Genotype x Environment Interaction for Tuber Yield, Dry Matter Content and Specific Gravity in Elite Tetraploid Potato (*Solanum Tuberosum* L.) Genotypes

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Abstract: A study was conducted to determine stability of tuber yield, dry matter content and specific gravity, and the nature and magnitude of genotype x environment (G x E) interaction in elite tetraploid potato genotypes. Eleven potato genotypes including two standard checks were evaluated in the eastern part of Ethiopia at Haramaya, Langae, Kulubi, Hirna and Arberekete during 2008 and 2009 cropping seasons under rainfed condition. There were significant variations among genotypes with respect to tuber yield and dry matter content while the genotypes exhibited comparable tuber specific gravity values. Significant G x E interaction was observed for tuber yield and dry matter content and G x E mean square for tuber specific gravity was not significant indicating that G x E has negligible influence on the trait. Partitioning of the G x E interaction for both tuber yield and dry matter content indicated the presence of both linear and non-linear types of G x E interactions. None of the genotypes were found to be stable and ranked at the top for tuber yield, dry matter and specific gravity. The stability and responsiveness appeared to be specific for specific character within a single genotype. Genotype CIP-392640-528 is stable for specific gravity, average responsive for tuber dry matter content and above responsive for tuber yield. Highly significant positive correlation (r = 0.99) was obtained between specific gravity and dry matter content proving that specific gravity is a true indicator of tuber dry matter content. The observed significant G x E interaction for tuber yield and dry matter content suggests that potato breeders should give special emphasis for G x E interaction while developing stable and high yielding genotypes in terms of tuber yield and dry matter content.

Keywords: Hararghe; Pooled Analysis; Pooled Deviation; Responsiveness; Stability

1. Introduction

Ethiopia has suitable edaphic and climatic conditions for the production of high quality ware and seed potatoes. About 70% of the available agricultural land is located at an altitude of 1800-2500 masl and receives an annual rainfall of more than 600 mm, which is suitable for potato production (Solomon, 1987). However, the total area under potato production is estimated at 36736 ha with an annual production of 385258 metric tons (FAOSTAT Data, 2004). The national average yield is approximately 10.5 tons ha^{-1}, which is very low compared to the world average of 16.4 tons ha^{-1}. A number of production problems that account for the small area cropped with potato and the low national yield have been identified. The major ones are unavailability and high cost of seed tubers, lack of well-adapted cultivars, sub-optimal agronomic practices, the prevalence of diseases and insect pests, and inadequate storage, transportation, and marketing facilities.

The entire variable encountered in producing a crop can be collectively called environment and every factor that is part of the environment has the potential to cause differential performance that is associated with G x E interaction in potatoes (Fehr, 1987). Potato is grown around the world in a wide array of environments and the crop is flexible to adapt to different growing conditions. Nevertheless, some of its traits such as tuber yield, specific gravity and dry mater contents are found to be influenced by environmental changes as shown by previous G x E studies (Tai and young, 1972; Tai, 1979, DeJong *et al.*, 1981, Yildirim and Caliskan, 1985, Stephen *and* Joseph 1991; Haynes *et al.*, 1995; Tekalign, 2003; Hassanpanah, 2010).

The dry matter content of tubers is an important measure of quality and it is used to assess suitability for the processing purpose as it influences process efficiency, product yield and oil absorption (Stevenson *et al.,* 1964). Specific gravity of raw potatoes is widely accepted by the potato processing industry as a measure of total solids, starch content and other qualities (Fitzpatrick *et al.,* 1964). High dry matter content and specific gravity in potato tubers are important to the grower and the processor.

A number of improved potato cultivars have been developed by different research institutions in Ethiopia and widely used for the preparation of traditional food types. In developing these varieties, however, much emphasis was given to productivity per unit area and late blight resistance or tolerance while less emphasis was given to processing quality. Currently, the demand for cultivars suitable for processing of potato crisps and French fries is increasing. To meet the demand, Potato Improvement Program of Haramaya University has revised its breeding strategy and working towards the development of late blight tolerant varieties with high tuber yield and dry matter content as well as specific gravity values. In addition, the suitability of the varieties for processing is being tested in a laboratory. As part of the breeding program, the study was undertaken to assess genetic variability for tuber yield, dry matter content and specific gravity in advanced breeding materials introduced from International Potato Center (CIP) and investigate the effect of different growing conditions on these characters; ultimately to identify stable genotypes with high tuber specific gravity and dry matter content for future improvement effort. This paper reports phenotypic stability of eleven elite tetraploid potato genotypes for

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tuber yield, dry matter content and specific gravity, and the nature and magnitude of G x E interaction in potato.

2. Materials and Methods

2.1. Description of the Study Areas

Eleven potato genotypes including two standard checks were grown at Haramaya, Langae, Kulubi, Hirna and Arberekete during the 2008 and 2009 cropping seasons under rainfed condition. The locations represent the major potato growing areas of eastern Ethiopia since they are diverse in climate and soil type and have been used as testing sites for Potato Improvement Program of Haramaya University (Table 1).

Table 1. Description of the experimental sites.

Location	Altitude (masl)	Soil type	Annual rainfall (mm)	Mean annual Max./Min. T^o (^{o}C)
Haramaya	1980	Alluvial soil	780	23.4/8.5
Langaie	2025	Vertisol	810	22.5/9.4
Kulubi	2330	Leptosol	862	19.5/7.3
Hirna	1845	Vertisol	847	21.8/8.6
Arberekete	1850	Verti-cambisol	890	21.5/10.3

2.2. Experimental Procedures

At all locations, the experimental plots were arranged in a randomized complete block design with three replications. Plots were arranged continuously and end plots were bordered by two rows of potato plants. Five rows of ten hills were planted at a spacing of 75 cm between rows and 30 cm between plants. Spacing between plots and replications were 1 m and 1.5 m, respectively. At each site, plots were fertilized with 150 kg phosphorus ha^{-1} in the form of diammonium phosphate and 100 kg nitrogen ha^{-1} in the form of urea. The entire rate of phosphorus and the half rate of the nitrogen fertilizer were applied at the time of planting. The remaining half of the nitrogen was applied at flowering. Cultural practices such as weeding, cultivation and ridging were practiced as per the regional recommendation (Teriessa, 1997).

2.3. Data Collection

Fresh tuber yield of 20 hills harvested from the central rows was used as a base to determine total tuber yield per ha. Tuber specific gravity was measured using the weight in air and weight in water method (Murphy and Goven, 1959). To determine dry matter content of tubers, ten tubers were taken at random from the harvested plot, washed, chopped and mixed. Two sub-samples 200 g each were taken and pre-dried at a temperature of 60°C for 15 h and further dried for 3 h at 105°C in a drying oven. Dry matter content was calculated as the ratio between dry and fresh mass expressed as a percentage.

2.4. Data Analysis

Data were subjected to combined analysis of variance after doing Barlett's test of homogeneity to obtain estimates of environmental, genotypic, and genotype x environment interaction source of variation. The following linear model developed by Eberhart and Russell (1966) was used..

$$Y_{ij} = \mu_i + \beta_i I_i + \delta_{ij}$$

where Y_{ij} = mean performance of the ith variety at the jth environment; μ_i = Mean of the ith variety over all the environments; β_i = Regression coefficient ; I_i = Environnemental index ; δ_{ij} = Deviation from regression of the ith variety at jth environment.

Computation of stability parameters for each genotypes and partitioning of G x E interaction into linear and non-linear components were done using the procedure developed by Elberhart and Russell (1966). The regression coefficient (β_i) and the mean square deviation (S^2d_i) were used as measures of responsiveness and stability, respectively, according to Elberhart and Russell (1966) and Finlay and Wilkinson (1963). The analysis of variance and the linear regression were performed using STATISTICA computer software (Statsoft, 1999). Simple linear correlations between parameters were computed when applicable.

3. Results and Discussion

According to Bartlett's homogeneity test, the observed chi-square (χ^2) is less than the table value (P< 0.01) indicating that error variances of the ten environments are homogeneous and hence pooled analysis was done.

The combined analysis of variance for G x E interaction is presented in Table 2. Mean squares for genotypes were highly significant for tuber yield and dry matter content signifying the existence of considerable variation among the genotypes. Various researchers reported the existence of significant variability among genotypes for tuber yield (Tai and young, 1972; DeJong *et al.*, 1981; Haynes *et al.*, 1995; Tekalign, 2003; Hassanpanah, 2010). Greater variation for dry matter and glucose contents were demonstrated in a pre-breeding population of diploid species than in the more advanced tetraploid breeding population (Amoros *et al.*, 1999-2000). On the contrary, mean square for specific gravity found to be non significant indicating that there is no significant variability among the genotypes for this specific trait. This may be attributed to the advancement of these genotypes from 150 initial breeding clones based on tuber specific gravity and dry matter content. Haynes *et al.* (1995) evaluated 72 diploid hybrid clones grown at two sites for three consecutive years for specific gravity and reported a significant variation among them.

Table 2. Analysis of variance for stability of potato tuber yield, dry matter and specific gravity.

		Mean squares		
Source	df	Tuber yield	Dry matter	Specific gravity
Genotype	10	125.19**	5.54**	0.00014^{ns}
Environment + (G x E)	99	55.55	3.85	0.00008
Environment (linear)	1	3309.58	290.47	0.00610
G X E (linear)	10	11.58**$^{(NS)}$	0.60**$^{(NS)}$	0.000019$^{ns(NS)}$
Pooled Deviation	88	23.57**	0.96**	0.00021^{ns}
Pooled Error	200	0.012	0.125	0.00033

*^{ns}, ** = Not significant at 5% and significant at 1% difference probability level, respectively, when tested against pooled error; $^{(NS)}$ = Not significant at 5% probability level when tested against pooled deviation.*

The mean squares for G x E were highly significant for tuber yield and dry matter content indicating that the genotypes showed a differential response to the characters in the different environments. The existences of significant G x E interaction in potato for tuber yield (Tai and young, 1972; Tai, 1979; DeJong *et al.*, 1981; Yildirim and Caliskan, 1985; Hassanpanah, 2010) and dry matter content (Tai and young, 1972) have been reported based on the findings of previous similar investigations. The G x E mean square for tuber specific gravity was not significant indicating that G x E has negligible influence on the trait. Stephen and Joseph (1991) found no relationship between mean specific gravity of clones and their stability across different environment. Similarly, Haynes *et al.* (1995) observed no correlation between average specific gravity during three years and stability variance statistics.

Partitioning of the G x E interaction for both tuber yield and dry matter content using Eberhart and Rusell (1966) model proved that mean squares due to G x E (linear) and the pooled deviation were significant indicating the presence of both linear and non-linear types of G x E interactions. G x E (linear) found to be non significant when tested against pooled deviation indicating the predominance of non-linear type of G x E interaction although appreciable linear type of interaction was noticed. Significant high pooled deviation suggests that deviations of all of the genotypes (from their expected performances) are not similar in magnitude and unpredictable causes of variation are responsible for the observed G x E interactions. Hence, it is difficult to predict the performance of the genotypes across the environments for tuber yield and dry matter content.

Table 3. Estimates of stability parameters for tuber yield, tuber dry matter and specific gravity of eleven potato genotypes.

	Tuber yield (ton ha^{-1})			Dry matter (%)			Specific gravity (g cm^{-3})		
Genotype	Mean	β_i	S^2d_i	Mean	β_i	S^2d_i	Mean	β_i	S^2d_i
1. AL-268	25.50 (9)	0.92**	17.81^{++}	23.76 (3)	1.05**	0.14^{NS}	1.0971 (3)	1.07**	-0.00032^{NS}
2. CIP-384321-3	32.11 (1)	1.06^{ns}	45.95^{++}	22.50 (11)	0.81**	0.78^{++}	1.0907 (11)	0.79**	-0.00031^{NS}
3. CIP-386423-13	30.49 (2)	1.28**	21.23^{++}	23.52 (4)	1.02**	0.01^{NS}	1.0958 (4)	0.99**	-0.00033^{NS}
4. CIP-387224-25	27.47 (6)	0.98**	18.31^{++}	22.88 (7)	0.66^{ns}	2.86^{++}	1.0930 (6)	1.31**	-0.00032^{NS}
5. CIP-391058-506	21.50 (10)	0.64^{ns}	44.90^{++}	23.29 (5)	1.28**	-0.19^{NS}	1.0948 (5)	1.26**	-0.00033^{NS}
6. CIP-391058-560	20.59 (11)	0.80^{ns}	59.09^{++}	22.90 (6)	0.83**	-0.37^{NS}	1.0928 (7)	0.73**	-0.00033^{NS}
7. CIP-392640-525	27.50 (5)	1.28**	8.29^{++}	24.15 (2)	0.89**	1.74^{++}	1.0990 (2)	0.97**	-0.00030^{NS}
8. CIP-392640-528	26.91 (8)	1.19**	4.60^{++}	24.87 (1)	0.85^{ns}	3.51^{++}	1.1027 (1)	0.94^{ns}	-0.00025^{NS}
9. CIP-392650-517	29.00 (4)	0.96**	17.50^{++}	22.86 (8)	1.42**	-1.35^{++}	1.0927 (8)	1.23**	-0.00031^{NS}
10. Gabissa	27.02 (7)	0.93**	4.60^{++}	22.70 (9)	0.90**	0.85^{++}	1.0921 (9)	0.96**	-0.00032^{NS}
11. Harchassa	29.99 (3)	0.96**	15.66^{++}	22.55 (10)	0.79**	0.64^{++}	1.0910 (10)	0.72**	-0.00031^{NS}
Mean	27.10			23.27			1.0947		

*^{ns}, ** = Not significantly different from unity at 5% and significantly different from unity at 1% probability level, respectively; ^{NS}, $^{++}$ = Not significantly different from zero at 5% and significantly different from zero at 1% probability level, respectively; Figures in parenthesis are ranks of genotypes.*

According to Perkins and Jinks (1968) a genotype having a mean higher than the overall mean, a regression coefficient (β_i) close to unity and deviation from regression coefficient (S^2d_i) equaling zero is considered to be superior for the character considered. The genotypes used in this study did not exhibit uniform stability and responsiveness pattern for the three traits (Table 3). None of the genotypes found to be stable and ranked at the top for tuber yield, dry matter and specific gravity. The stability and responsiveness appeared to be specific for specific character within a single genotype. For instance, genotype CIP-392640-528 is stable for specific gravity, average responsive for tuber dry matter content and above responsive for tuber yield. CIP-384321-3 was average responsive to changing environment for tuber yield, low responsive for tuber dry matter content and specific gravity. Genotypes CIP-386423-13 and CIP-392640-525 exhibited higher mean tuber yield and β_i value significantly higher than unity indicating that they are sensitive to environmental changes and responsive to high yielding environments. On the other hand, *Gabissa* and AL-268 had lower mean tuber yield along with β_i value significantly lower than unity indicating that the genotypes are least responsive to changing environments and can be considered as better adapted to poor environments.

From the study, it was observed that the best performing genotypes for tuber yield (CIP-384321-3 and CIP-386423-13), and dry matter content and specific gravity (CIP-392640-528 and CIP-392640-525) exhibited low stability, indicating that mean performance and stability are two different components probably genetically controlled in different manners. Similar findings were reported by Bucio-Alanis *et al.* (1969), Verma *et al.* (1978), Singh and Gupta (1984) and Singh (1988). In general, the highest specific gravity value corresponded with the higher percent dry matter content of the clones. Moreover, highly significant positive correlation (r = 0.99**) was observed between specific gravity and dry matter content, thus indicating that specific gravity was a true indicator of the amount of tuber dry matter. In agreement with the present study, Tsegaw and Zelleke (2002), Baye *et al.* (2005) and Tekalign and Hammes (2005) reported significant positive association between specific gravity and dry matter content at phenotypic level.

4. Conclusion

The study confirmed that the existence of considerable variation among the genotypes with respect to tuber yield and dry matter content but not for tuber specific gravity. The genotypes showed a differential response to tuber yield and dry matter content in the different environments. On the contrary, G x E has negligible influence on tuber specific gravity. The observed significant G x E interaction for tuber yield and dry matter content suggests that potato breeders should give special emphasis for G x E interaction while developing stable genotypes characterized by high tuber yield and dry mater content.

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Genotype x Environment Interaction for Yield in Field Pea (*Pisum sativum* L.)

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Abstract: The performance of a given genotype depends on its genetic potential and the environment upon which it is grown. In this study, sixteen genotypes of field pea (*Pisum sativum* L.) were tested over locations (Shambu and Arjo) for three years (2000-2002) and at Gedo (2002) with the objectives of identifying high yielding, stable and adaptable varieties for the Western highlands of Ethiopia. Regression and additive main and multiplication interaction (AMMI) analysis were computed to identify stable genotypes across multi-environments (location-year combinations). Analysis of variance revealed highly significant difference among genotype and genotype x environment (G x E) interactions, implying that genotypes suitable for specific environments can be selected. Regression and AMMI analysis were employed in order to determine the stability of genotypes. The two models regression analysis and AMMI revealed similar result in that *Bariso*, EH92049-1-2-1 and EH92049-2-2 were stable and widely adapted genotypes. However, the genotypes EH92049-1-3-1 and EH92039-1 are sensitive to changes in environmental conditions. *Bariso* was the most stable and high yielding genotype and was therefore released for the western Ethiopian highlands and other areas with similar agro-ecologies.

Keywords: AMMI; Genotype x Environment; *Pisum sativum;* Regression; Stable

1. Introduction

Field pea (*Pisum sativum L.)* has high levels of the essential amino acids, lysine and tryptophan, which are usually low in cereal grains. Consequently, it can supplement the low amount of protein present in food processed from cereal grains (Oelke *et al.*, 1991).

The performance of a genotype is dependent on its genetic potential, the environment where it is grown, and the interaction between the genotype and the environment (Yan, 2001; Yan and Hunt, 2001). Thus, research focusing on stability or genotype x environment interactions is necessary for plant breeders to develop genotypes that respond optimally and consistently across environments. Genotype x environment interactions are said to exist when the responses of two genotypes to different levels of environmental factors fail to be parallel (Allard and Bradshaw, 1964).

The regression model proposed by Eberhart and Russell (1966) allows for the computation of a complete analysis of variance with individual stability regression co-efficient (b_i) estimates and deviation from regression line (s^2d_i). The model considers a stable variety as the one with a high mean yield, $b_i = 1$ and $s^2d_i = 0$. Similarly, genotypes with a high s^2d_i deviate significantly from linearity and have a less predictable response for the given environments.

Moreover, the additive main effects and multiplication interaction (AMMI) model involves correlation or regression analysis which also relates the genotypic and environmental score derived from a principal component analysis of the genotype x environment interaction matrix to the genotypic and environmental covariates (Zobel *et al.*, 1988). Therefore, this experiment was intended to determine the nature and magnitude of genotype x environment interaction and identify superior and stable genotypes for different environmental conditions.

2. Materials and Methods

Nineteen field pea (*Pisum sativum* L.) genotypes including standard check (*Tegegnech*) and local checks were tested at Shambu and Arjo for three cropping seasons (2000-2002), and at Gedo for one year (2002). Genotypes were planted in a completely randomized block design with four replications in which each plot comprises of five rows having 5 m length. The spacing between rows and plants were 20 cm and 5 cm, respectively. A 100 kg per hectare (ha) of diamonium phosphate fertilizer (46% P_2O_5 and 18% N) was applied at planting. Management practices were done according to the recommendations for the particular crop and/or location.

