	T4953/11	SNNPS	Bench Maji	Sheko	Usika	1075, 1094, 1079, 1047, and 1110, resp.	5					Checks at Gera			
				Checks at Tepi				1	75227						
1	Geisha					For low land		2	7416					For high land	
2	J-19					For low land		3	8136					For high land	
3	Desu					Low to mid land		4	7514					For high land	
4	7454A					Low to mid land		5	741					For high land	
5	7440A					Low to mid land		6	7576					For high land	

Acc.: accessions, No.: number, resp.: respectively, SNNPS: South Nation Nationalities of People; low land (1000–1550 m), mid land (1550–1750 m), and high land (>1750 m).

Table 3: Variability and genetic parameters for yield performance and bienniality.

Locations	GP	2016	2017		2018		2019		2020		Mean
		YLD	YLD	I2	YLD	I3	YLD	I4	YLD	I5	YLD
Tepi	GCV	18.40	22.78	33.76	13.55	24.70	29.95	16.86	37.90	16.88	17.57
	PCV	45.04	48.80	37.93	54.64	30.71	37.77	24.67	40.24	24.43	35.51
	GA	89.23	198.13	0.18	66.56	0.08	228.91	0.06	504.84	0.07	128.74
	GAM	15.41	21.79	61.60	6.89	40.71	48.70	23.62	73.18	23.92	17.81
	H	16.69	21.78	79.22	6.15	64.65	62.90	46.71	88.71	47.75	24.46
	Mean	579.08	909.22	0.28	965.91	0.21	470.01	0.26	689.91	0.27	722.82
	CV (%)	41.11	43.16	17.29	52.94	18.26	23.00	18.01	13.52	17.66	30.87
	F-test	ns	ns	**	ns	ns	ns	ns	**	ns	ns
	CD (0.05)	1227	2023	0.25	2636	0.19	55	0.24	481	0.25	1150
	GP	2017	2018		2019		2020				Mean
		YLD	YLD	I2	YLD	I3	YLD	I4			YLD
Gera	GCV	11.60	14.12	24.49	12.64	19.89	26.69	18.02	—	—	14.48
	PCV	17.31	29.24	44.46	28.49	33.11	33.08	29.54	—	—	20.84
	GA	229.02	104.10	0.10	250.91	0.10	909.16	0.081	—	—	331.37
	GAM	16.01	14.05	27.66	11.54	24.50	44.36	22.54	—	—	20.73
	H	44.90	23.32	30.35	19.67	36.09	65.11	37.22	—	—	48.28
	Mean	1430.88	741.04	0.36	2173.63	0.42	2049.46	0.357	—	—	1598.75
	CV (%)	25.69	51.20	74.21	51.08	52.94	39.08	46.8	—	—	29.97
	F-test	ns	ns	ns	ns	ns	*	ns	—	—	ns
	CD (0.05)	1197	1235	0.86	3615	0.72	2608	0.54	—	—	1560

GP: genetic parameters, GCV: genetic coefficient of variation, PCV: phenotypic coefficient of variation, GA: genetic advance, H: heritability, YLD: yield, I2: biennial bearing intensity between 2016 and 2017 (I3: between 2017 and 2018, I4: between 2018 and 2019, and I5: between 2019 and 2020), CD: critical difference, CV: coefficient of variance, H: heritability, GA: genetic advance, and GAM: genetic advance as percentage of mean. Note: * and ** represent significant differences at 0.05 and 0.01, respectively; ns: nonsignificant difference.

2.4.1. Components of Variance. Error ($\sigma^2 e$) and genotypic ($\sigma^2 g$) and phenotypic ($\sigma^2 p$) variance were computed by the following formula suggested by Hallauer et al. [20] and Singh and Chaudhary [21]. $h^2 = s_g^2 / sp^2$, where s_g^2 is genotype, sp^2 is phenotypic variance, and h^2 is broad sense heritability.

The following random model is used to estimate variance components and response to phenotypic selection of pooled analysis: $Y_{ijk} = \mu + g_i + h_j + b_k + gh_{ij} + \varepsilon_{ijk}$, where y_{ijk} is the phenotypic value for the genotype i, year j, and block k, μ is the population mean, h_j is the random effect of year, g_i is the random genotypic effect, b_k is the effect of kth block, gh_{ij} is the interaction random effect between genotypes and years, and e_{ijk} is the random effect of residuals. $h^2 = s_g^2 / (s_g^2 + s_{gy}^2 / y + s_e^2 / yr)$, where s_g^2 is a genotype, s_{gy}^2 is the interaction between g and y, s_e^2 is the experimental error variance, and r and y are the number of replicates and years, respectively. Response to selection: $RS = ih\,\sigma p$, where i is the selection intensity (at 5%), h is the square root of heritability ($\sqrt{h^2}$), and σp is the phenotypic standard deviation.

3. Results and Discussion

3.1. Variability in Biennial Bearing and Yield. In most years or harvesting seasons including over year mean, a nonsignificant difference was observed among accessions in yield and biennial bearing at both locations (Table 3). This is due to a high mean square of error against which the whole accession mean square was tested. However, a highly significant ($P < 0.01$) difference in yield performance was observed among coffee accessions in the 2020 harvesting season at Tepi and significant difference ($P < 0.05$) in yield performance at Gera in the same harvesting season; this may be due to a difference in yield potential expression of coffee accessions as the evaluation years extend. Likewise, variability among Arabica coffee accessions in clean yield was reported by many investigators [15, 22–25]. At Tepi, a highly significant difference in biennial bearing was observed among testing materials during early harvesting seasons (2017 and 2018). This resulted from the bienniality range recorded from 0 (nonbiennial) to 38.9 in these consecutive years (Table 4). In agreement, at early stage, significant variability was detected among pistachio in alternate bearing [24]. Despite nearly null to complete range in biennial bearing being revealed among accessions including standard checks, a nonsignificant difference was observed at Gera (Tables 3 and 5), which resulted from a high mean square of error (high environmental contribution) against which bienniality of coffee was tested.

At Tepi, a high genotypic coefficient of variance (GCV > 20%) manifested in yield across harvesting seasons except in 2016 and 2018, whereas from over year mean of yield, moderate GCV (10–20%) was recorded. However, high PCV (>20) was observed across all seasons. High and moderate genetic gains as percentage of the mean (GAM > 20) and (GAM 10–20%) were observed in these harvesting seasons at this location. High heritability (62.9–88.71%) was recorded for yield in 2017, 2019, and 2020, but moderate to low was observed in the rest seasons. Moderate GCV (10–20%) was recorded at Gera except in 2020 (which was 26.69%), but except in 2017, high PCV (>20%) was observed in all seasons including over year mean

Table 4: Range of relative % of bienniality between consecutive harvesting seasons at Tepi.

Year	Range (%)	Genotypes
2016-2017	0.23–86.39	T20/11 and T66/11
2017-2018	0–39.90	T13/11, T19/11, T28/11, T35/11, T52/11 and T66/11 (0), and T8/11 (39.9)
2018-2019	0.88–9 0.68	T63/11 (0.88) and T20/11 (90.68)
2019-2020	0.26–81.59	T33/11 (0.26) and T14/11 (81.59%)

Table 5: Range of relative % of bienniality between consecutive harvesting seasons at Gera.

Years	Range	Genotypes
2017-2018	0.07–100	T13/11 (0.07) and T71/11 (100)
2018-2019	0.04–100	T34/11 (0.04) and T 37, T32, T71, and T83/ 11(100)
2019-2020	0.39–100	T55/11 (0.39) and T29/11(100)

of yield. In line with this, fluctuation of genetic parameters' results was observed across harvesting seasons in coffee yield [25, 26]. From the over year mean of yield, moderate GCV (10–20%), GAM, and heritability were clearly pointed out at both locations (except GAM (>20) at Gera) which elucidated the existence of moderate genetic variability among accessions in yield performance. Concurring, moderate genetic variability among coffee accessions was found in yield [22, 27]. Additionally, gene involvement for controlling biennial bearing had been detected [10, 13]. By selecting the top 5% high yielders' genotypes from the accessions in 2020 harvesting season, it is possible to improve clean coffee yield by 504.84 $kgha^{-1}$ and 909.16 $kgha^{-1}$ at Tepi and Gera, respectively (Table 3).