All five rows were harvested and the grain yield was adjusted to 10% seed moisture content before data processing for analysis. Grain yield analysis was carried out using regression (Eberhart and Russell, 1966) and AMMI models in Agrobase software (Agrobase, 2000). The linear model proposed by Eberhart and Russell (1966) is:

$$Y_{ij} = \mu_i + b_i I_j + S^2 d_{ij}$$

where Y_{ij} is the mean performance of the i^{th} variety (I = 1, 2, 3…, n) in the j^{th} environment; μ_i is the mean of the i^{th} variety over all the environments; b_i is the regression coefficient which measures the response of i^{th} variety to varying environments; S^2d_{ij} is the deviation from regression of i^{th} variety in the j^{th} environment and I_j is the environmental index of the j^{th} environment. Similarly, the AMMI model (Gauch and Zobel, 1996) is:

$$Y_{ger} = \mu + \alpha_g + \beta_e + \sum_n \lambda_n \gamma_{gn} \delta_{en} + \rho_{ge} + \varepsilon_{ger}$$

where Y_{ger} is the observed yield of genotype g in environment e for replication r; Additive parameters: μ is the grand mean; α_g the deviation of genotype g from the grand mean and β_e is the deviation of

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environment e; the multiplicative parameters: λ_n is the singular value for interaction principal component axis (IPCA) n, γ_{gn} is the genotype eigenvector for axis n, and δ_{en} is the environment eigenvector; ρ_{ge} PCA residuals (noise portion) and ε_{ger} is error term.

3. Results and Discussion

3.1. Analysis of Variance

Significant differences were observed for grain yield among the genotypes in all environments considered in the study (Table 1). This indicated the presence of genetic variability among the genotypes. The mean grain yield over seven environments ranged from 2.03 ton ha^{-1} (local check) to 2.62 ton ha^{-1} (*Bariso*) with a grand mean of 2.28 ton ha^{-1} (Table 1).

Table 1. Mean seed yield of field pea across years (2000-2002) and locations (Shambu, Gedo and Arjo).

		Mean seed yield (ton ha^{-1})							
		2000		2001			2002		
No.	Genotype*	Arjo	Shambu	Arjo	Shambu	Gedo	Shambu	Arjo	Mean
1	EH93067-1-9	1.76	1.97	2.88	1.96	2.79	1.38	3.74	2.35
2	EH92008-4-1	1.97	1.80	3.22	2.34	2.28	1.54	3.89	2.43
3	EH92008-4-2-1	1.86	1.68	3.11	2.75	2.45	1.24	3.85	2.42
4	EH90025-1 (*Arjo-1*)	2.08	2.05	3.41	2.67	2.45	1.14	3.83	2.52
5	EH92049-1-2-1	1.58	2.39	2.91	2.81	2.37	1.05	4.03	2.45
6	EH92009-1-4	1.67	2.24	2.78	1.86	2.64	0.90	3.68	2.25
7	EH92007-1-1	1.30	2.13	3.06	2.21	2.35	1.23	3.85	2.30
8	EH92052-1-1	1.66	1.85	2.55	1.87	2.21	0.68	3.74	2.08
9	EH92001-1-2	1.55	1.67	2.94	2.31	2.48	1.05	3.48	2.21
10	EH92049-1-3-1	1.69	1.96	3.27	1.85	2.14	0.60	4.13	2.23
11	EH90023-1-4	1.95	2.48	3.16	1.92	1.82	0.85	3.85	2.29
12	EH92049-2-2	2.01	1.88	2.98	2.02	2.38	1.14	3.70	2.30
13	EH90011-1-2 *(Bariso)*	1.99	2.52	3.54	2.95	2.57	1.00	3.76	2.62
14	EH90023-1-1	2.18	1.52	3.06	2.57	2.59	0.87	4.00	2.40
15	EH92039-1	1.61	1.51	3.36	2.16	2.01	0.74	3.86	2.18
16	EH92020-1-2-1	1.92	1.82	2.81	2.26	2.02	0.96	3.53	2.19
17	Tegegnech	1.23	2.03	2.79	2.14	2.15	0.95	3.05	2.05
18	G-22763-2C	1.63	1.28	2.97	1.65	2.22	0.80	3.76	2.04
19	Local check	1.47	2.21	2.33	1.71	2.26	1.56	2.67	2.03
	Mean	1.74	1.94	3.00	2.21	2.32	1.04	3.71	2.28
	LSD	0.49	0.64	0.67	0.63	0.74	0.37	0.56	

**LSD = Least significant difference*

3.2. Regression Analysis Based on Eberhart and Russell Model

Mean square due to genotypes and interaction of genotype x environment (linear) were found to be highly significant ($P < 0.01$ (Table 2). The significance of genotypes x environments (linear) showed difference in yield performance among the genotypes under different environments. In line with the findings of this study, Chaudhary *et al.* (1994) reported highly significant for genotypes and Genotype x environment (Linear) in field pea.

The mean performance, regression coefficient (b_i) and squared deviation (s^2d_i) from the regression values are presented in Table 3. According to Ebrehart and Russell (1996) genotypes with high mean yield and regression coefficient (b_i) equal to unity and deviation from regression (s^2d_i) approach to zero. The genotypes *Bariso*, *Arjo-1*, EH92049-1-2-1, EH92008-4-1, EH92008-4-2-1, EH90023-1-1, EH93067-1-9, EH9207-1-1, EH92049-2- 2 and EH90023-1-4 have mean yields higher than the average, (b_i) did not differ significantly from unity and (s^2d_i) approaching zero. This implied that these genotypes were stable and widely adapted. However, the local check performed poorly in all of the environments because its mean grain yield was lower than the average and its coefficient of regression was significantly less than unity. Any improvement in environment or agronomic practice will not bring change in grain yield increment in such varieties. On the other hand, the genotypes EH92049-1-3-1 and EH92039-1 had significantly higher b_i value showing that these genotypes were sensitive to charges in environmental conditions and tend to give high yield at a favorable environment.

Table 2. Analysis of variance for grain yield using the Eberhart-Russel Regression Model.

Source of variation‡	Degrees of freedom	Mean square
Genotype	18	0.195**
Environment + Genotype x Environment	114	0.826
Environment in linear	1	
Genotype x Environment (linear)	18	0.141**
Pooled deviation	95	0.062
Residual	399	0.072

‡ *Grand mean = 2.282; R^2 = 0.937; Coefficient of variation (CV, %) = 23.47; ** = Significant at P < 0.01.*

Table 3. Stability analysis in field pea grown in western highlands of Ethiopia.

Genotype‡	Regression coefficient (b_i)	Squared deviations from regression (S^2d_i)	Grain yield (tons ha^{-1})
EH93067-1-9	0.9002	-0.0049	2.35
EH92008-4-1	0.9346	-0.0229	2.43
EH92008-4-2-1	1.0043	-0.0056	2.42
EH90025-1-2 (*Arjo-1*)	1.0213	-0.0426	2.52
EH92049-1-2-1	1.0605	0.0258	2.45
EH92009-1-4	0.9885	0.0038	2.25
EH92007-1-1	1.0401	-0.0155	2.30
EH92052-1-1	1.0571	-0.0353	2.08
EH92001-1-2	0.9578	-0.0397	2.21
EH92049-1-3-1	1.3057**	-0.0378	2.23
EH90023-1-4	1.0569	0.0745	2.29
EH92049-2-2	0.9418	-0.0499	2.30
EH90011-1-2 (*Bariso*)	1.0314	0.0256	2.62
EH90023-1-1	1.1236	0.0334	2.40
EH92039-1	1.2332*	-0.0265	2.18
EH92020-1-2-1	0.9186	-0.0462	2.19
Tegegnech	0.8368	-0.0142	2.05
G-22763-2C	1.1472	-0.0017	2.04
Local check	0.4405*	-0.0025	2.03
Mean			2.28

*Standard error of beta = 0.1173; t = Tons; ha = Hectare; *, ** = Significant at P < 0.05 and P < 0.0 levels, respectively.*

3.3. Additive Main Effects and Multiplicative Interaction (AMMI) Model

Analysis of variance revealed a highly significant difference among environments and genotypes whereas it showed a significant difference (P < 0.05) for genotype x environment interactions. These results are in agreement with similar findings of Mulusew *et al.* (2009) in field pea. Interaction principal component analysis (IPCA) scores were reported as indication of stability of genotypes across tested environments Gauch and Zobel (1996).The (IPCA1) axis was significantly (P < 0.01) different and the remaining interaction was not significant (Table 4). The percentage of G x E interaction explained by IPCA1 was 39.30% of the G x E interaction sum of squares. Since IPCA1 axis was significant (P < 0.01), we preferred to carry out the analysis in AMMI1. The AMMI analysis result revealed that EH92049-2-2 was the most stable genotype followed by EH92020-1-2-1, EH90011-1-2 (*Bariso*) and EH92049-1-2-1 having IPCA scores closer to zero (Table 5 and Fig 1). Whereas, EH92039-1 and EH92049-1-3-1 with IPCA scores deviating from zero are suitable for specific adaptation. The environments of Arjo 2002, Arjo 2001 and Gedo 2002 gave higher environmental mean yields. This indicates that the varieties perform well in those environments due to proper agronomic practices and favorable environment.

Table 4. Analysis of variance for Additive Main effects and Multiple Interaction (AMMI).

Source of variation‡	Degrees of freedom	Mean square	% Genotype x Environment interaction explained
Environment	6	57.18**	
Replications within Environment	21	1.17	
Genotype	18	0.78**	
Genotype x Environment	108	0.31*	
IPCA1	23	0.58**	39.30
IPCA2	21	0.33	20.19
Residual	378	0.24	

‡*Grand mean = 2.282; R^2 = 0.822; Coefficient of variation (CV, %) = 21.38; *, ** = Significant at P < 0.05 and P < 0.01 levels, respectively.*

Table 5. IPCA1 scores of genotypes and environments.

Designation of:	Genotype	IPCA1 score	Grain yield (tons ha^{-1})
Genotype			
A	EH93067-1-9	0.244	2.35
B	EH92008-4-1	-0.044	2.43
C	EH92008-4-2-1	-0.153	2.42
D	EH90025-1 (*Arjo-1*)	-0.145	2.52
E	EH92049-1-2-1	0.032	2.45
F	EH92009-1-4	0.214	2.25
G	EH92007-1-1	0.122	2.30
H	EH92052-1-1	-0.036	2.08
I	EH92001-1-2	0.050	2.21
J	EH92049-1-3-1	-0.386	2.23
K	EH90023-1-4	-0.045	2.29
L	EH92049-2-2	0.017	2.30
M	EH90011-1-2 (*Bariso*)	-0.029	2.62
N	EH90023-1-1	-0.397	2.40
O	EH92039-1	-0.451	2.18
P	EH92020-1-2-1	-0.021	2.19
Q	Tegegnech	0.364	2.05
R	G-22763-2C	-0.294	2.04
S	Local check	0.958	2.03
Environment			
A	Gedo 2002	0.265	2.33
B	Shambu 2002	0.675	1.04
C	Arjo 2002	-0.739	3.71
D	Arjo 2001	-0.483	3.01
E	Shambu 2001	-0.167	2.21
F	Shambu 2000	0.665	1.95
G	Arjo 2000	-0.216	1.74

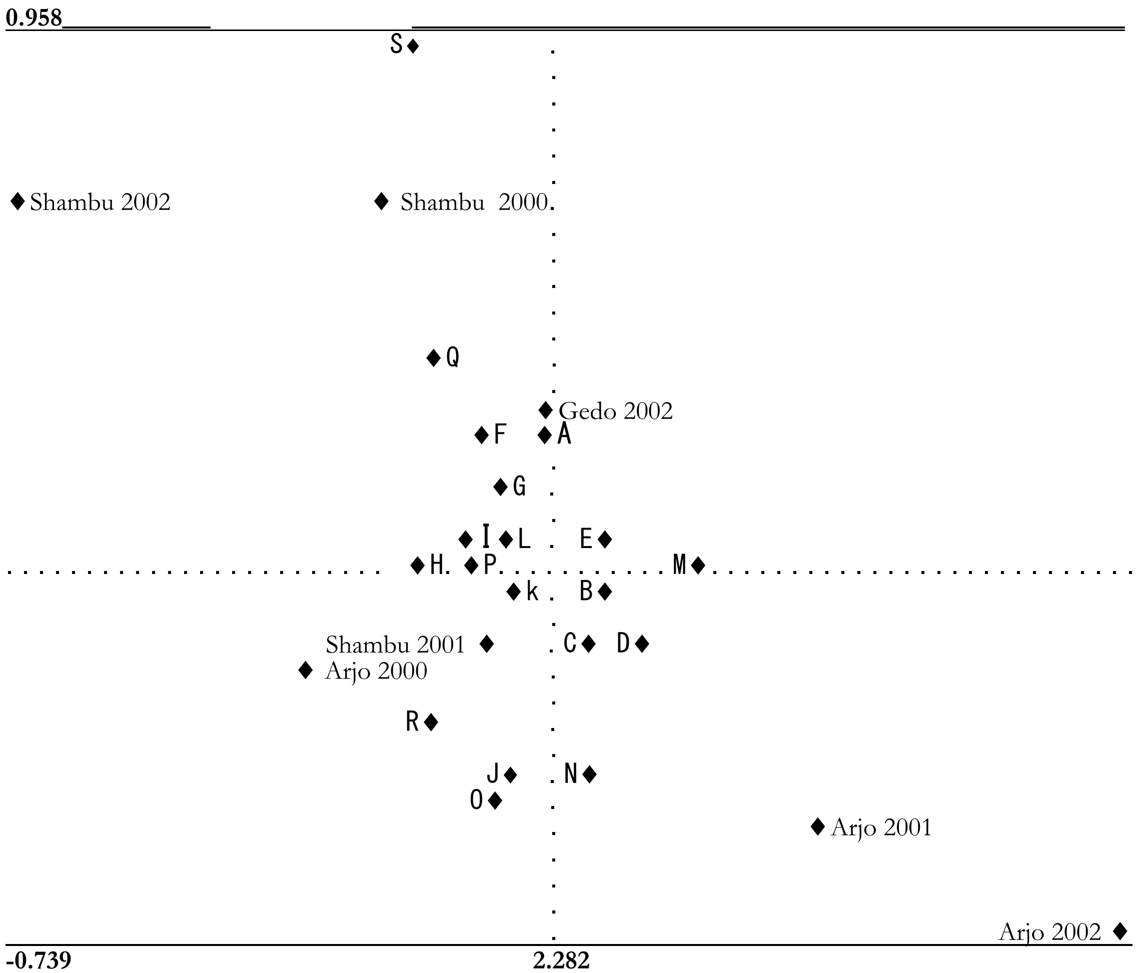

Figure 1. AMMI biplot for grain yield of 19 field pea genotypes tested at three locations with IPCA1 from -0.739 to 0.958. Note that genotypes are plotted as A, B, C ... S.

4. Conclusions

According to the Eberhart and Russell models (regression analysis), the genotypes *Bariso*, *Arjo-1*, EH92049-1-2-1, EH92008-4-1, EH92008-4-2-1, EH90023-1-1, EH93067-1-9, EH9207-1-1, EH92049-2-2 and EH90023-1-4 were stable and widely adapted. Whereas EH92049-2-2 was the most stable genotype followed by EH92020-1-2-1, EH90011-1-2 (*Bariso*) and EH92049-1-2-1 having IPCA score closer to zero. The two models regression analysis and the AMMI revealed similar result in that *Bariso*, EH92049-1-2-1 and EH92049-2-2 were stable and widely adapted genotypes. However, the genotypes EH2049-1-3-1 and EH92039-1 are sensitive to changes in environmental conditions. From the regression and AMMI analyses, therefore, *Bariso* was the most stable and high yielding genotype and as a result, it was released for the western highlands of Ethiopia and other areas with similar agro-ecologies.

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Heterosis and Combining Ability Analysis for Coffee Quality in Diallel Crosses of Diverse Coffee (*Coffea arabica* L.) Parents in Origin

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Abstract: In view of the lack of study on heterosis and combining ability in coffee quality breeding programs of Ethiopia, the present study was conducted on six distinct *Coffea arabica* L. lines in origin and 12 hybrids made among them in half diallel fashion to evaluate coffee hybrids for Sidamo coffee quality, to estimate heterosis effects for different coffee quality parameters and to determine the gene actions involved in controlling the quality parameters. Coffee samples were prepared during the 2002/2003 cropping season from hybrids and parents planted at the Wonago Agricultural Research Sub-station (06^o 03' N and 38^o 03' E) in Sidamo following a randomized complete block design. The coffee samples were evaluated for Sidamo coffee quality at the National Coffee and Tea Liquoring and Inspection Center. The hybrids exhibited positive and significant heterosis that ranged from 14 to 33% relative to the commercial Sidamo coffee variety for most of the parameters studied. Two hybrids; 7440 x 75227 and 744 x 1681, evaluated as having highly acceptable Sidamo coffee quality were the best specific combinations and heterotic for all coffee quality parameters. Two Kaffa coffee parents namely, 7440 and 75227 were good combiners and produced hybrids better than the commercial Sidamo coffee variety for Sidamo coffee quality. Predominance of non-additive gene actions were detected for acidity, body, cup quality and overall Sidamo coffee quality and additive gene action was important for the expression of flavor. The results of this study suggested selection of parents on the basis of their quality performance regardless of their origin and crossing among them is an appropriate breeding method to improve target region coffee quality. This study was conducted using coffee parents obtained only from two coffee growing regions and the results might not be sufficient to reach at a general conclusion for all coffee types in Ethiopia. However, the present findings can be used as good evidence for the possibility of using coffee lines of diverse origin and their crosses to improve unique coffee quality of the target region.

Keywords: Additive Gene Action; *Coffea arabica*; Combining Ability; Heterosis; Non-additive Gene Action; Sidamo Coffee Quality

1. Introduction

Many factors contribute to determine the quality of coffee, mainly non-genetic (harvest and post harvest, pedo-climatic effect and physiology) and genetic variations. Regarding cup quality, the geographical origin of the plants within the genetic groups is the main factor of variability (Moschetto *et al.,* 1996). In terms of genetics, significant genetic variability for bean chemical composition and organoleptic characteristics exists at both the between and within species levels (Thierry *et al.,* 2006). As a consequence, genetic gains for quality are assumed to be achieved either by interspecific (between species of coffee parents) or within species hybridization strategies.

There is a persistent demand for quality coffee in the world. As a result, coffee quality is the most important factor that determines the desirability and market value of coffee. However, coffee producing countries as a whole have been emphasizing more on yield increase and less on quality, and only recently have, many coffee growing countries, started giving emphasis for quality coffee production (Srinivasan and Vishveshwara, 1978; Walayro, 1983, Moreno *et al*., 1995). Coffee price in the international market has always been fluctuating affected mainly by overproduction. In this situation, improvement of coffee quality could provide the coffee chain with a new impetus. Therefore, it is necessary to integrate coffee quality as a main target in the breeding programs as opposed to its previous status as a secondary selection criterion.

The quality requirements in coffee are both voluntary as well as mandatory. Sanitary and phytosanitary measures under the World Trade Organization (WTO) agreement are mandatory. Besides, the consumers in most of the developed countries are preferring specialty coffees identified with distinct cup qualities or distinct production methods. The market share for specialty coffees is increasing at a steady rate. Specialty coffees are good opportunity for the growers as they fetch premium prices. In addition, coffee quality differs to everyone depending on their upbringing as well as their society. For instance, the Germans and Swedes prefer lighter and more acidic coffee than the Italians and Saudi Arabian Sheiks who like the most expensive of coffees, known as Bun Harrari or Khawa Harrari, which comes from the Eastern highlands of Ethiopia (Thierry *et al.,* 2006).

Ethiopia has diverse and favorable environments in five major coffee growing regions (Onwueme and Sinha, 1991) for the production of Arabica coffee and coffee types with unique flavor and taste, variable specialty distinguished as Sidamo; Yirgachefe; Hararghe, Gimbi and Limu types (Workafes and Kassu, 2000). These specialty coffees will have good opportunity in the international market to fetch premium prices as far as their conspicuous unique aroma and flavor are maintained and/or improved.