High GCV, GAM, and H (33.76% and 24.70%, 61.60% and 40.71%, and 79.22% and 64.65% for I2 and I3, respectively) were recorded from over two and three years for biennial bearing; moderate GCV (16.86 and 16.84%), H (46.71 and 47.75%), and high GAM (23.62 and 23.92%) were noted from over four (I4) and five (I5) harvesting seasons, respectively, at Tepi (Table 3). Also, moderate GCV, H, and high GAM (19.89 and 18.02%, 36.09 and 37.22%, and 24.50 and 22.54% for I3 and I4, respectively) were observed at Gera which indicated that the handiness of genetic variability among coffee accessions in biennial bearing. The present results confirmed with the findings of Esmailpour [28] and Todd et al. [5] who reported variability among pistachio sp. in alternate bearing. From the two locations' genetic parameters results, it was elucidated that the possibility of alternate bearing improvement via selection and/or hybridization. From the population of the top 5% low biennial bearing genotypes, it is possible to mitigate bienniality to the average values of 0.06 and 0.08 at Tepi and Gera, respectively.

3.2. Alternate Bearing of Arabica Coffee across Harvesting Seasons. Although the ANOVA of biennial bearing showed nonsignificant differences in some seasons, the bienniality range between pair of harvesting seasons was very large (Table 5). For the pair consecutive of harvesting seasons (2017 and 2018, 2018 and 2019, and 2019 and 2020), the relative percentage of bienniality ranges from 0.07, 0.04, and 0.39 to 100%, receptively. From theses ranges, it was clearly observed that the existence of almost nonbienniality (0.07 and 0.04 which was recorded by T13 and T34/11, respectively) to complete bienniality (100% which was recorded for T71, T37, T32, T83, and T29/11) among accessions was seen. Also, the bienniality range from 0 to 39.90% was observed between 2017 and 2018 harvesting seasons at Tepi (Table 4). For the others pair of consecutive harvesting seasons less than one (<1) to 90.68%, the range of bienniality was recorded at Tepi. This implies that the presence of genetic variability among Arabica coffee germplasms in biennial bearing which is a desirable trait for solving alternate bearing problem of commercially released varieties.

The lowest relative bienniality between 2017 and 2018 was recorded for T13/11 genotypes at both locations (Tables 4 and 5). Accessions such as T19, T28, T35, T52, and T66/11 showed zero in biennial bearing between 2017 and 2018 harvesting seasons. The relative biennial bearing for some accessions may vary from seasons to seasons and location to location; this indicates that the selection of coffee genotypes for less biennial to nonbienniality using relative biennial bearing of consecutive seasons should be supported by biennial bearing intensity. In agreement, variability of bienniality across seasons was reported for pistachio [24]. During nonbiennial bearing selection, one has to be conscious of the extraneous factors such as environment and weather condition of the harvesting seasons in addition to genetic factor.

3.3. Biennial Bearing Intensity (I) and Response to Selection (R). Biennial bearing intensity showed an increase during early harvesting seasons (from 2016-2017) at Tepi (Figure 1 (A)) but showed a decrease at Gera (Figure 1 (B)). At early, over two and three harvesting seasons (2016-2017 and 2016–2018, respectively) response to selection an upsurge and decrease, respectively, such as biennial bearing intensity at Tepi. From over three harvesting seasons to four (2016–2019), the overall bienniality was increased exponentially; also, a relatively increment of response to selection was observed. From over four to five seasons, the alternative bearing intensity and the overall mean performance almost remained constant, but response to selection was increased. This may be because sometimes coffee genotypes bear extremely high yield during on years relative to off years which may result in high biennial bearing and high phenotypic performance in yield which may contribute for increments of response to selection. Thus, biennial bearing and response to selection may be increasing or decreasing together or may

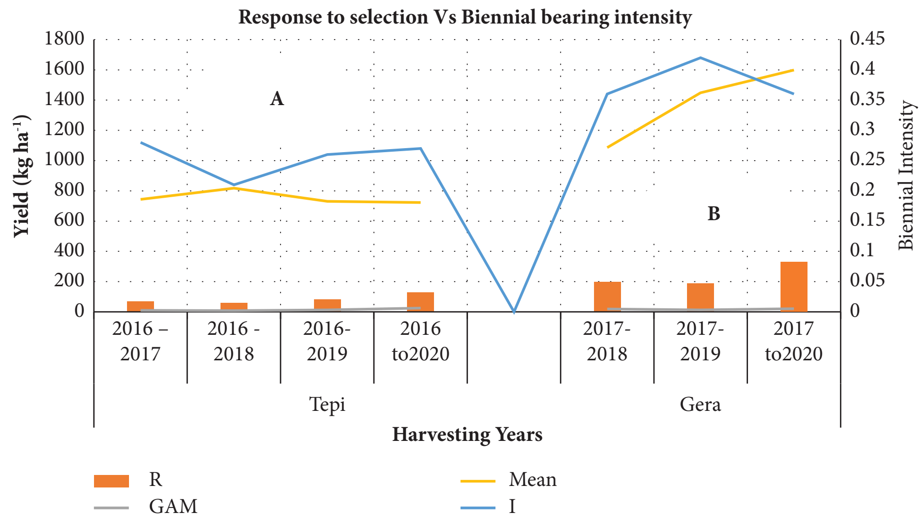

Figure 1: Alternate bearing intensity and response to selection for pooled harvesting seasons: I: biennial intensity, R: response to selection, and GAM: genetic advance as percentage of mean.

Table 6: Biennial bearing and selection of promising lines at Gera.

Acc.	Rank (2YRS)	RP1	Rank (3YRS)	RP2	Rank (4YRS)	RP3	I
T50/11	16	2.24	23	32.08	1	52.24	0.30
T78/11	1	82.94	1	81.46	2	8.74	0.58
T80/11	11	5.34	14	40.88	3	29.27	0.25
T53/11	5	39	4	56.21	4	6.16	0.34
T39/11	46	39.56	8	76.17	5	19.5	0.45
T38/11	23	18.16	37	32.89	6	38.41	0.31
T70/11	12	58.65	10	72.93	7	17.38	0.50
T60/11	2	0.79	2	8.33	8	22.05	0.10
T43/11	6	21.92	15	36.56	9	6.94	0.22
T85/11	8	42.2	5	59.32	10	23.95	0.42
T67/11	83	8.21	7	80.39	11	38.82	0.42
T64/11	15	39.94	19	54.75	12	9.13	0.35
T51/11	9	13.12	3	49.38	13	34.78	0.32
T59/11	26	33.16	30	51.68	14	18.27	0.34
T41/11	52	72.44	28	84.52	15	6.42	0.54
<15 HY in%	**60**		**66.7**		**100**		

Rank (2YRS): ranks of the top 15 genotypes using the mean of over two years (2017 and 2018), 3YRS: the mean of over three years (2017–2019), 4YRS: the mean of over three years (2017–2020), RP1-4: relative percentage of biennial bearing between consecutive years, Acc.: accessions, ≤15 HY in %: the top 15 high yielder in percentage, and I: biennial bearing intensity. Note: over the top 15 high yielders selected using the average mean of yield over four harvesting seasons. The bold values indicate the selection efficiency percentage using the top 15 high yielding promising lines.

show opposite relation. Concurring, Merga et al. [15] reported that bienniality nature of Arabica coffee could affect the genetic gain and response to selection.

At Gera, biennial bearing and response to selection showed contrasting relation (Figure 1 (B)). In addition, at early harvesting seasons, biennial bearing decreased. However, response selection showed upswing. Over two to three harvesting seasons, bienniality was upraised, whereas the reverse was true for response to selection. Response to selection exponentially increased, while biennial bearing exponentially decreased at over three to four harvesting seasons. The overall mean of yield across all harvesting seasons was increasing at this location. The relationship between response to selection and biennial bearing at Gera was logically expected as bienniality under normal state negatively influenced the overall yield performance which may affect response to selection of the top high yielder genotypes. The negative impact of bienniality on genetic gain or response to selection was confirmed in Arabica coffee [15].

3.4. Biennial Bearing Intensity and Selection Efficiency. Coffee accessions showed better performance having low biennial bearing found in rank of the top high yielders when compared with accessions with high biennial bearing

Table 7: Biennial bearing and selection of promising lines at Tepi.