In Ethiopia coffee hybridization program was started in 1978 by crossing coffee lines from similar origin (Mesfin, 1982; Mesfin and Bayetta, 1983) and from different origins (Bayetta *et al*., 2007; Wassu *et al*., 2007) with the objective of increasing clean coffee yield. However, coffee quality genetic studies have not been conducted on crosses of coffee parents having different or similar origin acclaimed for different coffee qualities. This remain as one of the bottlenecks in selection of coffee parents for coffee crossing programs to produce heterotic coffee

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hybrids suited for different coffee growing regions without blending their fine coffee quality. This implies that genetic study, evaluation and comparison of coffee qualities of hybrids obtained from diverse coffee parents in origin are necessary. Therefore, the present study was conducted with the objectives i) to evaluate coffee hybrids generated from parents diverse in origin for Sidamo coffee quality, ii) to estimate the magnitude of heterosis effects of hybrids for different coffee quality parameters and iii) to determine the gene actions involved in controlling coffee quality parameters.

2. Materials and Methods

The materials comprised of six distinct lines, three from southwestern Ethiopia (Kaffa type) namely, 744 (P1), 7440 (P2) and 75227 (P3) and two from southeastern Ethiopia (Sidamo type), 1377 (P4) and 1681 (P5) and their 10 hybrids made among them in the half-diallel fashion (Griffing's method 2 Model 1) for genetic analysis. A third Sidamo coffee type; 2970 (P6), with its two hybrids obtained by crossing it with the two Sidamo coffee parents from adjacent Sidamo x Sidamo crosses experimental block was included to compare the coffee hybrids for Sidamo coffee quality. The Kaffa parental lines were selected for their high or medium yielding ability and coffee berry disease resistance and the ones from Sidamo were selected for possessing typical flavor of Sidamo, high yielding and distinct differences from the former parents in origin.

Seeds of the six selfed parental lines and their 12 hybrids were sown in polythene tubes filled with a finely prepared mixture of top-soil, well rotted coffee husk and sand (6:2:1 ratio) in November 1996. Seven months old seedlings were planted in the field in August 1997 at the Wonago Agricultural Research Sub-station (06^{o} 03' N and 38^{o} 03' E) that represents the Sidamo coffee growing locations laid down in a randomized complete block design (RCBD) in four replications, five trees per plot with 2 m x 2 m spacing. All agronomic management practices were uniformly applied to the plots following the recommendation from the Jima Agricultural Research Center. The experimental plots were maintained under temporary shade trees known as *Sesbania sesban* planted with 4 m x 4 m spacing.

Red fresh cherries were selectively harvested during the 2002/2003 cropping season from each plot and wet processed following the standard processing procedures. These wet processed coffee samples were provided to the National Coffee and Tea Liquoring and Inspection Center in February 2003 for blind test to determine the performances of the coffee genotypes for Sidamo coffee quality. Group of professional and experienced cuppers evaluated the coffee samples for the Sidamo coffee beans for shape and make, color and odor that accounted for 15% each for the former two and 10% for the latter which summed up to 40% and determined the raw coffee quality value. The raw coffee beans quality parameters were analyzed following internationally accepted procedure. Cup quality (organoleptic quality measurement) which included acidity, body and flavor each accounted for 20% and summed to 60%. Organoleptic analysis relies overall on sensory evaluation of beverage prepared from roasted coffee beans and grinded by rosters using sample roasting machine and standard grinder, respectively, which were prepared in a set of cups, mixed with freshly boiled water and tasted by group of cuppers when the liquid has cooled to a palatable temperature. Raw and cup quality values of the coffee samples were summed and determined the overall Sidamo coffee quality and acceptability in the international coffee market. In addition, screen and moisture analyses were conducted from green beans samples at the laboratory to determine bean size and moisture contents, respectively. The average values of samples for each genotype for each coffee quality parameter were reported to the Jima Agricultural Research Center which was considered for statistical analysis.

Data analysis was conducted using MSTAT-C of Michigan University statistical soft ware (MSTAT Development Team, 1986). The data from the F_1 crosses and parents were subjected to analysis of variance for RCBD. Further genetic analysis was performed for the coffee quality parameters in which statistically significant differences existed among genotypes. To study the performance of hybrid for each cross combination (P1 x P2), the mid parent value (MP), absolute mid parent heterosis (MPH) and relative mid-parent heterosis (MPH%), better parent heterosis (BPH%) and standard heterosis (SH%) were calculated as follows: MP = (P1+P2)/2; MPH = HY-MP; MPH(%) = (MPH/MP) x 100; BPH = HY-BP; BPH(%) = (BPH/BP) x 100, SH = HY-SV and SH(%) = (SH/SV) x 100 where MP is mean of the two parents of the hybrid, BP and SV are better parent and commercial Sidamo coffee variety values, respectively, and HY is hybrid value. The significance of heterosis was tested by comparing mean differences between F_1, MP, BP and SV means to LSD values derived from genotypes (F_1 and parent) analysis of variance. The genetic analysis was performed according to the Griffing's method 2 Model 1 (Griffing, 1956).

3. Results

3.1. Variation and Performances of Parents and Hybrids

Highly significant differences among genotypes (coffee parents and hybrids) were detected for acidity (ACD) and cup value (CUV) and significant ($P < 0.05$) differences for moisture content (MC), body (BOD), flavor (FLV%) and overall coffee quality (OVQ). However, only significant ($P < 0.05$) differences of the parents were observed for MC and ACD among the parameters studied (Table 1).

The mean coffee bean sizes of genotypes were nearly equivalent and statistically non-significant differences were observed. The mean coffee bean sizes calculated as 96 and 97% of the beans screen size No. 14 for all groups of coffee parents and hybrids. Genotypes bean samples mean moisture contents ranged from 8.9 to 10.2%. Kaffa x Kaffa and Sidamo x Sidamo coffee hybrids had the highest beans mean moisture content of 9.9% followed by Kaffa coffee parents beans mean moisture content of 9.7%. The Kaffa x Sidamo coffee hybrids and Sidamo coffee parents registered the lowest beans mean moisture contents of 9.4 and 9.3%, respectively.

The overall mean coffee quality values of the hybrids considerably exceeded the parents, particularly overall mean Sidamo coffee quality value of Kaffa x Kaffa coffee hybrids exceeds all groups of genotypes overall mean values (Table 2). Both the Kaffa and Sidamo coffee parents had equal mean Sidamo raw coffee quality value of 33% and the Kaffa x Kaffa, and Kaffa x Sidamo hybrids had equal mean Sidamo raw coffee quality value of 37%. The mean Sidamo raw coffee quality value for the Sidamo x Sidamo hybrids was 36%. All groups of hybrids (Kaffa x Kaffa, Sidamo x Sidamo and Kaffa x Sidamo) mean Sidamo raw coffee quality values ranked as better than usual Sidamo coffees raw quality values. The Sidamo coffee parents, Sidamo x Sidamo and Kaffa x Sidamo hybrids performed mean Sidamo coffee cup quality value of 31% while the Kaffa x Kaffa hybrids and the Kaffa coffee parents had 36 and 32%, respectively.

Table 1. Mean squares due to quality parameters of *Coffea arabica* L. parents and hybrids.

Quality parameter	Parents plus hybrids: Genotype (14)	Parents plus hybrids: Error (42)	SE	CV (%)	Parents alone: Genotype (5)	Parents alone: Error (15)	SE
Moisture content (%)	0.57 *	0.22	0.47	4.88	0.73 *	0.19	0.15
SB > Scr. 14	4.02	2.22	1.49	1.54	8.57	2.37	0.51
Shape and make (%)	5.71	3.19	1.79	13.59	7.27	4.97	0.59
Color (%)	5.28	4.28	2.07	16.09	1.57	4.57	0.55
RV (%)	19.02	11.66	3.14	9.49	13.40	17.95	1.08
Acidity (%)	25.95 **	7.26	2.69	21.85	31.67 *	6.67	0.96
Body (%)	7.70 *	2.94	1.71	17.93	10.00	3.75	0.59
Flavor (%)	3.66 *	1.82	1.35	13.74	5.07	2.52	0.45
CUV (%)	87.20 **	25.39	5.04	15.94	107.07	31.27	1.84
OVQ (%)	83.79 *	29.61	5.44	8.01	75.17	50.32	1.86

**, ** = Significant at P < 0.05 and P < 0.01, respectively; Number in parenthesis are degrees of freedom; SB > Screen No. 14 = Percentage of beans size > Screen No. 14; RV = Raw coffee quality value; CUV = Cup coffee quality value; OVQ = Overall coffee quality value; SE = Standard Error; CV = Coefficient of variation*

The Kaffa coffee parent; P1 and Kaffa x Sidamo hybrid; P1 x P5 registered the highest Sidamo raw coffee quality values among the parents and genotypes, respectively. The mean Sidamo coffee cup quality values registered for the Kaffa coffee parent (38%) and the P2 x P3 or Kaffa x Kaffa (42%) hybrid were the highest among the coffee parents and the genotypes., respectively. The Sidamo x Sidamo coffee hybrid; P4 x P5 (21%) and Kaffa coffee parent; P1 (23%) registered the lowest Sidamo coffee cup quality values. The two hybrids; P2 x P3 (Kaffa x Kaffa) and P1 x P5 (Kaffa x Sidamo) registered highly acceptable overall Sidamo coffee quality values ($\geq$ 75%). One Kaffa coffee parent (P1) and one Sidamo x Sidamo hybrid (P4 x P5) performed < 60% of the overall Sidamo coffee quality values which was internationally unacceptable (Table 2).

3.2. Estimate of Heterosis for Coffee Quality Parameters

Heterosis relative to mid and better parent was computed and the results are presented in Table 3. The coffee hybrids exhibited mid and better parent heterosis for all the coffee quality parameters except for odor. The mid parent heterosis for shape and make ranged from -7.69 to 34.33%, while for color and raw coffee quality ranged from -1.41 to 27.27% and from -2.39 to 20.62%, respectively. Mid parent heterosis for body, flavor, acidity and cup value ranged from -33.33 to 23.09%, -20 to 23.08%, -42.86 to 63.64% and -32.68 to 32.08%, respectively, while for the overall coffee quality, it ranged from -13.13 to 22.28%. Five hybrids for Sidamo raw coffee quality, four for overall Sidamo coffee quality and for shape and make, three for color, two for acidity and one hybrid for body, flavor and Sidamo coffee cup quality exhibited positive and significantly (P < 0.01 and/or P < 0.05) different mid parent heterosis. On the other hand, two hybrids for acidity, flavor, Sidamo coffee cup quality, overall Sidamo coffee quality and one hybrid for body registered negative and significantly (P < 0.01 and/or P < 0.05) different mid parent heterosis.

Better parent heterosis for shape and make, color and Sidamo raw coffee quality ranged from -14.29 to 25%, -2.78 to 25% and -4.67 to 14.17%, respectively. Better parent heterosis for body, flavor, acidity and Sidamo coffee cup quality ranged from -33.33 to 14.29%, -20 to 14.29%, -50 to 50% and -36 to 16.67%, respectively, while it ranged from 15.69 to 17.19% for the overall Sidamo coffee quality (Table 3). Three hybrids for overall Sidamo coffee quality; two for shape and make and acidity; and one hybrid for color, Sidamo raw coffee quality and flavor exhibited positive and significantly (P < 0.01/P < 0.05) better parent heterosis. On the other hand, five hybrids for flavor, three for acidity, two for Sidamo coffee cup quality and one hybrid for body showed negative and significantly (P < 0.01/P < 0.05) better parent heterosis. Positive and significantly better parent heterosis was registered for the Kaffa x Kaffa hybrids while negative and significantly better parent heterosis were recorded for Kaffa x Sidamo and Sidamo x Sidamo hybrids (Table 3).

Table 2. Mean performance of coffee (*Coffea arabica* L.) parents and their 12 hybrids grown at Wonago for 11 coffee quality parameters.

Accessions*	MC (%)	SB > Scr.14 (%)	SM (15%)	CL (15%)	RV (40%)	ACD (20%)	BOD (20%)	FLV (20%)	CUV (60%)	OVQ (100%)	Remark
744 (P1)	9.9	99	14	12	36	8	7	8	23	59	4
7440 (P2)	9.1	95	12	12	34	15	10	10	35	69	3
75227 (P3)	10.0	95	10	10	31	15	12	12	38	69	3
Mean of Kaffa coffee	9.7	96	12	11	33	13	9	10	32	65	
1377 (P4)	9.9	97	14	12	35	13	10	10	33	68	3
1681 (P5)	9.0	98	12	12	34	10	10	10	30	64	3
2970 (P6)	9.0	92	12	8	30	10	10	10	30	60	3
Mean of Sidamo coffee	9.3	96	13	11	33	11	10	10	31	64	
744 x 7440 (P1 x P2)	9.8	98	12	12	34	15	10	10	35	69	3
744 x 75227 (P1 x P3)	10.2	97	15	14	39	13	10	10	33	72	2
7440 x 75227(P2 x P3)	9.6	95	14	13	37	15	13	13	42	79	1
Mean of K x K hybrids	9.9	97	14	13	37	14	11	11	36	73	
1377 x 1681 (P4 x P5)	9.7	97	14	12	36	7	10	8	21	57	4
1377 x 2970 (P4 x P6)	10.0	95	12	12	34	15	10	10	35	69	3
1681 x 2970 (P5 x P6)	10.0	98	15	12	37	15	10	10	35	72	2
Mean of S x S hybrids	9.9	97	14	12	36	12	10	9	31	67	
744 x 1377 (P1 x P4)	9.2	98	13	12	35	13	10	10	33	68	3
744 x 1681 (P1 x P5)	10.1	98	15	15	40	15	10	10	35	75	1
7440 x 1377 (P2 x P4)	9.9	98	15	13	38	8	7	8	23	61	2
7440 x 1681 (P2 x P5)	9.2	96	12	12	34	10	10	10	31	64	3
75227 x 1377 (P3 x P4)	9.2	97	14	13	37	13	10	10	33	70	2
75227 x 1681 (P3 x P5)	8.9	96	15	14	39	12	10	10	32	71	2
Mean of K x S hybrids	9.4	97	14	13	37	12	9	10	31	68	

** MC = Moisture content; SB > Scr.14 = Percentage of beans' size > Screen no.14; SM = Coffee beans shape and make; CL = Coffee beans' color; RV = Raw coffee beans' quality value; ACD = Acidity; BOD = Body; FLV = Flavor; CUV = Cup quality value; OVQ = Overall coffee quality value; K x K, S x S and K x S = Hybrids obtained from Kaffa x Kaffa, Sidamo x Sidamo and Kaffa x Sidamo coffee parents, respectively; Note that 1, 2, 3 and 4 under remark indicate raw coffee quality better than the usual Sidamo coffee and highly acceptable cup quality; raw coffee quality better than the usual Sidamo coffee and acceptable cup quality; acceptable cup quality; and raw coffee quality better than the usual Sidamo coffee but cup quality not acceptable, respectively.*

Table 3. Percentage of mid and better parent heterosis for eight coffee quality parameters of 12 coffee hybrids of diverse parents in origin grown at Wonago as evaluated for Sidamo coffee quality.

Parameter	Heterosis†	P1 x P2	P1 x P3	P1 x P4	P1 x P5	P2 x P3	P2 x P4	P2 x P5	P3 x P4	P3 x P5	P4 x P5	P4 x P6	P5 x P6
Coffee beans shape and make (15%)	MPH (%)	-7.69	23.29**	-7.14	15.38	25.37**	15.38	0.00	15.07	34.33**	7.69	-7.69	25.00**
	BPH (%)	-14.29	7.14	-7.14	7.14	16.67	7.14	0.00	0.00	25.00**	0.00	-14.29	25.00**
	LSD (0.05) = 2.59, and LSD (0.01) = 2.99												
Coffee beans color (15%)	MPH (%)	1.41	27.27*	-1.41	26.76*	16.42	8.33	0.00	13.43	25.37*	0.00	20.00	20.00
	BPH (%)	2.86	20.00	-2.78	25.00*	8.33	8.33	0.00	5.56	16.67	0.00	0.00	0.00
	LSD (0.05) = 3.00, and LSD (0.01) = 3.46												
Raw coffee quality value (40%)	MPH (%)	-2.39	17.59**	-1.89	14.83*	14.43*	10.14	0.00	11.68	20.62**	4.35	4.62	15.63*
	BPH (%)	-4.67	9.35	-2.80	12.15	8.82	8.57	0.00	4.76	14.71*	2.86	-2.86	8.82
	LSD (0.05) = 4.95, and LSD (0.01) = 5.72												
Acidity (20%)	MPH (%)	28.57	14.29	23.08	63.64**	0.00	-41.18**	-20.00	-5.88	-6.67	-42.86**	28.57	50.00**
	BPH (%)	0.00	-11.11	0.00	50.00**	0.00	-44.44**	-33.33**	-11.11	-22.22	-50.00**	12.50	50.00**
	LSD (0.05) = 3.90, and LSD (0.01) = 4.51												
Body (20%)	MPH (%)	20.00	9.09	20.00	20.00	23.08*	-33.33*	0.00	-7.69	-7.69	0.00	0.00	0.00
	BPH (%)	0.00	-14.29	0.00	0.00	14.29	-33.33*	0.00	-14.29	-14.29	0.00	0.00	0.00
	LSD (0.05) = 2.48, and LSD (0.01) = 2.87												
Flavor (20%)	MPH (%)	11.11	1.69	11.11	11.11	23.08*	-20.00*	0.00	-7.69	-7.69	-20.00*	0.00	0.00
	BPH (%)	0.00	-14.29*	0.00	0.00	14.29*	-20.00*	0.00	-14.29*	-14.29*	-20.00*	0.00	0.00
	LSD (0.05) = 1.95, and LSD (0.01) = 2.26												
Coffee cup quality value (60%)	MPH (%)	20.69	8.70	18.34	32.08*	13.64	-32.68**	-3.59	-6.98	-7.32	-32.63**	10.53	16.67
	BPH (%)	0.00	-13.04	0.00	16.67	8.70	-34.29**	-10.48	-13.04	-17.39	-36.00**	5.00	16.67
	LSD (0.05) = 7.30, and LSD (0.01) = 8.44												
Overall coffee quality (100%)	MPH (%)	8.09	13.32*	7.37	22.28**	14.01**	-10.95*	-3.76	2.19	6.27	-13.13*	7.81	16.13**
	BPH (%)	0.00	4.83	0.00	17.19**	14.01**	-11.59*	-7.25	1.45	2.42	-15.69**	1.47	12.50*
	LSD (0.05) = 7.88, and LSD (0.01) = 9.11												

‡*, ** = *Significant at P < 0.05 and P < 0.01, respectively; MPH = Mid parent heterosis; BPH = Better parent heterosis; P1 = 744; P2 = 7440; P3 = 75227; P4 = 1377; P5 = 1681 and P6 = 2970. The significance of the percent heterosis was tested by comparing the differences between F_1, MP and BP means to the LSD values derived from genotypes (F_1 and parent) analysis of variance.*

Table 4. Percentage standard heterosis for seven coffee quality parameters of 12 coffee hybrids of diverse parents in origin grown at Wonago as evaluated for Sidamo coffee quality.