Access.	Rank (2YRS)	RP1	Rank (3YRS)	PR2	Rank (4YRS)	RP3	Rank (5YRS)	RP4	I
T 21/11	15	0.23	15	11.90	15	28.83	10	47.87	0.22
T 22/11	14	79.20	8	5.88	7	39.31	7	28.88	0.38
T 36/11	13	63.32	7	10.00	8	49.45	6	44.90	0.42
T 37/11	2	45.50	4	11.11	4	46.83	1	56.23	0.40
T 38/11	5	64.63	11	22.22	10	43.63	2	66.91	0.49
T 40/11	1	73.79	3	33.33	3	40.44	4	39.33	0.47
T 41/11	7	10.74	6	26.43	6	56.40	8	28.77	0.31
T 42/11	4	56.09	2	4.76	2	35.01	5	43.28	0.35
T43/11	3	9.16	1	15.79	1	22.05	3	48.99	0.24
T51/11	12	9.78	5	36.10	5	51.68	9	4.66	0.26
≤10 HY in %	**70**		**80**		**90**		**100**		

Rank (2YRS): ranks of the top 10 genotypes using the mean of over two years (2016 and 2017), 3YRS: the mean of over three years (2016–2018), 4YRS: the mean of over three years (2016–2019), 5YRS: the mean of over five years (2016–2020), RP1-5: relative percentage bienniality between consecutive years, ≤15 HY in %: the top 15 high yielder in percentage, and I: biennial bearing intensity. Note: over the top 15 high yielders selected using the average mean of yield over five harvesting seasons. The bold values or selection efficiency in the percentage show the experts' efficiency in selecting promising line across harvesting season. Also, the values predict how much promising lines could be excluded from the selection due to their bienniality nature; additionally, the values manifest the appropriate time or harvesting season of selecting promising lines or at the time when high selection efficiency is achieved. This part is highly important to create awareness for coffee experts not to simply select advanced line during selection and bold-out the influence of bienniality to the experts. In general, all these were clearly discussed in the article text or body.

(Tables 6 and 7). This is due to their inherency in consistent high yielding performance across years as compared to those exhibiting high biennial bearing. Coffee genotypes such as T60/11, T43/11, and T80/11 revealed 0.1, 0.22, and 0.25 biennial bearing intensity (I), respectively, at Gera (Table 6). Also, at Tepi, T41/11, T42/11, and T43/11 showed low biennial bearing intensity (0.31, 0.35, and 0.24, respectively) (Table 7). These genotypes were ranked the top 15 (at Gera) and the top 10 high yielders (at Tepi) in all over year yield performance from over two (2YRS) to four (at Gera) and five (at Tepi) harvesting seasons. For such coffee genotypes, early selection (before or at three harvesting seasons) may be as efficient as late (four or late harvesting seasons) selection. T41/11 showed high relative percentage of biennial bearing across overall harvesting (72.44% from over two seasons and 84.25% from over three seasons) and biennial intensity (0.54) at Gera (Table 6). Thus, it ranked below the top 15 high yielders in yield performance by over two and three (3YRS) mean of yield; thus, early selection may exclude such genotypes from the next breeding program. Likewise, biennial bearing intensity ranges from 0.19 to 0.93 and 0.14 to 0.89 were recorded for pecan and pistachio, respectively [24, 29].

Some coffee genotypes such as T70/11, T78/11, and T85/11 showed high relative percentage of bienniality (RP) and biennial bearing intensity (0.5, 0.58, and 0.42, respectively) at Gera (Table 6); also, T37/11, T38/11, and T48/11 recorded high RP in pair of consecutive seasons and biennial intensity (0.4, 0.49, and 0.47, respectively) at Tepi (Table 7). But from population, they ranked the top 15 high yielder in over two, three, and four harvesting seasons (at Gera) and five harvesting seasons (at Tepi) (Tables 6 and 7). Additionally, genotype T78/11 had recorded the highest biennial bearing intensity (0.58) and high RP (which were 82.94 and 81.46% in RP1 and RP2, respectively); however, it ranked 1st, 1st, and 2nd by the mean of 2YRS, 3YRS, and 4YRS, respectively. This resulted from the extremely high yield recorded by this genotype during on years relative to off year and other genotypes that compensate its low yield in off seasons. Thus, the mean of yield over seasons maintains superiority of genotypes, while a high difference in yield between on and off seasons causes high alternate bearing intensity. Thus, while promising line selection, coffee breeders should be conscious of the biennial bearing nature of coffee genotypes.

High relative percentage of biennial bearing was observed early in RP1 and RP2 at Gera and in RP1 at Tepi (Tables 6 and 7). Depending on the top 15 high yielders by 4YRS mean yield performance, 60 and 66.7% of the top 15 were selected by 2YRS and 3YRS, respectively, at Gera (Table 6), whereas at Tepi, 70, 80, and 90% of the top 10 high yielders were selected by 2YRS, 3YRS, and 4YRS when compared with 5YRS of the top 10 high yielders (Table 7). Thus, the two locations' results elucidated that selection is ideal and more efficient at fourth harvesting seasons; selection of early four harvesting seasons may ignore some promising line from further evaluation.

3.5. Advanced Selection of Top High Yielder and Top Less Alternate Bearing. The top 10 and 15 high yielders were selected from accessions using over five and four harvesting seasons at Tepi and Gera, respectively, regardless of their biennial nature (Tables 8 and 9). Coffee accessions were less performed in yield at Tepi when compared with Gera. All accession yield performance at Tepi was less than checks. The highest yielder accession at Tepi was T37/11 which had recorded 1838.07 kgha^{-1}. From the top 10 in yield performance, T21/11, T43/11, and T51/11 showed relatively low biennial bearing. The check, Desu showed very low biennial bearing (I = 0.09) such as T33/11, T61/11, and T62/11 which were the top 10 in low alternate bearing at Tepi. Also, this check was a high yielder (recorded 2336 kgha^{-1}) in addition to its low in biennial bearing. This material is prominent in the future coffee improvement for alternate bearing.

Table 8: The top ten high yielders (kg ha^{-1}) and low biennial bearing accessions at Tepi.

Genotypes	Top ten high yielder (kg ha^{-1})								Genotypes	Top ten very low biennial bearing accessions							
	2016	2017	2018	2019	2020	Mean	CV (%)	I		2016	2017	2018	2019	2020	Mean	CV (%)	I
T21/11	1143.8	1149.1	1459.5	806.2	2287.01	1369.12	36.76	0.22	T26/11	250.2	561.6	505.4	426.3	460.4	440.77	23.94	0.14
T22/11	250.2	2155.4	2424.9	1056.4	1914.49	1560.28	51.25	0.38	T28/11	379.9	270.6	270.6	463.3	443.2	365.52	22.5	0.11
T36/11	444.8	1980.4	2420.5	818.8	2153.24	1563.55	50.05	0.42	T32/11	656.8	418.7	523.3	333.6	506	487.67	22.22	0.19
T37/11	984.1	2627.1	2101.7	761	2716.46	1838.07	44.55	0.40	T33/11	762.5	656.1	664.8	852.5	856.9	758.57	11.46	0.05
T38/11	553.5	2575.9	1639.2	643.4	3245.45	1731.49	61.04	0.49	T49/11	417	687.2	712.2	934.1	1177	785.47	32.5	0.13
T40/11	533.8	3539.5	1769.7	750.6	1723.6	1663.44	63.87	0.47	T55/11	740.2	388.2	533.8	545.9	510.8	543.79	20.8	0.13
T41/11	1684.7	1357.8	2333.5	650.5	1175.94	1440.49	38.75	0.31	T61/11	342.9	433.7	481.9	525.4	454.1	447.59	13.56	0.07
T42/11	708.9	2520.2	2772.2	1334.4	528.2	1572.78	58.48	0.35	T62/11	386.7	398.9	435.2	375.3	583.8	435.98	17.57	0.09
T43/11	1595	1916.7	2635.4	1683.2	576.22	1681.3	39.4	0.24	T73/11	262.1	265.4	417	379.1	215.5	307.81	24.92	0.14
T51/11	1121.3	1364.4	2906	925.7	843.27	1432.13	52.96	0.26	T77/11	222.4	417	486.5	393.2	342.9	372.39	23.66	0.14
	Check								Mean	**442.07**	**449.74**	**503.07**	**522.87**	**555.1**	**494.56**		
Geisha	3684	4759.6	5707.4	1058.4	2713.79	3584.7	45	0.34									
J-19	3243	5485.6	4220.4	2245.2	2009.53	3440.65	37.5	0.19									
Desu	2356	2861.3	2538.3	1843.9	2085.38	2336.92	15.1	0.09									
7454A	3097	3393.4	5408.1	1262.4	1886.23	3009.37	47.5	0.27									
7440A	3583	2461.9	2640.1	1477.3	2639.06	2560.21	26.1	0.20									
Mean	**672.48**	**1055.87**	**1121.7**	**545.81**	**801.18**	**839.41**	**26.21**	**0.19**									
			CDD (0.05)														
CI-CJ	734	1209	1576	333	287	687		0.15									
VI-VJ	1607	2649	3452	730	630**	1506		0.33									
CI-VJ	1227	2023	2636	55	481	1150		0.25									