Hybrid‡	Color (15%)	Raw value (40%)	Acidity (20%)	Body (20%)	Flavor (20%)	Cup value (60%)	Overall quality (100%)	Remark
744 x 7440 (P1 x P2)	0	-3	13	0	0	5	1	Cup: acceptable
744 x 75227 (P1 x P3)	17	11	0	0	0	0	6	Raw: better than usual Sidamo coffee, Cup: acceptable
7440 x 75227(P2 x P3)	8	6	13	33**	33*	25**	16**	Raw: better than usual Sidamo coffee, Cup: highly acceptable
Mean of K x K hybrids	8.33	4.76	8.33	11.11	11.11	10.00	7.35	
1377 x 1681 (P4 x P5)	0	3	-50**	0	-20*	-36**	-16**	Raw: better than usual Sidamo coffee, Cup: not acceptable
1377 x 2970 (P4 x P6)	0	-3	13	0	0	5	1	Cup: acceptable
1681 x 2970 (P5 x P6)	0	6	13	0	0	5	6	Raw: better than usual Sidamo coffee, Cup: acceptable
Mean of S x S hybrids	0	2.86	-8.00	0	-6.67	-8.33	-3	
744 x 1377 (P1 x P4)	-3	-1	0	0	0	0	0	Cup: acceptable
744 x 1681 (P1 x P5)	25*	14*	13	0	0	5	10	Raw: better than usual Sidamo coffee, Cup: highly acceptable
7440 x 1377 (P2 x P4)	8	9	-38**	-33**	-20*	-31**	-10	Raw: better than usual Sidamo coffee, Cup: acceptable
7440 x 1681 (P2 x P5)	0	-3	-25	0	0	-6	-6	Cup: acceptable
75227 x 1377 (P3 x P4)	6	5	0	0	0	0	3	Raw: better than usual Sidamo coffee, Cup: acceptable
75227 x 1681 (P3 x P5)	17	11	-13	0	0	-5	4	Raw: better than usual Sidamo coffee, Cup: acceptable
Mean of K x S hybrids	8.80	5.87	-10.42	-5.56	-3.33	-6.17	0.16	
Mean of hybrids	2.31	4.60	-3.36	1.85	1.11	-1.50	1.50	
LSD (0.05)	3.00	4.95	3.90	2.48	1.95	7.30	7.88	
LSD (0.01%)	3.46	5.72	4.51	2.87	2.26	8.44	9.11	

‡*, ** = *Significant at P < 0.05 and P < 0.01, respectively; K x K, S x S and K x S = Hybrids obtained from Kaffa x Kaffa, Sidamo x Sidamo and Kaffa x Sidamo coffee parents, respectively.*

Standard heterosis relative to the Sidamo coffee variety (1377) was calculated to observe the advantage of the hybrids over the commercial variety and the results are presented in Table 4. Six and eight hybrids exhibited heterosis of -3 to 25% and -3 to 14%, respectively, relative to the commercial Sidamo coffee variety (1377) for color and Sidamo raw coffee quality, respectively. Only the Kaffa x Sidamo hybrid registered positive and significantly ($P < 0.05$) different standard heterosis for color (25%) and for Sidamo raw coffee quality (14%). Two hybrids, (Kaffa x Kaffa and Kaffa x Sidamo), registered significantly ($P < 0.05$) different positive and negative standard heterosis of 33 and -33%, respectively, for body. Similarly, the Kaffa x Kaffa hybrid registered a positive and significantly ($P < 0.01$) different standard heterosis of 33% while the P2 x P4 (Kaffa x Sidamo) and P4 x P5 (Sidamo x Sidamo) hybrids registered negative and significantly ($P < 0.05$) different standard heterosis of -20% for flavor. Five and eight hybrids exhibited positive standard heterosis for Sidamo coffee cup quality and the overall Sidamo coffee quality which ranged from -36 to 25% and -16 to 16%, respectively. Only the Kaffa x Kaffa hybrid exhibited a positive and a highly significant standard heterosis of 25 and 16% for Sidamo coffee cup quality and the overall Sidamo coffee quality, respectively.

3.3. Combining Ability for Coffee Quality Parameters

Variations due to both the general (GCA) and specific (SCA) combining ability effects were significant ($P < 0.01/P < 0.05$) for acidity, body and cup value whereas only the effects of GCA and SCA were significant ($P < 0.01/P < 0.05$) for flavor and the overall Sidamo coffee quality, respectively. The calculated variance component ratios for all organoleptic parameters (acidity, flavor and body), cup value and overall value were less than unity (Table 5).

In this study, the two Kaffa coffee parents; P2 (7440) and P3 (75227) possessed positive GCA effects for acidity, body, flavor and cup value whereas one Sidamo coffee parent; P5 (1681) had negative GCA effects for all these coffee quality parameters. One Kaffa, P1 (744) and one Sidamo, P4 (1377) coffee parents had positive GCA effects only for cup value and acidity, respectively, and negative GCA effects for all other coffee quality parameters (Table 6).

Table 5. General (GCA) and specific (SCA) combining ability mean squares for five coffee organoleptic quality parameters in a 5 x 5 diallel cross of coffee (*Coffea arabica* L.).

	Mean square			Component due to		Variance ratio of
Organoleptic parameter	GCA (4)	SCA (10)	Error (28)	GCA	SCA	GCA to SCA
Acidity (20%)	24.17*	26.67**	7.26	2.42	19.41	0.13
Body (20%)	9.88*	6.83*	2.94	0.99	3.89	0.26
Flavor (20%)	5.94*	2.75ns	1.82	0.59	0.93	0.63
Cup value (60%)	88.96*	86.5**	25.39	9.08	61.11	0.15
Overall value (100%)	60.04ns	90.08**	29.61	4.35	60.47	0.07

**, ** = Significant at P < 0.05 and P < 0.01, respectively; ns = Not significant at P > 0.05; Number in parenthesis = Degrees of freedom.*

Table 6. Estimate of general combining ability (GCA) effect for five coffee organoleptic quality parameters of five coffee (*Coffea arabica* L.) parents.

Parent	Acidity (20 %)	Body (20%)	Flavor (20%)	Cup value (60%)
744 (P1)	-0.10ns	-0.50*	-0.42ns	0.99**
7440 (P2)	0.62**	0.14ns	0.11ns	0.96**
75227 (P3)	1.33**	1.10**	0.87**	3.15**
1377 (P4)	0.33ns	-5.70**	-0.42ns	-1.23**
1681 (P5)	-1.52**	-0.10ns	-0.13ns	-1.90**
SE (gi)	0.20	0.22	0.23	0.20

**, ** = Significant at P < 0.05 and P < 0.01, respectively; ns = Not significant at P > 0.05; SE (gi) = Standard error for general combining ability*

Four coffee hybrids (P1 x P2, P2 x P3, P1 x P4 and P1 x P5) had positive SCA effects for acidity, body, cup value and overall Sidamo coffee quality whereas P2 x P4 and P4 x P5 registered negative SCA effects for all these coffee quality parameters (Table 7). Other coffee hybrids; P1 x P3 and P3 x P5 for overall coffee quality; P2 x P5 for body and P3 x P4 for acidity and overall Sidamo coffee quality had positive SCA effects.

Hybrids with highest SCA effects were arisen from any possible combinations of parents having negative and positive GCA effects as observed in P1 x P5 (4.29) for acidity and P1 x P4 (1.59) for body generated from parents both having negative GCA effects while in P1 x P5 (6.29) for cup value had parents with negative and positive GCA effects. Although, parents with good GCA effects not always produced good specific combinations as observed in P2 x P4 (-4.29) for acidity and P1 x P3 (-0.43) for cup value, all the highest mean values in all parameters were registered for hybrids that were generated from parents both having highest GCA effects.

In addition, in all the parameters, the highest performances were registered for the parents that possess the highest GCA effects with the exception of one parent (P1) which registered a positive GCA effect but registered the lowest mean cup value among the coffee parents.

Table 7. Estimate of specific combining ability (SCA) effect for five coffee organoleptic quality parameters of 10 coffee (*Coffea arabica* L.) hybrids.

Hybrid	Acidity (20 %)	Body (20%)	Cup value (60%)	Overall value (100%)
744 x 7440 (Kaffa x Kaffa)	2.14	0.87	3.43	0.84
744 x 75227 (Kaffa x Kaffa)	-0.24	-0.08	-0.43	1.46
744 x 1377 (Kaffa x Sidamo)	1.43	1.59	3.95	1.27
744 x 1681 (Kaffa x Sidamo)	4.29	1.11	6.29	8.75
7440 x 75227 (Kaffa x Kaffa)	0.71	0.87	2.62	5.46
7440 x 1377 (Kaffa x Sidamo)	-4.29	-2.46	-8.33	-5.73
7440 x 1681 (Kaffa x Sidamo)	-1.43	0.40	-0.67	-2.25
75227 x 1377 (Kaffa x Sidamo)	0.01	-0.08	-0.19	0.56
75227 x 1681 (Kaffa x Sidamo)	-0.48	-0.56	-2.86	1.70
1377 x 1681 (Sidamo x Sidamo)	-3.81	-2.22	-7.14	-7.49
SE (Sij)	3.84	1.72	6.81	6.78

SE (Sij) = Standard error for specific combining ability.

4. Discussion

Bean size, from a commercial point of view is an important factor since price is related to the coffee grade where small beans of the same variety can bring lower prices (Thierry *et al.*, 2006). Roasting of uneven sized beans affect the visual appearance of the roasted beans since the smallest tend to burn and the largest tend to be under-roasted. More importantly, roasting of uneven sized beans affect the cup quality (Barel and Jacquet, 1994). According to the national standard, if coffee sample size has $\geq$ 80% of a size of screen No.14, it qualifies for the international market (Endale, 2007). In this study, all the genotypes registered $\geq$ 92% sample coffee beans a size of screen > No.14 indicating all genotypes produced internationally acceptable bean size. Nearly all of the sample beans of the entry 744 met a size of screen > No.14 indicating this parent had uniform and bold beans. Moreover, hybrids involving in this parent produced nearly similar beans' size to that of the parent coffee. This apparently indicates that this parent can be used in crossing if the objective of breeding is to increase bean size.

Moisture is an important attribute and indicator of quality. High moisture content of the beans is a loss of material and leads to physical and sensorial defects. If the beans are too wet (above 12.5% moisture), they will mould easily during storage and if the beans are too dry (below 8% moisture), they will loose flavor. The moisture content influences the way coffee roasts and loss of weight during roasting. Coffee beans with low moisture content tend to roast faster than those with high moisture content. In general, moisture influences the way coffee roasts, loss of weight during roasting and leads to physical and sensorial defects (ICO, 2002). In the present study, the beans of none of the genotypes evaluated registered moisture contents below or above the established limit. This showed that coffee samples were prepared carefully and the cup quality test was done with appropriate moisture content of samples.

All highest mean raw coffee quality values ranked as better than the usual Sidamo coffee were registered for the hybrids. Moreover, the highest mean overall Sidamo coffee quality values ranked as highly acceptable for coffee hybrids while the coffee parents failed to perform the same. This result showed the advantage of selection of coffee lines and followed by crossing among them to improve coffee quality than only selection of best performing coffee lines. In addition, one Kaffa coffee parent produced better than the usual Sidamo raw coffee quality and two Kaffa coffee parents registered higher overall Sidamo coffee quality than the Sidamo coffee parents. This result showed the advantage of including coffee lines other than the target region in crossing program or to use as a variety to improve the target specialty coffee quality.

It was observed that the highest mean cup quality values were registered for the Kaffa coffee parents and their crosses. Besides, individual Kaffa coffee parents and their hybrids registered the highest Sidamo coffee cup quality values. In addition, the mean cup quality value of the Kaffa x Sidamo hybrids was observed to be equivalent to the Sidamo coffee parents and Sidamo x Sidamo coffee hybrids. Five out of six Kaffa x Sidamo coffee hybrids showed the Sidamo coffee cup quality performances that were either better or equivalent to Sidamo coffee genotypes. These results showed the possibility of improving Sidamo coffee cup quality value by using coffee parents other than Sidamo origin as far as they have inherent best cup quality values. It also revealed that crossing of Sidamo coffee parents with Kaffa coffee lines did not negatively blend the Sidamo coffee cup quality.

All positive and significant heterosis relative to the mid parent and better parent were registered for either Kaffa x Kaffa or Kaffa x Sidamo except one Sidamo x Sidamo coffee hybrid. More importantly, the two hybrids that exhibited positive and significant heterosis relative to the commercial Sidamo coffee variety for six important coffee quality parameters were Kaffa x Kaffa and Kaffa x Sidamo coffee hybrids. This suggested that the Kaffa coffee parents possessed favorable genes that complement each other or with the Sidamo coffee parents better than the Sidamo coffee parents did. This implies the possibility of improving Sidamo coffee quality parameters through crossing of Kaffa parents among them or with the Sidamo coffee parents than selection of Sidamo coffee lines and crosses made among them. This study results were in contrast with studies conducted in Brazil that showed no clear differences for cup quality in sensory evaluations comparing F_1 hybrids with traditional cultivars while the result for acidity was in agreement with the results where F_1 hybrids appeared to be inferior to the traditional cultivars for acidity (Bertrand *et al.,* 2006).

Both additive and non-additive gene actions were important for the expression of acidity, body and coffee cup quality parameters as these are evident from the mean squares being significant for both GCA and SCA. However, the variance ratios of GCA to SCA being less than unity for these parameters suggested the predominance of non-additive gene actions. More importantly, significant ($P < 0.01$) mean square only for SCA was detected for the overall coffee quality indicating the importance of non-additive gene actions to determine the international marketability of Sidamo coffee. These results suggested the importance of coffee hybrids production either by crossing parents having similar or diverse origin to improve most important Sidamo coffee quality parameters. On the other hand, only the importance of additive gene action was detected in controlling coffee flavor suggesting selection of best performing coffee lines to improve Sidamo coffee for this coffee quality parameter. The results of this study are in contrast with Walayro (1983) who reported the predominance of additive gene action for cup quality parameters.

The high GCA effects of the two Kaffa coffee parents (P2 and P3) for acidity, body and cup values suggested the usefulness of these parents to include in coffee breeding program to improve the Sidamo coffee quality parameters. In addition, if it is necessary to improve only coffee beans cup quality and acidity, it is important to use P1 (Kaffa coffee parent) and P4 (Sidamo coffee parent), respectively, since they possessed positive GCA effects for the corresponding parameters. However, it might not be necessary to include P5 (Sidamo coffee parent) in coffee crossing program to improve any one of coffee quality parameters since it had negative GCA effects for all coffee quality parameters.

In this study, two Kaffa x Kaffa (P1 x P2 and P2 x P3) and two Kaffa x Sidamo (P1 x P4 and P1 x P5) coffee hybrids had good specific combinations for acidity, body, cup and overall coffee quality which was evident from their positive SCA effects for these coffee quality parameters. It was also observed that the hybrids with highest SCA effects arisen from any possible combinations of parents having negative and positive GCA effects and parents with good GCA effects did not always produce good specific combinations. But the highest performances were registered for the parents that had highest GCA effects and for hybrids obtained by crossing these parents. This result suggested the importance of selection of coffee parents with highest performances and then crossing of these parents to improve coffee quality.

5. Conclusion

In this study, superiorities of coffee hybrids for all Sidamo coffee quality parameters were registered. The results suggested selection of coffee parents and then crossing among them regardless of their origin is an appropriate breeding method than selection of Sidamo coffee lines to improve Sidamo coffee qualities. Moreover, Kaffa coffee parents and their crosses made among them or with Sidamo coffee parents performed better Sidamo coffee qualities as compared to the Sidamo coffee parents and their crosses. This suggested that the Kaffa coffee lines and their crosses either among them or with the Sidamo coffee parents did not negatively blend Sidamo coffee quality. This encouraged the use of Kaffa coffee parents and their crosses to improve Sidamo coffee qualities.

The predominance of non-additive gene actions for the expression of acidity, body and Sidamo coffee cup quality were evident from the variance component ratios of GCA to SCA being less than unity. In addition, the importance of non-additive gene actions for the overall Sidamo coffee quality was detected from the highly significant ($P < 0.01$) mean square only for SCA. These results suggested the importance of coffee hybrid production by crossing parents having similar or diverse origin to improve the Sidamo coffee quality parameters. Only the importance of additive gene action in controlling coffee flavor was detected which suggested selection of best performing coffee lines is an appropriate breeding method to improve this coffee quality parameter.

The two Kaffa coffee parents (P2 and P3) for acidity, body, and cup value, P1 (Kaffa coffee parent) and P4 (Sidamo coffee parent) for cup quality and acidity, respectively, possessed positive GCA effects suggesting their usefulness to include in coffee breeding program to improve the respective coffee quality parameters. However, it might not be necessary to include P5 (Sidamo coffee parent) in coffee crossing program to improve any one of the coffee quality parameters since it had negative GCA effects for all of the coffee quality parameters.

In this study, the majority of Kaffa x Kaffa or Kaffa x Sidamo coffee hybrids were heterotic, had good specific combinations and exhibited highest percentage and exploitable heterosis for almost all important Sidamo coffee quality parameters. The parents which produced these hybrids had positive or negative GCA effects, i.e. often coffee parents with good GCA effects did not necessarily produce good specific combinations. However, the coffee parents having the highest values for coffee quality parameters had also highest GCA effects for the same parameters. In addition, superior hybrid for

Sidamo coffee quality parameters was produced from both parents that had highest GCA effects and highest mean performances. This might suggested the importance of selection of coffee parents on the basis of their coffee quality performances and GCA effects then crossing among them than selection depending on their origin *per se* (in this case only selection of Sidamo coffee lines) to improve Sidamo coffee quality.

This study depended on coffee parents and their crosses having two distinctly different origins that were acclaimed for two unique Ethiopian coffee qualities grown at a single Sidamo coffee growing location and evaluated for Sidamo coffee quality. Thus, the results might not be sufficient to give general conclusion for all coffee types in Ethiopia that are known for their unique coffee qualities, rather it can be used as good evidence for the possibility of using coffee lines and their crosses having diverse origin to improve the known unique coffee quality of the target region. Therefore, instead of only selecting coffee lines and crossing among themselves from each coffee growing region to improve the corresponding known coffee quality parameters, it is important to conduct studies using coffee lines and their crosses regardless of their origin in all of the coffee growing regions.

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Magnitude of Exploitable Heterosis for Yield and Quality Traits of Coffee (*Coffea arabica* L.) Hybrids as Affected by Distant Parents in Origin and Morphology in Ethiopia

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Abstract: This study was conducted to generate information on the effects of distant parents in origin, growth habit and leaf tip color on the magnitude of standard heterosis (SH) in *Coffea arabica* L. hybrids for yield and quality in 34 hybrids generated from 15 parents in Ethiopia. The results showed distant parents in origin produce hybrids with higher standard heterosis in magnitude in a greater number of hybrids. It was observed that 16 and 11 out of 17 between and within region hybrids exhibited standard heterosis ranging from 0.8 to 52.8% and from 3.58 to 44.95%, respectively, for fresh cherry yield. In comparison, hybrids obtained from crossing distant parents in all factors (origin, growth habit and leaf tip color) registered the highest magnitude of SH, which ranged from 21.05% (clean coffee yield) to 52.80% (fresh cherry yield) with mean SH of 36.64 and 28.95% for fresh cherry and clean coffee yield, respectively. For coffee quality parameters, the effect of parents' leaf tip color on the magnitude of heterosis was observed to be more important than the parents' geographical origin. Five out of six hybrids having both parents green leaf tip color (Kaffa x Kaffa and Kaffa x Sidamo) exhibited SH of 1 to 16% for the overall coffee quality. These hybrids also exhibited positive and significant SH (14 to 33%) for 6 out of 8 coffee quality parameters. The results of this study suggested the importance of including distant parents in all possible factors to produce greater number of high yielding hybrids with highest magnitude of standard heterosis in Ethiopia. The results further revealed the possibility of improving target region coffee quality through selection of parents on the basis of their leaf tip color for crossing regardless of their origin.

Keywords: Distant Parents; Growth Habit; Hybrids; Leaf Tip Color; Origin; Standard Heterosis

1. Introduction

Information on heterosis in *Coffea arabica* L. is scanty because its hybridization started only very recently, and the perennial nature of the crop requires several years to obtain meaningful results (Wrigley, 1988; Cilas *et al.,* 1998). Moreover, research results on the effect of parental diversity in terms of geographical origin and/or morphology on magnitude of heterosis is lacking. In heterosis breeding, it has been established that the more distant the parents in origin (geographical separation), ancestral relationships, gene frequencies and morphological characteristics, the greater is the potential for heterosis (Mopurtary and Frakes, 1973; Moll and Stuber, 1974; Falconer, 1989; Virmani, 1996; Wang *et al.,* 1996).

However, although systematic research result is scanty, reports indicating the importance of distant coffee parents to produce heterotic hybrids from separate coffee hybrid trials are observable around the world. In Ethiopia, where maximum diversity of *C. arabica* lines are expected to be involved, heterosis over the better parent of up to 60% for yield was reported (Mesfin and Bayetta, 1983). Similarly, Ferine (1970) in Tanzania and Srinivasan and Vishveshwara (1978) in India reported 53 and 100% highest heterosis over the mean of two standard varieties and over the better parent for yield, respectively. These hybrids had complementary parents, VC496 and Chochie, which were of Ethiopian origin. This showed the effect of parents' diversity in one or other factors on magnitude of heterosis displayed by hybrids. On the other hand, heterosis was reported to be lacking in crosses of selected indigenous *C. arabica* L. varieties in Brazil after several years of studies (Carvalho *et al.,* 1969) where diversity of parental lines were not expected.