CD: least significant difference, CV: coefficient of variation, I: intensity of biennial index, Geno.: genotypes, CD: critical difference, CI-CJ: between two control treatments, VI-VJ: between two augmented treatments in different blocks, and CI-VJ: between control treatment and augmented treatment. Note: yield was expressed in kg·ha^{-1}. The bold values show the mean of yield down column of harvesting seasons.

TABLE 9: The top fifteen high yielders (kg ha^{-1}) and top ten low biennial bearing accessions at Gera.

Geno.	The top fifteen high yielders (kg ha^{-1})							Geno.	The top ten very low biennial bearing accessions						
	2017	2018	2019	2020	Mean	CV (%)	I		2009	2010	2011	2012	Mean	CV (%)	I
T38/2011	1462.28	1012.89	2005.77	4507.77	2247.18	60.15	0.30	T10/2011	952.09	873	1271.9	804.81	975.45	18.34	0.15
T39/2011	1399.45	606.04	4481.36	3019.08	2376.48	62.88	0.45	T13/2011	685.18	686.1	1507.5	1784.76	1165.9	42.04	0.15
T41/2011	1627.97	260.21	3101.74	3526.99	2129.23	60.53	0.54	T33/2011	1059.2	956.2	2243	2668.8	1731.8	42.76	0.18
T43/2011	1624.16	1861.91	2939.73	1718.04	2035.96	25.96	0.18	T34/2011	1392.2	885.2	884.41	839.56	1000.3	22.69	0.08
T50/2011	1282.36	1341.07	2607.92	4987.01	2554.59	85.45	0.29	T43/2011	1624.2	1862	2939.7	1718.04	2036	25.96	0.18
T51/2011	1690.24	1298.26	3830.68	1853.86	2168.26	45.23	0.32	T47/2011	1342.4	1182	2767.2	2433.61	1931.3	35.31	0.18
T53/2011	2244.02	984.86	3513.23	3105.82	2461.98	39.32	0.34	T49/2011	1471.5	1083	1857.5	2176.74	1647.2	24.92	0.16
T59/2011	1594.05	800.22	2511.67	3634.57	2135.13	49.48	0.34	T55/2011	635.27	617.2	717.24	711.68	670.34	6.66	0.03
T60/2011	2288.87	2253.05	2662.68	1700.43	2226.26	15.42	0.10	T60/2011	2288.9	2253	2662.7	1700.43	2226.3	15.42	0.10
T64/2011	1872.43	803.56	2748.45	3300.56	2181.25	43.30	0.35	T61/2011	1272.5	820.7	725.41	1064.18	970.69	22.01	0.16
T67/2011	673.46	571.29	5255.03	2315.74	2203.88	85.88	0.42	Mean	**1272.34**	**1121.84**	**1557.66**	**1590.26**	**1435.53**		
T70/2011	2182.37	568.79	3633.65	2557.60	2235.60	49.20	0.50								
T78/2011	2051.10	431.83	4226.53	2128.10	2209.34	51.40	0.58								
T80/2011	1456.53	1308.86	3119.16	3838.01	2430.64	61.05	0.25								
T85/2011	2232.15	907.21	3552.63	2179.52	2217.88	42.18	0.42								
	Check														
75227	1528.07	382.02	2649.35	3067.38	2139.66	50.03	0.47								
7416	1819.43	454.86	3191.43	2714.67	2179.82	48.20	0.48								
8136	1567.58	391.89	2976.87	2440.81	1871.71	52.26	0.49								
7514	1676.65	419.16	2776.70	1701.36	1695.77	49.33	0.53								
741	1411.33	352.83	3378.98	2987.47	2083.90	58.49	0.49								
7576	1481.00	370.25	2704.59	1936.2	1698.97	49.95	0.51								
Mean	**1402.19**	**709.46**	**2025.67**	**1968.04**	**1532.45**	**34.64**	**0.27**								
CD(0.05)															
CI-CJ	554	572	1673	1207	722		0.25								
VI-VJ	1197	1235	3615	2608*	1560		0.54								
CI-VJ	919*	948	2775**	2002*	1198		0.42								