In classical theories, genetic relationships, geographic origins, and morphological and isozymes markers were used to predict heterosis (Zhu and Zhang, 1987; Zhu *et al*., 2001; Hinze and Lamkey, 2003). In agreement with the classical theories of heterosis, some authors in *Brassica* spp. such as Pradhan *et al.* (1993) in *Brassica juncea*, Falk *et al.* (1994) in *Brassica rapa* and Ali *et al.* (1995) in *Brassica napus* observed an increase in heterosis with increasing parental distance using morphological markers and geographic origin. Moll *et al.* (1962) and other authors reported hybrid superiority in crosses of maize inbreds, especially in crosses among divergent parents and their wide exploitation in commercial production.

Ethiopia has diverse and favorable environments in five major coffee growing regions (Onwueme and Sinha, 1991) for the production of *Coffea arabica* L. These regions also produce coffee types acclaimed for their unique flavor and taste and variable speciality distinguished as Sidamo, Yirgachefe, Hararghe, Gimbi and Limu types (Workafes and Kassu, 2000). This wide genetic variability and diversity in Ethiopian coffee was also observed in a series of hybrid trials in Ethiopia. Starting in 1978 up to 2007, a total of 105 hybrids were tested of which 27 F_1 hybrids were selected and advanced to verification for final release. Hybrids obtained from crossing parents having different or similar geographic origin and morphological characteristics expressing average heterosis over standard check ranged from 16 to 43% for yield (Behailu *et al.*, 2007).

However, the effect of diversity of parents in geographic origin and/or morphology on magnitude of heterosis has not yet been well studied except in the case of two hybrid trials where attempts have been made to explain the effect of parents' diversity in geographical origin on heterosis (Bayetta *et al.,* 2007; Wassu *et al.,* 2007). Moreover, the effects of parents' leaf tip color (green and bronze) has not been discussed at all in the past works. The effect of parents' leaf tip color on the observed magnitude of heterosis is important since it is one of the distinguishable traits for two *Coffea arabica* L. varieties, typica and bourbon. Besides, the effect of geographical origin and/or leaf tip color of parents on magnitude of heterosis for coffee quality have not been studied. These justify the need to conduct research to reveal the effects of parents' diversity on heterosis, and identify the factor or combination of factors which affect

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the magnitude of heterosis for yield and coffee quality parameters. Therefore, this study was conducted to generate information on the effects of origin, growth habit and leaf tip color of parents on observed heterosis that can be considered in parental selection.

2. Materials and Data Analysis

2.1. Coffee Genotypes Included in the Study

Coffee parents and hybrids in three coffee hybrid trials conducted in different time and at different locations in Ethiopia (Mesfin and Bayetta, 1983; Bayetta *et al.,* 2007; Wassu *et al.*, 2007) were considered for reanalysis in this study. The first and second hybrid trials were conducted at the Jima Agricultural Research Center for three and six years both for yield and other traits, respectively. The research results of Set I trial were published in 1983 in the Ethiopian Journal of Agricultural Science (Mesfin and Bayetta, 1983) while that of the second trial were reported at the Coffee Diversity and Knowledge, Four Decades of Coffee Research and Development in Ethiopia. The third trial was conducted at the Wonago Research Station for four years and its results were reported at the National Coffee Research Review Workshop (Wassu *et al.*, 2007).

In all the trials, parents from different geographical origin were included. Parents from Sidamo represent south coffee growing region with bimodal rainfall while parents from Kaffa and Illubabor represent south-western Ethiopia representing regions with monomodal rainfall pattern. Parents also had distinct leaf tip color (bronze and green) which is the major difference between the two *Coffea arabica* L. varieties in the world. In two studies (Bayetta *et al.*, 2007; Wassu *et al.*, 2007), an attempt has been made to single out the importance of diversity of parents in origin on the observed magnitude of heterosis. However, Bayetta *et al.* (2007) suggested that morphological differences of parents were more important while Wassu *et al.* (2007) suggested that differences in geographical origin of parents were more important for the observed higher magnitude of heterosis. Both investigators did not consider all differences (geographical, morphological and leaf tip color) rather mainly focused on either geographical and morphological or geographical differences based on separate trials. In addition, both investigators made conclusions on the basis of mid and better parent heterosis and not on the standard heterosis which is supposed to determine the commercial exploitation of hybrids. Therefore, this study was conducted by considering all types of differences of parents in all the three hybrid trials on the basis of standard heterosis to provide more conclusive information for future coffee breeding program.

In three trials, 34 hybrids obtained by crossing 15 parents in half diallel fashion, Griffing's Method 2 Model 1 (Griffing, 1956) planted at two coffee growing regions following randomized block design (RCBD) in four replications, five trees per plot with 2 m x 2 m spacing were included. Details of the parental lines description is presented in Table 1.

2.2. Data Collection

In the Set I hybrid trial, fresh cherry yield was recorded on tree basis in grams while in Sets II and III hybrid trials, the fresh cherry yield was recorded and converted to kilograms per tree. Yields of clean coffee obtained as the product of fresh cherry weight and out turn ratio of each genotype were recorded in kg per tree in Sets II and III hybrid trials. In all trials, an average of five trees was computed for each experimental unit and used for statistical analysis. An average of three, six and four years yield data were considered for statistical analysis for Sets I, II and III hybrid trials, respectively.

2.3. Data Analysis

Standard heterosis for fresh cherry and clean coffee yield were computed as SH (%) = (HYB-CV)/CV) x 100 where CV is commercial varieties yield used as a checks in three trials. The mid parent heterosis (MPH) and better parent heterosis (BPH) were registered as reported by the investigators. However, systematic arrangement has been made to fulfil the objectives of this study. In Set III, the three heterosis viz., MPH (%), BPH (%) and SH (%) for 12 hybrids were computed for the Sidamo coffee quality parameters as MP = P1+P2/2; MPH = HY-MP; MPH (%) = (MPH/MP) x 100; BPH = HY-BP; BPH (%) = (BPH/BP) x 100 and SH (%) = (HYB-CV)/CV) x 100 where MP = mean of the two parents involved in producing the hybrids computed as (P1+P2)/2, HY = hybrid value; BP = the better parent value of a hybrid and CV is commercial variety value. The significance of the percent heterosis was tested by comparing mean differences between F_1, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance.

Coffee quality parameters used in the study are shape and make which accounts for 15%, odour (10%), color (15%) and all summed to raw coffee quality that accounted for a total of 40%, and acidity, body and flavor each accounting for 20% and summed to 60% which is categorized as coffee cup quality. The overall coffee quality was the sum of raw coffee quality and cup quality and sums up to 100%. Coffee quality was determined by the blind evaluation method (no information provided about the origin and type of coffee samples) of hybrids and their parents at the National Coffee and Tea Liquoring and Inspection Center.

Hybrids' heterosis effects for fresh cherry and clean coffee yield as well as coffee quality parameters were systematically organized in relation to their parents' origin, growth habit and leaf tip color. This helped to asses the effects of distant parents in these factors on the observed magnitude of heterosis.

Table 1. Description of *Coffea arabica* L. parental lines used in three hybrid trials in Ethiopia.

Parental lines	Geographical origin	Growth habit and some special features of coffee parents
		Set I hybrid trial
741 (P1)	Gera, Kaffa	Highly resistant to CBD
7332 (P2)	Gera, Kaffa	Resistant to CBD
7395 (P3)	Yayu, Illubabor	70-75% resistant to CBD
2970 (P4)	Yirgachefe, Sidamo	High yielding and resistant to CBD
F-59 (P5)	Bonga, Kaffa	High yielding and resistant to CBD used as check
	Set II hybrid trial [Note: F-59 (P5) named as Desu used as a check]	
74110 (P1) 74158 (P2)	Bishare, Illubabor	Compact with flexible stem, small leaves and internodes length, medium and round beans
20071 (P3) 221A71 (P4)	Maji, Kaffa	Medium open to open, with short and broad leaves, small and round beans
1377 (P5) 1577 (P6)	Wonago and Handida, Sidamo	Open with vigorous growth, broad leaves, bronze tip, bold bean
		Set III hybrid trial
744 (P1)	Washi, Kaffa (South-western Ethiopia) 1700 masl	Released Coffee Berry Disease (CBD) resistant cultivar; good adaptation to medium and high altitude; open canopy; green leaf tip color and broad leaves; bold beans.
7440 (P2)	Washi, Kaffa, (South-western Ethiopia) 1700 masl	Released CBD resistant cultivar; good adaptation to medium and high altitude; open canopy; green leaf tip color and broad leaves; small beans.
75227(P3)	Near Washi, Kaffa, (South-western Ethiopia) 1900 masl	Released CBD resistant cultivar; good adaptation to higher altitudes; open canopy; green leaf tip color and broad leaves; small beans.
1377 (P4)	Wonago, Sidamo (Southern Ethiopia) 1850 masl	First released Sidamo coffee variety, high yielding; open canopy; bronze leaf tip color and broad leaves; bold beans. Used also as a check commercial variety.
1681(P5)	Areka, Sidamo (Southern Ethiopia) 1850 masl	High yielding; open canopy; green leaf tip color, broad leaves; medium size beans.

***Kaffa and Illubabor regions lie along the same climatic belt and enjoy more or less similar weather (humid with mono-modal distribution of high rainfall and categorized as south-western coffee growing region, which are distinctly different from Sidamo characterized by lower humidity (drier weather), lower and bimodal pattern of rainfall; **Shorter internodes on main stem and primers, shorter and dense primary branches and overall reduced plant size are the main differentiating characteristics of compact growth, whilst the open types are mainly characterized by spreading branches and longer internodes; **Sidamo and Kaffa coffee parents are acclaimed for their different coffee quality (Sidamo and Limu); **Young leaves having bronze and green tip color is one of distinguishable trait for Coffea arabica L. var. typica and var. bourbon in the world.*

3. Results

3.1. Heterosis in Relation to Parents Origin and Morphology for Yield

3.1.1. Heterosis in Relation to Parents' Origin

Hybrids' heterosis for yield was rearranged and calculated based on parents origin to observe if it had an effect on hybrids heterosis expression and its magnitude (Tables 2a and 2b). The within region hybrids registered mean MPH of 23.33, 65.07 and 25.7% while the between region registered 49.33, 70.65 and 60.75% in Set I, II and III hybrid trials, respectively, for fresh cherry yield. The mean BPH calculated for the within region hybrids were 9.83, 58.9 and 7.68%, while that of the between region hybrids were 32.67, 47.8 and 44.02% in Set I, II and III trials, respectively, for fresh cherry yield. Moreover, 10.54, 10.79 and -1.61% mean SH were recorded for the within region hybrids whilst 11.28, 30.35 and 22.01% were recorded for the between regions hybrids in the trials of Sets I, II and III, respectively, for fresh cherry yield.

Heterosis calculated for clean coffee yield revealed that the within region hybrids exhibited mean MPH of 64.76 and 22.78% while the between regions hybrids recorded 80.46 and 58.3% in Set II and III trials, respectively. Mean BPH of 57.19 and 8.38% were calculated for the within region hybrids while mean BPH of 57.71 and 37.63% were obtained for the between region crosses in Set II and III trials, respectively. Similarly, mean SH values of 0.26 and -12.35% were calculated for the within region hybrids and the calculated between region hybrids' SH values were 20.57 and 10.59 in Set II and III trials, respectively (Table 2b).

In all the trials, 15 and 13 out of 17 between region hybrids exhibited positive and significant different MPH and BPH, respectively, for fresh cherry yield. In Sets II and III hybrid trials, 11 out of 14 between region hybrids registered significantly ($P < 0.05$) different percent MPH and BPH for clean coffee yield. Eight out of 14 between region hybrids exhibited positive and significant ($P < 0.05$) different SH for fresh cherry yield which ranged from 28.51 to 52.8%. Five of the between region hybrids displayed positive and significant ($P < 0.05$) different SH for clean coffee yield which ranged from 23.17 to 44.62% in Sets II and III hybrid trials. On the other hand, 11 and 8 out of 17 of within region hybrids registered positive and significantly ($P < 0.05$) different MPH (%) and BPH (%), respectively, in all trials. However, only two out of 11 within region hybrids exhibited positive and significantly ($P < 0.05$) different SH of 35.27 and 44.95% for fresh cherry and 25.1 and 33.6% for clean coffee yield in Set II and III hybrid trials.

Table 2a. Mid parent (MPH), better parent (BPH) and standard heterosis (SH) for fresh cherry yield in relation to parents' origin of coffee (*Coffea arabica* L.) hybrids in Ethiopia.

Set I hybrid trial			
Hybrid	MPH (%)	BPH (%)	SH (%)
P1 x P2	25*	5	11.63
P1 x P3	22	15	-6.38
P1 x P5	38**	18	18.42
P2 x P3	4	-8	3.58
P2 x P5	13	9	16.21
P3 x P5	32**	20*	19.77
Mean (K x K)	22.33	9.83	10.54
P1 x P4	69**	60**	14.69
P2 x P4	27*	2	8.06
P3 x P4	52**	36**	11.09
P4 x P5	-	-	-
Mean (K x S)	49.33	32.67	11.28
Grand mean	31.33	17.45	10.79

Set II hybrid trial			
Hybrid	MPH (%)	BPH (%)	SH (%)
P1 x P2	13.7	9.0	-27.09*
P3 x P4	56.7**	54.0*	-0.95
P5 x P6	62.3**	41.2**	44.95**
P1 x P3	64.9**	59.0**	6.40
P1 x P4	47.7*	44.8*	-3.09
P2 x P3	119.1**	117.7**	35.27*
P2 x P4	91.1**	86.7**	20.04
Mean (Within)	65.07	58.91	10.79
P1 x P5	80.2**	48.8**	52.80**
P1 x P6	81.5**	70.8**	29.64*
P2 x P5	65.4**	32.1*	35.60*
P2 x P6	87.2**	69.3**	28.51*
P3 x P5	61.6**	29.7*	33.13*
P3 x P6	55.2**	41.1*	7.13
P4 x P5	62.8**	32.4*	35.89**
P4 x P6	71.3**	58.2**	20.11
Mean (Between)	70.65	47.8	30.35
Grand mean	68.0	53.0	21.22
LSD (0.05) = 0.741 and LSD (0.01) = 0.986			

Set III hybrid trial‡			
Hybrid	MPH (%)	BPH (%)	SH (%)
P1 x P2	8.7	-12.8	-14.89
P1 x P3	59.5*	41.3*	9.53
P2 x P3	52.0**	36.4**	33.10
P4 x P5	-17.4	-34.2*	-34.17*
Mean (Within)	25.7	7.68	-1.61
P1 x P4	52.8*	22.1	22.08
P1 x P5	116.4**	115.9**	29.06
P2 x P4	-13.9	-14.2	-14.23
P2 x P5	28.4	3.3	0.80
P3 x P4	66.7**	48.0*	47.87**
P3 x P5	114.0**	89.0**	46.50**
Mean (between)	60.73	44.02	22.01
Grand mean	46.72	29.48	12.57
LSD (0.05) = 1.214 and LSD (0.01) = 1.622			

‡*, ** = *Significant at P < 0.05 and P < 0.01 levels, respectively; MPH = Mid parent heterosis; BPH = Better parent heterosis; SH = Standard heterosis. Note: The within region crosses in Set II include Ilubabor x Ilubabor (P1 x P2), Kaffa x Kaffa (P3 x P4), Sidamo x Sidamo (P5 x P6) and Ilubabor x Kaffa (P1 x P3, P1 x P4, P2 x P3 and P2 x P4) and the between region crosses include Ilubabor x Sidamo (P1 x P5, P1 x P6, P2 x P5 and P2 x P6) and Kaffa x Sidamo (P3 x P5, P3 x P6, P4 x P5 and P4 x P6). The within region crosses in Set III include Kaffa x Kaffa (P1 x P2, P1 x P3 and P2 x P3) and Sidamo x Sidamo (P4 x P5) while the between region crosses include Kaffa x Sidamo (P1 x P4, P1 x P5, P2 x P4, P2 x P5, P3 x P4 and P3 x P5); F-59 (P5 in Set I) was used as check and the commercial variety yielded 4779 g per tree and 2.75 kg per tree in Sets I and II, respectively and P4 (1377) yielded 3.64 kg per tree in Set III. In Set I: P1 = 741, P2 = 7332, P3 = 7395, P4 = 2970 and P5 = F-59; in Set II, P1 = 74110, P2 = 74158, P3 = 20071, P4 = 221A71, P5 = 1377 and P6 = 1577, and in Set III, P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377 and P5 = 1681. The significance of the percent heterosis was tested by comparing mean differences between F_1, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance, where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of the commercial variety (check).*

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Table 2b. Mid parent (MPH), better parent (BPH) and standard heterosis (SH) for clean yield in relation to parents' origin in Sets II and III coffee (*Coffea arabica* L.) hybrid trials in Ethiopia.

Set II hybrid trial‡			
Hybrid	MPH (%)	BPH (%)	Standard heterosis (%)
P1 x P2	13.1	9.6	-36.03**
P3 x P4	55.1*	50.2*	-8.91
P5 x P6	66.0**	39.4**	33.60**
P1 x P3	55.4*	53.3*	-10.53
P1 x P4	56.7**	53.8*	-6.68
P2 x P3	124.4**	120.3**	25.10*
P2 x P4	82.6**	73.7**	5.26
Mean for within	64.76	57.19	0.26
P1 x P5	84.4**	48.3**	42.31**
P1 x P6	96.1**	86.0**	21.05
P2 x P5	70.3**	33.8*	28.34*
P2 x P6	107.1**	90.5**	24.09
P3 x P5	66.5**	32.5*	27.13*
P3 x P6	67.2**	56.5**	2.02
P4 x P5	72.8**	41.0**	35.22**
P4 x P6	79.3**	73.1**	12.75
Mean for between	80.46	57.71	20.57
Grand mean	73.10	57.50	12.96
LSD (0.05) = 0.124 and LSD (0.01) = 0.165			

Set III hybrid trial‡			
Hybrid	MPH (%)	BPH (%)	Standard hetrosis (%)
P1 x P2	-1.2	-14.4	-26.60
P1 x P3	55.7**	48.1*	-2.47
P2 x P3	59.2*	40.9**	20.78
P4 x P5	-22.6*	-41.1*	-41.13*
Mean for within	22.78	8.38	-12.35
P1 x P4	25.2	-0.3	-0.29
P1 x P5	107.3**	94.6**	15.41
P2 x P4	-13.1	-19.3	-19.33
P2 x P5	34.4	8.0	-7.41
P3 x P4	74.3**	44.6**	44.62**
P3 x P5	121.7**	98.2**	30.52
Mean for between	58.3	37.63	10.59
Grand mean	44.3	25.93	1.16
LSD (0.05) = 0.219 and LSD (0.01) = 0.296			

‡, ** = Significant at P < 0.05 and P < 0.01levels, respectively, MPH = Mid parent heterosis, BPH = Better parent heterosis. Note: The within region crosses in Set II include Ilubabor x Ilubabor (P1 x P2), Kaffa x Kaffa (P3 x P4), Sidamo x Sidamo (P5 x P6) and Ilubabor x Kaffa (P1 x P3, P1 x P4, P2 x P3 and P2 x P4) and the between region crosses include Ilubabor x Sidamo (P1 x P5, P1 x P6, P2 x P5 and P2 x P6) and Kaffa x Sidamo (P3 x P5, P3 x P6, P4 x P5 and P4 x P6). The within region crosses in Set III include Kaffa x Kaffa (P1 x P2, P1 x P3 and P2 x P3) and Sidamo x Sidamo (P4 x P5) while the between region crosses include Kaffa x Sidamo (P1 x P4, P1 x P5, P2 x P4, P2 x P5, P3 x P4 and P3 x P5); F-59 which yielded 0.494 kg per tree was used as check in Set II and P4 (1377) which yielded 0.688 kg per tree was used as a check in Set III. In Set II, P1 = 74110, P2 = 74158, P3 = 20071, P4 = 221A71, P5 = 1377 and P6 = 1577 and in Set III, P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377 and P5 = 1681. The significance of the percent heterosis was tested by comparing mean differences between F, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance, where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of the commercial variety (check).*

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3.1.2. Heterosis in Relation to Parents' Origin and Growth Habit

Heterosis in relation to parents origin and growth habit was calculated for Set II hybrid trial (Table 3) since hybrids included in Set III had parents with similar canopy class (open canopy) and all parents' canopy classes in Set I were not provided in the report. Coffee hybrids generated from similar parents in origin and growth habit registered the lowest mean MPH of 44.2 and 44.7% and mean BPH of 34.7 and 8.0% for fresh cherry and clean coffee yields, respectively. On the other hand, the Illubabor x Kaffa hybrids which their parents enjoy nearly similar environmental condition (south-western Ethiopia coffee growing region) but having distinctly different canopy classes (compact and medium open) registered higher mean MPH of 80.7 and 76.68% and mean BPH of 77 and 75.3% for fresh cherry and clean coffee yields, respectively. On the other hand, the Kaffa x Sidamo hybrids having parents distinct distant in origin (south-western and southern Ethiopia coffee growing regions) but with nearly similar canopy class (open) registered the lowest mean MPH of 62.7 and 71.5% and mean BPH of 40.4 and 50.8% for fresh cherry and clean coffee yields, respectively. The hybrids generated from distant parents both in origin and growth habit (Illubabor x Sidamo, compact x open) registered lower mean MPH of 78.6 and 89.5% and mean BPH of 55.3 and 64.7% for fresh cherry and clean coffee yields, respectively (Table 3). These results are extracted from Bayetta *et al.* (2007) report.

In Set II, hybrids standard heterosis relative to the best yielding commercial cultivar used as check is presented in Table 4a. Standard heterosis was considered as most important since decision making on economic importance of hybrids and accordingly release for growers depends on it. Hybrids generated from distant parents both in origin and growth habit (Illubabor x Sidamo, compact x open) registered the highest mean SH of 36.64 and 29.95% for fresh cherry and clean coffee yield, respectively. The Kaffa x Sidamo hybrids having distant parents in origin but similar canopy class (open) registered the second highest mean SH of 24.06 and 19.28% for fresh cherry and clean coffee yields, respectively. Hybrids having similar parents in origin and growth habit registered the lowest mean SH of 5.64 and -3.78% for fresh cherry and clean coffee yields, respectively. The Illubabor x Kaffa hybrids generated from near to similar parents in origin but having distinct canopy classes (compact and medium open) recorded lower mean SH of 14.65 and 0.26% for fresh cherry and clean coffee yields, respectively. None of the hybrids obtained from distant parent in origin either with distinct or similar growth habit exhibited negative SH. In Set II hybrid trial, the highest (42.31%) and the second highest (35.22%) positive and significant SH for yield were registered for hybrids obtained by crossing parents distant both in origin and in morphology. On the other hand, two out of four hybrids having parents with distinct growth habit but similar in origin exhibited negative SH for clean coffee yield.

In this study, the yields of three hybrids generated from distant parents both in origin and growth habit (Illubabor x Sidamo, compact x open) for fresh cherry and two hybrids for clean coffee exhibited positive and significant SH. Two Kaffa x Sidamo hybrids having distant parents in origin but similar canopy class (open) registered positive and significant SH for fresh cherry and clean coffee yields. One hybrid each for other combinations registered positive and significant SH for fresh cherry and clean coffee yields.

3.1.3. Heterosis in Relation to Parents' Origin and Leaf tip Color

Heterosis in relation to hybrids parents' leaf tip colors (green and bronze) was calculated for Set II and Set III hybrid trials for which the parents' leaf tip colors are reported in the materials and methods section of the original reports. The hybrids generated from distant parents for leaf tip colors (green and bronze) regardless of their differences in origin and growth habit registered the highest mean MPH, BPH and SH of 70.65, 47.85 and 30.35%, respectively, for fresh cherry yield (Table 4a). Similarly, this group of hybrids registered the highest mean MPH, BPH and SH of 80.5, 57.75 and 24.12%, respectively, for clean coffee yield in Set the II hybrid trial. The green x green leaf tip color hybrids registered mean MPH, BPH and SH of 57.95, 54.3 and 0.32%, respectively, for fresh cherry yield. These group of hybrids also registered mean MPH, BPH and SH of 55.45, 52.6 and -5.3%, respectively, for clean coffee yield. In the Set III hybrid trial, green x green leaf tip color hybrids recorded the highest mean MPH, BPH and SH of 63.17, 45.52 and 17.35% for fresh cherry yield and 62.85, 45.9 and 5.04%, respectively, for clean coffee yield. The green x bronze leaf tip color registered 22.05, 5.42 and 5.39% mean MPH, BPH and SH, respectively, for fresh cherry yield. This group of hybrids resulted in the lowest mean MPH, BPH and SH of 15.95, -4.03 and -4.03% for clean coffee yield, respectively (Table 4b).

Hybrids' heterosis effects on yield considering all differences of parents (origin, growth habit and leaf tip colors) which were used as sources of parents distant are presented in Tables 4a and 4b. In Set II, hybrids generated from distant parents in all factors (Illubabor x Sidamo with compact x open and green x bronze leaf tip color) exhibited the highest mean SH of 36.64 and 28.95% for fresh cherry and clean coffee yields, respectively (Table 4a). The second highest mean SH of 24.06 and 19.28% for fresh cherry and clean coffee yields, respectively, were registered for hybrids obtained from crossing of distant parents in origin and leaf tip color but nearly similar for growth habit (Kaffa x Sidamo with green x bronze with medium to open and open). Hybrids having less distant parents in origin and similar leaf tip color but with distinct growth habit (Illubabor x Kaffa, compact x medium to open, green x green leaf tip color) registered the second lowest mean SH of 14.65 and 0.26%. Hybrids having similar parents for all factors recorded the lowest mean SH of -14.02 and -22.47% for fresh cherry and clean coffee yields, respectively.

In Set III, hybrids obtained by crossing distant parents in origin with similar leaf tip color (Kaffa x Sidamo with green x green) registered the highest mean SH of 25.45 and 12.84% followed by hybrids generated from distant parents in origin and leaf tip color (Kaffa x Sidamo with green x bronze) with mean SH of 18.57 and 8.33% for fresh cherry and clean coffee yields, respectively (Table 4b). Hybrids having parents similar in origin and leaf tip color (Kaffa x Kaffa, green x green) registered the lowest mean SH of 9.25 and -2.76% for fresh cherry and clean coffee yields, respectively. In Set II, one hybrid that obtained from crossing both Sidamo coffee parents and bronze tip color registered 44.95 and 33.60% SH while the other hybrid in Set III, which was obtained from crossing both Sidamo coffee parents but having green and bronze leaf tip colors recorded -34.17 and -41.13% for fresh cherry and clean coffee yield, respectively (Table 4b).

Table 3. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for fresh cherry and clean coffee yield in relation to parents' origin and growth habit in Set II coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

Origin	Growth habit	Hybrid	Fresh cherry yield (kg tree^{-1})‡ MPH (%)	BPH (%)	SH (%)	Clean coffee yield(kg tree^{-1})‡ MPH (%)	BPH (%)	SH (%)
Ilubabor x Ilubabor	C x C	P1 x P2	13.7	9.0	-27.09*	13.1	9.6	-36.03**
Kaffa x Kaffa	MO x MO	P3 x P4	56.7**	54.0*	-0.95	55.1*	50.2*	-8.91
Sidamo x Sidamo	O x O	P5 x P6	62.3**	41.2**	44.95**	66.0**	39.4**	33.60**
Mean			44.2	34.7	5.64	44.7	8.0	-3.78
Ilubabor x Kaffa	Compact x	P1 x P3	64.9**	59.0**	6.40	55.4*	53.3*	-10.53
	Medium to	P1 x P4	47.7*	44.8*	-3.09	56.7**	53.8*	-6.68
	open	P2 x P3	119.1**	117.7**	35.27*	124.4**	120.3**	25.10*
	canopy	P2 x P4	91.1**	86.7**	20.04	82.6**	73.7**	5.26
Mean			80.7	77.1	14.65	76.8	75.3	0.26
Ilubabor x Sidamo	Compact x	P1 x P5	80.2**	48.8**	52.80**	84.4**	48.3**	42.31**
	Open	P1 x P6	81.5**	70.8**	29.64*	96.1**	86.0**	21.05
	canopy	P2 x P5	65.4**	32.1*	35.60*	70.3**	33.8*	28.34*
		P2 x P6	87.2**	69.3**	28.51*	107.1**	90.5**	24.09
Mean			78.6	55.3	36.64	89.5	64.7	28.95
Kaffa x Sidamo	Open x	P3 x P5	61.6**	29.7*	33.13*	66.5**	32.5*	27.13*
	Open	P3 x P6	55.2**	41.1*	7.13	67.2**	56.5**	2.02
		P4 x P5	62.8**	32.4*	35.89**	72.8**	41.0**	35.22**
		P4 x P6	71.3**	58.2**	20.11	79.3**	73.1**	12.75
Mean			62.7	40.4	24.06	71.5	50.8	19.28
Grand mean			68.0	53.0	21.22	73.1	57.5	12.96
			LSD (0.05) = 0.741; LSD (0.01) = 0.986			LSD (0.05) = 0.124; LSD (0.01) = 0.165		

‡ **, ** = Significant at P < 0.05 and P < 0.01 levels, respectively; MPH = Mid parent heterosis; BPH = Better parent heterosis; SH = Standard heterosis, C x C = Compact x Compact, MO x MO = Medium to open x Medium to open, O x O = Open x Open, in Set II, P1 = 74110, P2 = 74158, P3 = 20071, P4 = 221A71, P5 = 1377 and P6 = 1577. The significance of the percent heterosis was tested by comparing mean differences between F, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance, where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of the commercial variety (check).*

3.2. Heterosis in Relation to Parents' Origin and Leaf Tip for Coffee Quality

3.2.1. Heterosis In relation to Parents' Origin

Heterosis was calculated for Sidamo coffee quality for 12 hybrids six each for the within and between hybrids (Tables 5a and 5b). Among the group of hybrids, the within region crosses viz., Kaffa x Kaffa registered the highest mean MPH, BPH and SH of 11.81, 6.28 and 7.35%, respectively, for overall Sidamo coffee quality parameters. Considering all coffee quality parameters, the Kaffa x Kaffa group of hybrids registered mean MPH, BPH and SH which ranged from 9.53 to 17.39,-3.7 to 17.39 and -2.38 to 11.11, respectively. The Kaffa x Kaffa group of hybrids registered negative mean BPH and SH only for acidity and shape and make, respectively. The between region hybrids (Kaffa x Sidamo) registered the second highest mean MPH, BPH and SH of 3.9, 0.37 and 0.16, respectively, for overall Sidamo coffee quality. This group of hybrids exhibited mean MPH, BPH and SH ranged from -1.45 to 12.17%, -10.32 to 8.80% and -10.42 to 8.80%, respectively, for all the quality parameters. The Kaffa x Sidamo group of hybrids exhibited positive mean MPH and BPH for acidity, shape and make, color, raw coffee quality and overall coffee quality (Table 5a). This group of hybrids registered positive mean SH for most important Sidamo coffee raw and overall quality. The Sidamo x Sidamo group of hybrids recorded the lowest mean MPH, BPH and SH of 3.60, -0.57 and -3.00%, respectively, for overall Sidamo coffee quality. This group of hybrids had mean MPH, BPH and SH ranging from -6.67 to 11.90%, -6.67 to 10.40% and -8.33 to 8.30%, respectively, for all coffee quality parameters. The Sidamo x Sidamo group of hybrids registered negative mean MPH, BPH and SH both for flavor and Sidamo coffee cup quality (Table 5a). Besides, they also exhibited negative mean BPH and SH for overall Sidamo coffee quality as well as negative mean SH for acidity. This group of hybrids registered positive mean SH only for color and Sidamo raw coffee quality.

Table 4a. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for fresh cherry and clean coffee yield in relation to parents' origin, growth habit and leaf tip color in Set II coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

			Fresh cherry yield (kg tree^{-1})			Clean coffee yield(kg tree^{-1})		
Origin and leaf tip color	Growth habit	Hybrid	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)
Ilubabor x Ilubabor, Green x Green	Compact x Compact	P1 x P2	13.7	9.0	-27.09*	13.1	9.6	-36.03**
Kaffa x Kaffa, Green x Green	Medium to open x Medium to open	P3 x P4	56.7**	54.0*	-0.95	55.1*	50.2*	-8.91
Mean for within region, similar growth habit and leaf tip color			35.2	31.5	-14.02	34.1	29.9	-22.47
Ilubabor x Kaffa, Green x Green	Compact x Medium to open canopy	P1 x P3	64.9**	59.0**	6.40	55.4*	53.3*	-10.53
Ilubabor x Kaffa, Green x Green	Compact x Medium to open canopy	P1 x P4	47.7*	44.8*	-3.09	56.7**	53.8*	-6.68
Ilubabor x Kaffa, Green x Green	Compact x Medium to open canopy	P2 x P3	119.1**	117.7**	35.27*	124.4**	120.3**	25.10*
Ilubabor x Kaffa, Green x Green	Compact x Medium to open canopy	P2 x P4	91.1**	86.7**	20.04	82.6**	73.7**	5.26
Mean similar origin and different canopy and similar leaf tip color			80.7	77.1	14.65	76.8	75.3	0.26
Mean Green x Green leaf tip color			57.95	54.3	0.32	55.45	52.6	-5.30
Sidamo x Sidamo, Bronze x Bronze	Open x Open canopy	P5 x P6	62.3**	41.2**	44.95**	66.0**	39.4**	33.60**
Mean of similar leaf tip color crosses			60.13	47.75	7.82	60.73	46	0.26
Ilubabor x Sidamo, Green x Bronze leaf tip color	Compact x Open canopy	P1 x P5	80.2**	48.8**	52.80**	84.4**	48.3**	42.31**
Ilubabor x Sidamo, Green x Bronze leaf tip color	Compact x Open canopy	P1 x P6	81.5**	70.8**	29.64*	96.1**	86.0**	21.05
Ilubabor x Sidamo, Green x Bronze leaf tip color	Compact x Open canopy	P2 x P5	65.4**	32.1*	35.60*	70.3**	33.8*	28.34*
Ilubabor x Sidamo, Green x Bronze leaf tip color	Compact x Open canopy	P2 x P6	87.2**	69.3**	28.51*	107.1**	90.5**	24.09
Mean different origin , canopy and leaf color (G x B)			78.6	55.3	36.64	89.5	64.7	28.95
Kaffa x Sidamo, Green x Bronze leaf tip color	Medium to Open x Open canopy	P3 x P5	61.6**	29.7*	33.13*	66.5**	32.5*	27.13*
Kaffa x Sidamo, Green x Bronze leaf tip color	Medium to Open x Open canopy	P3 x P6	55.2**	41.1*	7.13	67.2**	56.5**	2.02
Kaffa x Sidamo, Green x Bronze leaf tip color	Medium to Open x Open canopy	P4 x P5	62.8**	32.4*	35.89**	72.8**	41.0**	35.22**
Kaffa x Sidamo, Green x Bronze leaf tip color	Medium to Open x Open canopy	P4 x P6	71.3**	58.2**	20.11	79.3**	73.1**	12.75
Mean of different origin and leaf color (G x B) with nearly similar canopy			62.7	40.4	24.06	71.5	50.8	19.28
Mean Green x Bronze leaf tip color			70.65	47.85	30.35	80.5	57.75	24.12
Grand mean			68.0	53.0	21.22	73.1	57.5	12.96

‡*, ** = *Significant at* $P < 0.05$ *and* $P < 0.01$ *levels, respectively; MPH = Mid parent heterosis; BPH = Better parent heterosis; SH = Standard heterosis. In Set II, P1 = 74110, P2 = 74158, P3 = 20071, P4 = 221A71, P5 = 1377 and P6 = 1577. The significance of the percent heterosis was tested by comparing mean differences between F, MP, BP and CV means to LSD values derived from genotypes (*F_1 *and parent) analysis of variance, where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of the commercial variety (check).*

Table 4b. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for fresh cherry and clean coffee yield in relation to parents' origin and leaf tip color in Set III coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

Origin and leaf tip color	Hybrid	Fresh cherry yield (kg tree^{-1})‡			Clean coffee yield (kg tree^{-1})‡		
		MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)
Kaffa x Kaffa, Green x Green	P1 x P2	8.70	-12.8	-14.89	-1.20	-14.40	-26.60
Kaffa x Kaffa, Green x Green	P1 x P3	59.50*	41.3*	9.53	55.70**	48.10*	-2.47
Kaffa x Kaffa, Green x Green	P2 x P3	52.0**	36.40**	33.10	59.20*	40.90**	20.78
Mean similar origin and leaf tip color (Green x Green)		40.07	21.63	9.25	37.90	24.87	-2.76
Kaffa x Sidamo, Green x Green	P1 x P5	116.40**	115.90**	29.06	107.30**	94.60**	15.41
Kaffa x Sidamo, Green x Green	P2 x P5	28.40	3.30	0.80	34.40	8.00	-7.41
Kaffa x Sidamo, Green x Green	P3 x P5	114.00**	89.00**	46.50**	121.70**	98.20**	30.52
Mean between region and similar leaf tip color (Green x Green)		86.27	69.40	25.45	87.80	66.93	12.84
Mean of Green x Green leaf tip color		63.17	45.52	17.35	62.85	45.90	5.04
Kaffa x Sidamo, Green x Bronze leaf tip color	P1 x P4	52.80*	22.10	22.08	25.20	-0.30	-0.29
Kaffa x Sidamo, Green x Bronze leaf tip color	P2 x P4	-13.90	-14.20	-14.23	-13.10	-19.3	-19.33
Kaffa x Sidamo, Green x Bronze leaf tip color	P3 x P4	66.70**	48.00*	47.87**	74.30**	44.60**	44.62**
Mean between region and different leaf tip color (Green x Bronze)		35.20	18.63	18.57	28.80	8.33	8.33
Sidamo x Sidamo, Green x Bronze leaf tip color	P4 x P5	-17.40	-34.20*	-34.17*	-22.60*	-41.10*	-41.13*
Mean of Green x Bronze leaf tip color		22.05	5.42	5.39	15.95	-4.03	-4.03
Grand mean							

‡*, ** = *Significant at P < 0.05 and P < 0.01levels, respectively,* ‡*, ** = *Significant at P < 0.05 and P < 0.01 levels, respectively; MPH = Mid parent heterosis; BPH = Better parent heterosis; SH = Standard heterosis, P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377 and P5 = 1681. The significance of the percent heteerosis was tested by comparing mean differences between F, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance, where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of the commercial variety (check).*

Table 5a. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for Sidamo coffee cup and overall quality in relation to parents' origin in Set III coffee hybrid (*Coffea arabica* L.) trial in Ethiopia.