CD: least significant difference, * and **: significant ($p < 0.05$) and highly significant difference ($p < 0.01$), CV: coefficient of variation, I: intensity of biennial index, Geno.: genotypes, CD: critical difference, CI-CJ: between two control treatments, VI-VJ: between two augmented treatments in different blocks, and CI-VJ: between control treatment and augmented treatment. *Note.* The unit of yield is kg·ha^{-1} The bold values indicate the mean performance of the whole coffee genotypes down column or harvesting seasons.

In contrast, most high yielder accessions showed superior in yield performance than checks at Gera. A significant difference in yield performance was exhibited in 2017 and 2020 harvesting seasons, and it was highly significant as observed in the 2019 season between control and accessions at Gera. Genotype T80/11 recorded the 3rd highest yield following T53/11 and T50/11, respectively, (Table 9). Despite nonsignificant differences among treatments, these high yielders gave 374.77 kgha^{-1}, 282.16 kgha^{-1}, and 250.82 kgha^{-1} yield advantage over high yielder check 7416 (which recorded 2179.82 kgha^{-1}), respectively. Except T41/11, T70/11, and T78/11, all the top 15 high yielders at Gera exhibited low biennial bearing relative to standard checks. From the top 10 (at Tepi) and top 15 (at Gera) high yielders, T43/11 and T51/11 recoded low biennial bearing at both locations. Among the top 10 very low biennial bearing selected, T33/11, T49/11, T55/11, and T61/11 showed very low biennial bearing at Gera and Tepi; these accessions' biennial bearing ranged from 0.18 to 0.03 which is very low. Such genotypes have to be taken into consideration during the coffee alternate bearing improvement breeding program. Multitude of scholars authenticated the existence of biennial variability among different horticultural crops [24, 29–33].

4. Conclusion

Variability was observed among coffee accessions in yield performance and biennial bearing in some harvesting seasons. Highly significant ($p < 0.01$) and significant ($p < 0.05$) variability was shown among the entire testing materials at Tepi and Gera, respectively, in the 2020 harvesting season. Among coffee accessions, a highly significant difference was indicated in biennial bearing at early stage at Tepi. The over season pooled analysis of yield and alternate bearing intensity revealed the existence of moderate genetic variability among coffee accessions. The moderate genetic coefficient of variance (GCV) (17.57 and 14.48%), heritability (H) (24.46 and 48.28%), and high genetic advance as percentage of the mean (GAM) (17.81 and 20.74) were recorded in yield at Tepi and Gera, respectively. For bienniality, moderate GCV (18.02 and 16.57%), H (37.22 and 47.75%), and high GAM (22.54 and 23.92%) were observed at Gera and Tepi, respectively.

Alternate bearing could affect response to selection which leads to less selection efficiency. Early selection, using two and three harvesting seasons, excludes 30–40% and 33.3–20% high yielders from advanced selection. Selection at four harvesting seasons revealed 90% and more selection efficiency which is the appropriate time for promising line selection.

Over year yield performance of coffee accessions at Tepi was less than checks. However, at Gera, most of the top 15 selected ones were high yielder than standard checks. T43/11 and T51/11 were the top high yielders and showed low biennial bearing at Gera and Tepi. T33/11, T49/11, T55/11, and T61/11 showed very low biennial bearing at both locations. Thus, these accessions need to be taken into consideration during the bienniality improvement breeding program. Generally, one has to be conscious of the biennial bearing nature of Arabica coffee during advanced selection.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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