Hybrid‡	Acidity MPH (%)	Acidity BPH (%)	Acidity SH (%)	Body MPH (%)	Body BPH (%)	Body SH (%)	Flavor MPH (%)	Flavor BPH (%)	Flavor SH (%)	Cup quality MPH (%)	Cup quality BPH (%)	Cup quality SH (%)	Overall quality MPH (%)	Overall quality BPH (%)	Overall quality SH (%)
P1 x P2	28.57	0.00	13.00	20.00	0.00	0.00	11.11	0.00	0.00	20.69	0.00	5.00	8.09	0.00	1.00
P1 x P3	14.29	-11.11	0.00	9.09	-14.29	0.00	1.69	-14.29*	0.00	8.70	-13.04	0.00	13.32*	4.83	6.00
P2 x P3	0.00	0.00	13.00	23.08*	14.29	33.00**	23.08*	14.29*	33.00*	13.64	8.70	25.00**	14.01**	14.01**	16.00**
Mean (K x K)	9.53	-3.70	8.33	17.39	0.00	11.11	11.57	0.00	11.11	14.34	-1.45	10.00	11.81	6.28	7.35
P4 x P5	-42.86**	-50.00**	-50.00**	0.00	0.00	0.00	-20.0*	-20.0*	-20.00*	-32.63**	-36.00**	-36.00**	-13.13*	-15.69**	-16.00**
P4 x P6	28.57	12.50	13.00	0.00	0.00	0.00	0.00	0.00	0.00	10.53	5.00	5.00	7.81	1.47	1.00
P5 x P6	50.00**	50.00**	13.00	0.00	0.00	0.00	0.00	0.00	0.00	16.67	16.67	5.00	16.13**	12.50*	6.00
Mean (S x S)	11.90	4.17	-8.00	0.00	0.00	0.00	-6.67	-6.67	-6.67	-1.81	-4.78	-8.33	3.60	-0.57	-3.00
Mean (Within)	10.72	0.24	0.17	8.70	0.00	5.50	2.45	-3.34	2.22	6.27	-3.12	0.84	7.71	2.86	2.18
P1 x P4	23.08	0.00	0.00	20.00	0.00	0.00	11.11	0.00	0.00	18.34	0.00	0.00	7.37	0.00	0.00
P1 x P5	63.64**	50.00**	13.00	20.00	0.00	0.00	11.11	0.00	0.00	32.08*	16.67	5.00	22.28**	17.19**	10.00
P2 x P4	-41.18**	-44.44**	-38.00**	-33.33*	-33.33*	-33.00**	-20.0*	-20.00*	-20.00*	-32.68**	-34.29**	-31.00**	-10.95*	-11.59*	-10.00
P2 x P5	-20.00	-33.33**	-25.00	0.00	0.00	0.00	0.00	0.00	0.00	-3.59	-10.48	-6.00	-3.76	-7.25	-6.00
P3 x P4	-5.88	-11.11	0.00	-7.69	-14.29	0.00	-7.69	-14.29*	0.00	-6.98	-13.04	0.00	2.19	1.45	3.00
P3 x P5	-6.67	-22.22	-13.00	-7.69	-14.29	0.00	-7.69	-14.29*	0.00	-7.32	-17.39	-5.00	6.27	2.42	4.00
Mean (Between)	2.17	-10.18	-10.42	-1.45	-10.32	-5.56	-1.42	-8.10	-3.33	-0.03	-9.76	-6.17	3.90	0.37	0.16
Grand mean	7.73	5.97	-3.36	4.35	-6.19	1.85	0.62	-5.72	-0.55	3.74	-7.73	-1.50	6.96	1.94	1.50
	LSD (0.05) = 3.90, LSD (0.01) = 4.51			LSD (0.05) = 2.48, LSD (0.01) = 2.87			LSD (0.05) = 1.95, LSD (0.01) = 2.26			LSD (0.05) = 7.30, LSD (0.01) = 8.44			LSD (0.05) = 7.88, LSD (0.01) = 9.11		

‡ **, ** = Significant at P < 0.05 and P < 0.01 levels, respectively; MPH = Mid parent heterosis; BPH = Better parent heterosis; SH = Standard heterosis, K x K = Kaffa x Kaffa, S x S = Sidamo x Sidamo, K x S Kaffa x Sidamo coffee hybrids P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377 and P5 = 1681. Note: The significance of the percent heterosis was tested by comparing mean differences between* F_1, *MP, BP and CV means to LSD values derived from genotypes (*F_1 *and parent) analysis of variance where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of commercial variety (check).*

Table 5b. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for Sidamo raw coffee quality parameters and ranking in relation to parents' origin in Set III coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

	Shape and Make			Color			Raw quality			
Hybrid	MPH	BPH	SH	MPH	BPH	SH	MPH	BPH	SH	Rank
P1 x P2	-7.69	-14.29	-14.29	1.41	2.86	0	-2.39	-4.67	-3	Cup: acceptable
P1 x P3	23.29**	7.14	7.14	27.27*	20.00	17	17.59**	9.35	11	Raw: better than usual Sidamo coffee ,Cup: acceptable
P2 x P3	25.37**	16.67	0.00	16.42	8.33	8	14.43*	8.82	6	Raw: better than usual Sidamo coffee ,Cup: highly acceptable
Mean (K x K)	13.72	3.17	-2.38	15.03	10.40	8.33	9.88	4.50	4.7	
P4 x P5	7.69	0.00	0.00	0.00	0.00	0	4.35	2.86	3	Raw: better than usual Sidamo coffee ,Cup: not acceptable
P4 x P6	-7.69	-14.29	-14.29	20.00	0.00	0	4.62	-2.86	-3	Cup: acceptable
P5 x P6	25.00**	25.00**	7.14	20.00	0.00	0	15.63*	8.82	6	Raw: better than usual Sidamo coffee ,Cup: acceptable
MS x S	8.33	3.57	-2.38	13.33	0.00	0.00	8.20	2.94	2	
Mean (Within)	11.03	3.37	-2.38	14.18	5.2	4.17	9.04	3.72	3.35	
P1 x P4	-7.14	-7.14	-7.14	-1.41	-2.78	-3	-1.89	-2.80	-1	Cup: acceptable
P1 x P5	15.38	7.14	7.14	26.76*	25.00*	25*	14.83*	12.15	14*	Raw: better than usual Sidamo coffee ,Cup: highly acceptable
P2 x P4	15.38	7.14	7.14	8.33	8.33	8	10.14	8.57	9	Raw: better than usual Sidamo coffee ,Cup: acceptable
P2 x P5	0.00	0.00	-14.29	0.00	0.00	0	0.00	0.00	-3	Cup: acceptable
P3 x P4	15.07	0.00	0.00	13.43	5.56	6	11.68	4.76	5	Raw: better than usual Sidamo coffee ,Cup: acceptable
P3 x P5	34.33**	25.00**	7.14	25.37*	16.67	17	20.62**	14.71*	11	Raw: better than usual Sidamo coffee ,Cup: acceptable
Mean (Between)	12.17	5.36	-2.38	12.08	8.80	8.8	9.23	6.23	6.5	
Grand mean	11.41	4.03	-2.38	13.48	6.4	5.71	9.1	4.56	4.4	
	LSD (0.05) = 2.59, LSD (0.01) = 2.99			LSD (0.05) = 3.00, LSD (0.01) = 3.46			LSD (0.05) = 4.95, LSD (0.01) = 5.72			

**, **, Significant at P < 0.05 and P < 0.01 levels, respectively; K x K = Kaffa x Kaffa, S x S = Sidamo x Sidamo, K x S = Kaffa x Sidamo coffee hybrids P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377, P5 = 1681; Note: - The significance of heterosis was tested by comparing mean differences between F_1, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance; MP = Mean performance of the two parents; BP = Mean performance of better parent and CV = Mean performance of commercial variety (check).*

Two hybrids each from Kaffa x Kaffa and Sidamo x Sidamo and four from Kaffa x Sidamo registered positive SH for Sidamo raw coffee quality. Similarly, three hybrids each from Kaffa x Kaffa and Kaffa x Sidamo and two Sidamo x Sidamo hybrids recorded positive SH for overall Sidamo coffee quality. None of the Kaffa x Kaffa and Kaffa x Sidamo hybrids were evaluated as having internationally unacceptable Sidamo coffee quality, but one Sidamo x Sidamo hybrid was evaluated as having internationally unacceptable Sidamo coffee quality. Two and four Kaffa x Kaffa and Kaffa x Sidamo hybrids, respectively, were evaluated as having coffee raw quality better than usual Sidamo coffees. Even though, two Sidamo x Sidamo hybrids were evaluated as having coffee raw quality better than the usual Sidamo coffees, one hybrid's overall Sidamo coffee quality was internationally unacceptable. One Kaffa x Kaffa (P2 x P3) and one Kaffa x Sidamo (P1 x P5) hybrids were evaluated as having internationally highly acceptable overall Sidamo coffee quality. These hybrids also exhibited positive SH for all other coffee quality parameters. None of the Sidamo x Sidamo hybrids exhibited positive and significant SH for any one of the Sidamo coffee quality parameters.

3.2.2. Heterosis in Relation to Parents' Origin and Leaf tip Color

Hybrids obtained from green x green leaf tip color parents regardless of parents origin registered positive mean MPH for all coffee quality parameters which ranged from 1.14 to 17.38%. Hybrids having green x bronze leaf tip colors regardless of parents origin exhibited negative MPH for all Sidamo coffee parameters except shape and make (7.75%), color (5.09%) and raw quality (6.07%) which exhibited positive mean MPH. The result is presented in Tables 5c and 5d.

Hybrids obtained by crossing parents with green x green leaf tip color registered positive BPH for shape and make, color and Sidamo raw coffee, and the over all quality ranged from 2.78 to 6.94% while acidity, flavor, body and Sidamo coffee cup quality had negative mean BPH ranging from -2.38 to -2.78. On the other hand, hybrids having parents' green and bronze leaf tip colors registered positive BPH of 2.78 and 3.35% only for color and Sidamo raw coffee quality, respectively. This group of hybrids exhibited negative mean BPH for all other coffee quality parameters which ranged from -6.46 to -20.83%. Hybrids obtained from both parents with green leaf tip color had mean advantages over the best commercial Sidamo coffee variety/cultivar for all the Sidamo coffee quality parameters except for shape and make. The mean SH for all coffee quality parameters ranged from 0.17 to 11.17%. On the other hand, hybrids obtained by crossing parents with green x bronze leaf tip colors registered positive mean SH of 2.75 and 4.00% only for color and Sidamo raw coffee quality, respectively, while negative mean SH (-5.75 to -26.39%) were observed for all the other coffee quality parameters (Tables 5c and 5d). Five out of six hybrids generated from parents both having green leaf tip color but either similar or distant parents in origin (Kaffa x Kaffa and Kaffa x Sidamo) exhibited positive SH in the range of 1 to 16% for over all the Sidamo coffee quality which is a single most important parameter that determine the acceptability of Sidamo coffee in international coffee market. On the other hand, only one hybrid among the green x bronze hybrids having distant parents in origin (Kaffa x Sidamo) exhibited a positive SH (3%) for this important trait.

4. Discussion

In Ethiopia, consistently hybrids yield advantages over the better parents and best yielding checks (commercial cultivars) were observed and progressively increased as distant parents in origin included in crossing. It was observed that 20% of SH for a hybrid obtained by crossing parents from similar origin in Set I progressed to 42.3% for Set II for hybrid obtained by crossing parents from different geographical origin. Besides, in Set III the magnitude of SH was increasing to 44.62% for hybrids obtained by crossing distant parents in origin. Most of the hybrids obtained by crossing distant parents in origin exhibited higher SH for coffee yield. In Ethiopia, the observed magnitude of standard heterosis was much greater than other coffee growing countries. In Brazil, heterosis in terms of yield was studied over several years in crosses of selected indigenous C. *arabica* L. varieties, but it was reported to be lacking (Carvalho *et al.,* 1969; Carvalho, 1988). In this country, the absence of heterosis in *Coffee arabica* L. lead to in crossing of Catuai lines (*Coffea arabica*) with 12 descendents from the Hybrido Timor (*Coffea canephora*). In one of such trial, heterosis values of 28.7 and 19.1% over the best control yield, respectively, in the first four and six years were recorded (Fontes *et al.,* 2000). In Kenya Van der Vossen and Walyaro (1981) reported better parent heterosis of 19.7% in Catura x Hybrido Timor and 15% heterosis in Padang x SL34 hybrids (Van der Vossen, 1985). The higher magnitude of heterosis over the best checks in Ethiopian coffee hybrids might be due to high genetic variability among and between coffee growing regions' coffee types as it was reported by many researchers (IBPGR, 1980); Carneriro, 1997; Fazuoli *et al.*, 2000).

This study revealed that coffee hybrids generated from distant parents both in origin and growth habit were most heterotic for coffee yield. Other group of hybrids which had distant parents in origin but similar growth habit were the second most heterotic hybrids. The lowest magnitude of SH was recorded for hybrids having both parents similar in origin and growth habit. Hybrids obtained from parents having nearly similar origin but distinct difference in growth habit also registered lower magnitude of SH. These results are in contrast to Bayetta *et al.* (2007) who reported the superiority of hybrids having parents nearly similar origin but distinct differences in growth habit. The authors also suggested that variation in geographical origin had no significant effect on heterosis. Bayetta *et al.* (2007) who compared hybrids based on mean MPH (%) and BPH (%) for yield and other traits reported that the hybrids that exhibited the highest mid and better parent heterosis did not always exhibit the highest yield and standard heterosis. Besides, economically important heterosis is standard heterosis and selection and ranking of hybrids based on the degree of mid and better parent heterosis per se is misleading in respect to commercial importance of hybrids. Therefore, on the basis of the results of standard heterosis, it is possible to suggest the importance of considering parents diversity both in origin and growth habit; if not possible the origin of parents' should be considered to obtain heterotic commercial hybrids.

Table 5c. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for Sidamo coffee cup quality parameters in relation to parents' origin and leaf tip color in Set III coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

Origin and leaf tip color‡	Hybrid	Acidity			Body			Flavor			Cup quality		
		MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)
Kaffa x Kaffa, Green x Green	P1 x P2	28.57	0.00	13	20.00	0.00	0	11.11	0.00	0	20.69	0.00	5
Kaffa x Kaffa, Green x Green	P1 x P3	14.29	-11.11	0	9.09	-14.29	0	1.69	-14.29*	0	8.70	-13.04	0
Kaffa x Kaffa, Green x Green	P2 x P3	0.00	0.00	13	23.08*	14.29	33**	23.08*	14.29*	33*	13.64	8.70	25**
Mean similar origin and Green x Green		9.53	-3.70	8.67	17.39	0.0	11.11	11.57	0	11.11	14.34	-1.45	10
Kaffa x Sidamo, Green x Green	P1 x P5	63.64**	50.00**	13	20.00	0.00	0	11.11	0.00	0	32.08*	16.67	5
Kaffa x Sidamo, Green x Green	P2 x P5	-20.00	-33.33**	-25	0.00	0.00	0	0.00	0.00	0	-3.59	-10.48	-6
Kaffa x Sidamo, Green x Green	P3 x P5	-6.67	-22.22	-13	-7.69	-14.29	0	-7.69	-14.29*	0	-7.32	-17.39	-5
Mean between region and Green x Green		12.32	-1.85	-8.33	4.10	-4.76	0	1.14	-4.76	0	7.06	-3.73	-2
Mean of Green x Green leaf tip color		13.31	-2.78	0.17	10.75	-2.38	5.50	6.55	-2.38	5.50	10.70	-2.59	4.00
Kaffa x Sidamo, Green x Bronze	P1 x P4	23.08	0.00	0	20.00	0.00	0	11.11	0.00	0	18.34	0.00	0
Kaffa x Sidamo, Green x Bronze	P2 x P4	-41.18**	-44.44**	-38**	-33.33*	-33.33*	-33**	-20.0*	-20.0*	-20*	-32.68**	-34.29**	-31**
Kaffa x Sidamo, Green x Bronze	P3 x P4	-5.88	-11.11	0	-7.69	-14.29	0	-7.69	-14.29*	0	-6.98	-13.04	0
Mean between region and Green x Bronze		-7.99	18.52	-12.67	7.01	-15.87	-11	-5.53	-11.43	-3.33	-7.11	-15.78	-10.33
Sidamo x Sidamo, Green x Bronze	P4 x P5	-42.86**	-50.00**	-50**	0.00	0.00	0	-20.0*	-20.0*	-20*	-32.63**	-36.0**	-36**
Mean of Green x Bronze leaf tip color		-16.71	-26.39	-22.00	-5.26	-11.91	-8.25	-4.15	-13.57	-10.0	-13.49	-20.83	-16.75

**, ** = Significant at P < 0.05 and P < 0.01levels, respectively, B x B = Bronze x Bronze, P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377 and P5 = 1681*

Table 5d. Mid parent (MPH %), better parent (BPH %), and standard (SH %) heterosis for Sidamo raw coffee parameters and overall quality in relation to parents' origin and leaf tip color in Set III coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

Origin and Leaf tip color	Hybrid	Shape and Make			Color			Raw quality			Overall coffee quality		
		MPH	BPH	SH	MPH	BPH	SH	MPH	BPH	SH	MPH	BPH	SH
Kaffa x Kaffa, Green x Green	P1 x P2	-7.69	-14.29	-14.29	1.41	2.86	0	-2.39	-4.67	-3	8.09	0.00	1
Kaffa x Kaffa, Green x Green	P1 x P3	23.29**	7.14	7.14	27.27*	20.00	17	17.59**	9.35	11	13.32*	4.83	6
Kaffa x Kaffa, Green x Green	P2 x P3	25.37**	16.67	0.00	16.42	8.33	8	14.43*	8.82	6	14.01**	14.01**	16**
Mean similar origin and Green x Green		13.72	3.17	-2.38	15.03	10.40	8.33	9.88	4.50	4.7	11.81	6.28	7.35
Kaffa x Sidamo, Green x Green	P1 x P5	15.38	7.14	7.14	26.76*	25.00*	25*	14.83*	12.15	14*	22.28**	17.19**	10
Kaffa x Sidamo, Green x Green	P2 x P5	0.00	0.00	-14.29	0.00	0.00	0	0.00	0.00	-3	-3.76	-7.25	-6
Kaffa x Sidamo, Green x Green	P3 x P5	34.33**	25.00**	7.14	25.37*	16.67	17	20.62**	14.71*	11	6.27	2.42	4
Mean between region and G x G		16.57	10.71	0	17.38	13.89	14	11.82	8.95	7.33	8.26	4.12	2.67
Mean of G x G leaf tip color		15.11	6.94	-1.19	16.21	12.14	11.17	10.85	6.73	6.00	10.04	5.20	5.17
Kaffa x Sidamo, Green x Bronze	P1 x P4	-7.14	-7.14	-7.14	-1.41	-2.78	-3	-1.89	-2.80	-1	7.37	0.00	0
Kaffa x Sidamo, Green x Bronze	P2 x P4	15.38	7.14	7.14	8.33	8.33	8	10.14	8.57	9	-10.95*	-11.59*	-10
Kaffa x Sidamo, Green x Bronze	P3 x P4	15.07	0.00	0.00	13.43	5.56	6	11.68	4.76	5	2.19	1.45	3
Mean between region and Green x Bronze		7.77	0.00	0.00	6.78	3.7	3.67	6.43	3.51	4.33	-0.46	-3.38	-2.33
Sidamo x Sidamo, Green x Bronze	P4 x P5	7.69	0.00	0.00	0.00	0.00	0	4.35	2.86	3	-13.13*	-15.69**	-16**
Mean of Green x Bronze leaf tip color		7.75	0	0.00	5.09	2.78	2.75	6.07	3.35	4.00	-3.63	-6.46	-5.75

**, ** = Significant at P < 0.05 and P < 0.01 levels, respectively; * Set III, P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377, P5 = 1681*

The findings of the present study are in agreement with Pradhan *et al.* (1993), Falk *et al.* (1994) and Ali *et al.* (1995) who using morphological markers and geographic origin observed an increase in heterosis with increasing parental distance in *Brassica juncea*, *Brassica rapa* and *Brassica napus,* respectively..

Hybrids heterosis effects calculated in relation to parents' leaf color regardless of their origin and growth habit revealed that hybrids having parents with different leaf tip colors were more heterotic for yield than hybrids which had parents with similar leaf tip color. Two hybrids that exhibited the highest SH (P3 x P4, 44.62% in Set II and P1 x P5, 42.31% in Set III for yield were obtained by crossing distant parents in origin with different leaf tip color and distant parents in all factors origin, morphology and leaf tip color). This result could be a good indicator of the need to consider leaf tip color differences in parental lines selection to produce heterotic hybrids.

The Kaffa x Kaffa (P2 x P3) and Kaffa x Sidamo (P1 x P5) hybrids were evaluated as having highly acceptable Sidamo coffee quality for international coffee market. These hybrids also exhibited positive SH for all other Sidamo coffee quality parameters. Besides, the Kaffa x Kaffa and Kaffa x Sidamo hybrids were superior over the Sidamo x Sidamo hybrids for all coffee quality parameters. This suggested the possibility of improving target region coffee quality as well as yield through selection and then crossing coffee parents regardless of their origin. This result was in agreement with Montagnon *et al.* (1998) who reported variation of yield and quality traits are independent form genetic correlations study between yield and several quality traits, in crosses of Congolese and Guinean group of parents.

Hybrids heterosis effects calculated for quality parameters in relation to parents' origin and leaf tip color revealed the superiority of hybrids generated from parents with similar leaf tip color (green) over the hybrids obtained from parents with different leaf tip colors. Distant parents in origin had little effect on hybrids magnitude of SH. The hybrids obtained from crossing of two Sidamo coffee parents either considering or without considering their leaf colors did not perform better than the hybrids obtained from Kaffa x Kaffa hybrids in both combinations. This result suggested the importance of considering parents leaf tip color to improve the target region coffee quality than the coffee parents' to be originated in target region.

5. Conclusions

The magnitude of standard heterosis progressively increased in Ethiopian coffee hybrids (*Coffea arabica* L.) as distant parents' in all factors were included in the crossing program. It was recorded the highest standard heterosis of 20% for the within region hybrids in the first hybrid trial which progressed to 42.3% for clean coffee yield for hybrid generated from distant parents in all factors (origin, growth habit, leaf tip color) in second hybrid trial. The highest standard heterosis (44.62%) for clean coffee yield was also observed in the third hybrid trial. This hybrid was obtained from distant parents in origin and leaf tip color. The advantage of inclusion of distant parents in all possible factors was not only observed in the magnitude of exploitable heterosis but also in obtaining greater number of heterotic hybrids from each trial. These results suggested the importance of inclusion of distant parents in one or more factors to produce greater number of coffee hybrids with highest magnitude of heterosis.

In this investigation, the within region (Kaffa x Kaffa) and the between region (Kaffa x Sidamo) hybrids showed superiority over the released Sidamo coffee parent used as check. These hybrids also showed superiority over the hybrids obtained from crossing of two Sidamo parents for Sidamo coffee quality parameters. The superiorities of the Kaffa x Kaffa and Kaffa x Sidamo over the Sidamo x Sidamo coffee hybrids did not only exhibit higher magnitude of standard heterosis but also most of the hybrids displayed higher magnitude of SH. It was also observed that the parents green leaf tip color affected the magnitude of heterosis regardless of their distant in origin. It was interesting to observe the superiority of hybrids generated from parents' other than the target region crossed among them or crossed with the target region coffee parents for the target region coffee quality. This indicates inclusion of parents other than the target region did not negatively blend the target region coffee quality. It is suggested to consider and study further on the effects of parents leaf tip color on the magnitude of heterosis for coffee quality to design appropriate breeding method to improve the target region coffee quality.

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Evaluation of Some Botanicals to Control Potato Tuber Moth *Phothoromaea operculella* (Lepidoptera: Gelechiidae) at Bako, West Shoa, Ethiopia

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Abstrac: *Lantana camara, Eucalyptus globulus*, *Tagetus minuta,* Pyretherum flowers and *Azadiractha indica,* were evaluated against potato tuber moth damage including two checks (Diazinon 60% EC and untreated check) at Bako Agricultural Research Center in 2003/2004 and 2004/2005 cropping seasons. A total of twenty-one huts were constructed from locally available materials. Inside each store, $1m^2$ bed storage sacks were constructed 65 cm above the ground. Six hundred and fifty (650) numbers of potato tubers were stored on the bed of each hut in two layers one over the other. The treatments were arranged in a randomized complete block design with three replications. Plant powder and Diazinon 60% EC were applied at the rate of 50 g/bed and 3.5 ml/bed respectively at two months interval. The treatments that showed promising effects were further advanced on a large bed (2 m x 3 m) without replication. Data was collected for the number of potatoes infested and damaged by potato tuber moth, and number of potatoes damaged by some factors other than potato tuber moth. Evaluations were made at an interval of fifteen days for seven consecutive months. Analysis of variance showed that there were significant differences among the treatments. Number of potatoes infested and damaged by potato tuber moth was significantly ($P < 0.05$) lower in *Lantana camara*, *Eucalyptus globulus* and *Pyretherum flowers* than the other treatments. Percent of potatoes infested and damaged by potato tuber moth on a large bed were lower for *Lantana camara*, *Eucalyptus globules, Pyretherum flowers* and Diazinon , while higher for the other treatments. Percent of potatoes damaged by diseases and other factors were significantly high in all treatments and non-significant differences were observed among them. From this study it can be conclude that *Lantana camara, Eucalyptus globules* and *Pyretherum flowers* could be used to protect seed potatoes from potato tuber moth damage in diffused light storage.

Keywords: Seed Potato; Potato Tuber Moth; Botanicals

1. Introduction

Potato is one of the major tuber crops that is grown in the high lands of western Ethiopia, particularly around Bako area. It serves as food and income security to farmers especially during seasonal food shortage and when grain is depleted from store.

Improved seed is one of the packages to be used to get high yield and must be free from insect attack. But there are multifarious farming systems constraints that are imminent and plague that inflict great economic losses on potato tuber seeds in a rustic storage system. Potato tuber moth is the bottleneck that may cause damage to seed tuber under storage.

Good postharvest handling is an important and crucial factor for uniform sprout growth free from insect attack. Unless protected in the storage, potato tuber moth, PTM (*Phothoromaea operculella)* is one of the noxious insect pests of potato tuber seeds in the storage. According to Anonymous (1980), storage losses due to storage pests are reported to vary from 30-70% in India, and as high as 86% in Tunisia, Algeria and Turkey. Infestation of tubers in the field is estimated to be 50% in Peru. According to Adhanom *et al.* (1985), potato tuber moth is the most damaging pest of potato, which could reach up to 91% in 90 days in Ethiopia (Adahanom, 1985). In western parts of Ethiopia research to mitigate the problem is only limited to screening resistant genotypes for potato tuber moth. The widely adopted method to control potato tuber moth is chemical application. Currently, the problem associated with the use of chemicals is recognized in terms of its sustainability and effect on environment and on non-target organisms. Therefore, it is important to search for alternatives that are effective, environmentally safe and economically feasible.

The use of natural plant products is found to be promising against potato tuber moth. Use of extracts of wild coastal "tonuz" (*Plucheachinyoyo*) has shown great potential to control "Polill" (*Phthorimaea operculella*) in stored potato (Luis, 2001; Solomon, 1985). Similarly, the use of *eucalyptus spp*, Muna (*Minthostachis spp*) and *Lantana camara* has been reported by International Potato Center (CIP) as being capable of controlling pest attack in stored potato (Luis, 2001; Tindal, 1983). At present, environmentally friendly biological options exist. These options based on use of botanicals and natural diversity needs to be addressed for their application and effectiveness. One of the natural crop protection approaches is the use of plant, which are having insecticidal properties. Hence, the objective of this study was to evaluate potential botanicals for the control of potato tuber moth.

2. Material and Methods

The experiment is conducted at Bako Agricultural Research Center that is located 9^{o} 6`N latitude and $37^{o}$ 09` E longitude, 260 km west of Addis Ababa, at an altitude of 1650 masl The area is characterized by warm and humid climate. The annual average rainfall and relative humidity during the study period were 1341 mm and 60.11%, respectively. The average minimum (12.58 ^{o}C) and maximum (27.21 ^{o}C) atmospheric temperatures of the area during the study period were recorded.

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Eucalyptus globulus, *Tagetus minuta, Pyretherum flowers* and *Azaddiractha indica* were evaluated against potato tuber moth with two checks (Diazinon 60% EC and untreated check) for two years (2003/2004 and 2004/2005) at Bako Agricultural Research Center. The treatments were arranged in randomized complete block design with three replications. A total of twenty-one huts (cottages) were constructed from locally available materials and inside each cottage the bed (1 m^2 area) was constructed 65 cm above the ground. An improved potato variety Menagesha was multiplied at Bako Agricultural Research Center. The botanicals were obtained from the vicinity and Pyrethrum flower was obtained from Kulumsa Research Center. Potato tubers (#650) were stored on the bed of each cottage. The botanicals were dried under shade and grinded in to fine powder using mortal and pestle. Leaf and/or flower powder of the botanicals and chemical were applied at the rate of 50 g/bed and 3.5 ml /bed, respectively, at two-month interval. The treatments that showed promising effects were advanced on large beds (2 m x 3 m) without replication and 150 g powder was used for each at an interval of two months. Data was collected on number of potatoes damaged by potato tuber moth and number of potatoes damaged by some factors other than potato tuber moth. Affected tubers were counted at fifteen days intervals for seven consecutive months during each experimental period. Data was subjected to SAS version 6.12 software. Mean separations were done using SNMK range test.

Table 1. List of botanicals evaluated against potato tuber moth in 2003/2004 and 2004/2005 cropping seasons at Bako, western Ethiopia.

Common name	Scientific name	Plant parts used
Lantana camara	Lantana Camara	Leaf powder
Eucalyptus Globulus.	*Eucalyptus Globulus.*	Leaf powder
Tagetus minuta	*Tagetus minuta*	Leaf powder
Pyretherum flowers	*Chrysanthemum spp*	Flower power
Neem	*Azadrachta indica*	Leaf powder
Diazinon 60% EC		Diazinon 60% EC
Control (Untreated check)		

3. Results and Discussion

Combined effects of different botanicals on percent of potatoes infested and damaged by potato tuber moth, and percent of potatoes damaged by diseases are indicated in Table 2. Percent of potatoes infested and damaged by potato tuber moth were significantly lower in *Lantana camara, Eucalyptus globules* and *Pyretherum flowers* treated huts than the other treatments. Percent of potatoes damaged by diseases such as Helminthosporium solani [*H. atrovirens syn. Spondylocladium atrovirens*), Soft rotting bacteria (*Erwinia carotovora)*, *Common scab (Streptomyces scabies)* were significantly high in all of the treatments and no-significant differences were recorded among them (Table 2). Similar results were observed in 2004/2005 experimental results (Table 4).

Percent of potatoes infested by PTM was significantly ($P < 0.05$) lower in *Eucalyptus spp, Lantana camara and* chemical than other treatments (Table 3). Percent of potatoes damaged by PTM was significantly high in *Lantana camara, Tagetus minuta, Azadrachta indica* and the check. However, significantly ($P < 0.05$) lower in the other treatments (Table 3). Low percent of potatoes infested and damaged by PTM was observed in *Lantana camara, Eucalyptus globules, Pyretherum flowers* and Diazinon. However, high percent damage was observed on the untreated check (Tables 5 and 6).

The results of the study have shown that *Eucalyptus spp, pyretherum* flowers and *Lantana camara* had potential effect against PTM damage and comparable results were observed with Diazinon 60% EC (Table 2). These findings agree with the research results reported by International Potato Center, and Palecios and Cisnerose, (1997) that reported the use of some plant materials such as *Lantana camara* as being capable of controlling pest attack in stored potato (Luis, 2001). From such results, it appears that those efficient botanicals may possess antifedant, repellent, insecticidal effects or the combination of these effects that reduce the damage level caused by insect pests. According to the work of Gabby (1996) and the International Potato Center, it was possible to control PTM by storing potatoes on the bed of *Eucalyptus spp*. leaves (Luis, 2001). Some plants and weeds such as Muna (*Minthosstachys spp*), Eucalyptus (*Eucalyptus globules*), Chilca (*Baccharis spp*), *Curry plants*, *Indian pivets*, *lantana camara, Mentha arvensis* and *Artemesi vulgaris*, and *Lycopersiconhirsutum* were reported to offer effective control of PTM (Kennedy, 1984). Therefore, *Eucalyptus spp, pyretherum* flowers and *Lantana camara* can effectively protect seed potato tubers from potato tuber moth and can be used by farmers.

Table 2. Effects of different botanicals on infested and damaged potatoes by potato tuber moth (PTM), and damaged by diseases and other factors at Bako (combined ANOVA of 2003/2004 and 2004/2005 cropping seasons).

Treatment	Infested potatoes (%)	Damaged potatoes (%)	Potatoes damaged by diseases (%)
Lantana camara	0.97±0.26c	2.82±0.87c	1.03±0.24a
Eucalyptus globulus	1.13±0.28c	1.87±0.25c	1.20±0.19a
Tagetus minuta	5.48±0.29a	7.87±0.91a	1.13±0.19a
Pyretherum flowers	1.84±0.23c	2.48±0.188c	1.41±0.14a
Azadirachta indica	4.10±0.36b	4.99±0.34b	0.97±0.12a
Diazinon 60% EC	0.95±0.16c	1.51±0.37c	1.20±0.24a
Control	5.87±0.64a	8.26±1.08a	1.18±0.22a
CV%	23.61	27.71	26.46

Different letters within the same column are significantly different from each other at 5% probability level (SNK range test)

Table 3. Mean potatoes infested and damaged by potato tuber moth (PTM), and damaged by diseases and other factors at Bako (2003/2004 cropping season).

Treatment	Infested potatoes (%)	Damaged potatoes (%)	Potatoes damaged by diseases (%)
Lantana camara	1.43±0.34c	4.31±1.23ab	0.56±0.18a
Eucalyptus globulus	1.69±0.27c	2.36±0.20b	0.87±0.13a
Tagetus minuta	5.84±0.35b	6.61±1.07a	0.77±0.09a
Pyretherum flowers	2.10±0.40c	2.72±0.20b	1.13±0.05a
Azadiractha indica	4.71±0.34b	5.59±0.34a	0.82±0.10a
Diazinon 60% EC	1.18±0.13c	1.89±0.67b	0.77±0.31a
Control	6.61±0.87a	5.89±0.48a	0.72±0.13a
CV%	19.59	29.67	18.29

Different letters within the same column are significantly different from each other at 5% probability level (SNKRT)

Table 4. Mean potatoes infested and damaged by potato tuber moth (PTM), and damaged by diseases and other factors at Bako (2004/2005 cropping season).

Treatment	Infested potato (%)	Damaged potatoes (%)	Potatoes damaged by diseases (%)
Lantana camara	0.51±0.13c	1.33±0.22c	1.49±0.18a
Eucalyptus globulus	0.56±0.13c	1.38±0.18c	1.54±1.54a
Tagetus minuta	5.13±0.40a	9.12±1.20a	1.49±1.49a
Pyretherum flowers	1.59±0.18c	3.23±1.12bc	1.69±1.69a
Azadiractha indica	3.49±0.41b	4.41±0.36b	1.13±1.13a
Diazinon 60% EC	0.72±0.22c	1.13±0.34c	1.64±1.64a
Control	5.12±0.85a	10.61±0.23a	1.64±1.64a
CV%	29.11	25.82	21.36

Different letters within the same column are significantly different from each other at 5% probability level (SNKRT)

Table 5. Effects of different botanicals on potatoes infested and damaged by potato tuber moth, and damaged by diseases and other factors at Bako, Legaya on large bed with out replication (2005/2006 cropping season).

Treatments	Potatoes infested (%)	Potatoes damaged (%)	Potatoes damaged by diseases (%)	Yield advantage over the control (%)
Lantana camara	7.01	2.41	0.56	16.49
Eucalyptus globulus	6.14	2.88	0.44	16.02
Pyretherum flowers	4.85	1.99	0.35	16.91
Diazinon 60% EC	9.11	3.97	0.48	14.93
Control	56.00	18.90	0.58	

Table 6. Effects of different botanicals on percent of potatoes infested and damaged by potato tuber moth, and damaged by diseases and other factors at Bako Siree on large bed with out replication (2005/2006 cropping season).

Treatments	Potatoes infested (%)	Potatoes damaged (%)	Potatoes damaged by diseases (%)	Yield advantage over the check (%)
Lantana camara	4.57	1.89	0.24	14.98
Eucalyptus globulus	7.24	4.58	0.18	12.59
Pyretherum flowers	3.45	2.45	0.28	14.42
Diazinon 60% EC	8.75	1.24	0.34	15.63
Control	38.45	16.87	0.41	

4. Conclusions

The over all study showed that application of *Eucalyptus spp, pyretherum* flowers and *Lantana camara* leaf powder at the rate of 50 g per 650 potato tubers can be used as a component of integrated pest management by farmers around Bako area in western Ethiopia to tackle the problem of potato tuber moth.

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Coffee Berry Insect Pests and their Parasitoids in the Afromontane Rainforests of Southwestern Ethiopia

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Abstract: A study was conducted to investigate the presence, intensity and damages caused to coffee berries by major insect pests of coffee in wild coffee populations in Afromontane rainforests of Southwestern Ethiopia. The parasitoids associated with those insect pests were also studied. Based on ecological descriptions of forest coffee population, each forest locality was stratified in to three forest sites. In each stratum, 40 coffee trees were randomly taken for insect pests and parasitoids collection; whereas 16 random coffee trees were used to study the incidence of the pests on coffee berries at different phenological stages. Fifteen insect pest species in 10 families under five orders were recorded. Among the insects recorded, *Ceratitis fasciventris* (Bezzi) and *Ceratitis anonae* Graham were new records for Ethiopia. Similarly, *Prorops nasuta* and *Psyttalia* spp. were new parasitoids reported for the first time in Ethiopia. The damage caused by coffee berry moth was low and analysis of variance revealed that there is a significant difference ($P < 0.05$) among the forest coffee populations. Fruit fly mean incidences on ripen coffee berries reached 52.12% ± 14.31, 71.08% ± 4.48 and 82.73% ± 3.61 at Yayu, Berhane-Kontir and Bonga, respectively. Mean damage by *Hypothenemus hampei* was less than 10% in most of the forest coffee populations, which is relatively low incidences in less disturbed ecosystem. In general, difference in occurrences of insect pest incidences between and within forest coffee populations **was** observed, which could be due to variations in ecology, and diversity of the insect pests and their parasitoids. From the results, it is thought that these forest coffee sites would be used as the main genetic resources for exploration of insect pests and their natural enemies in the future, which undoubtedly needs detailed research work.

Keywords: *Coffea arabica*; Afromontane Rainforest; Insect Pests; Parasitoids; Incidence

1. Introduction

Coffee berries (beans) are the final product for consumption. Several insect pests are known to attack berries at different phenological development stages and affect both quality and quantity of the product. Coffee berry infestation by insects starts at bud formation and flowering stage. General feeders such as larvae of lepidoptera damage buds, whereas scale insects and aphids infest and suck the sap from the plant at all times during their nymphal and adult stages. The most injurious pests at green berry stages are Pentatomid and Mirid bugs (Le Pelley, 1968; Million, 1987; Crowe, 2004). Small green berries are attacked by general feeders including Coleoptera, many Lepidoptera, scale insects and thrips. The pentatomids *Antestiopsis* spp. feed on small green berries and mostly cause berry drop-off. Fully developed green berry is the stage at which the beans differentiate developing a hard endosperm and are suitable for many general feeders like berry-boring Lepidoptera (Le Pelley, 1968; Million, 1987; Crowe, 2004). Ripe berry is the stage at which pulp becomes soft, sweet and the parchment surrounding the endocarp hardens. The seeds or beans at this stage are not easily attacked by almost all sucking insects. Several authors reported ripe berries are attacked by fruit fly larvae (Le Pelley, 1968; Mekuria *et al*., 1995; Million, 2000; Crowe, 2004; Esayas, 2005). Following the ripening process of coffee, the fruit either falls to the ground or remains on the tree, if not harvested. The pulp starts drying up and the stage is referred to as over ripened or mummified berries and liable to be attacked by *Hypothenemus hampei* (Million, 2001; Esayas *et al*., 2003).

There are different coffee growing and production systems in Ethiopia mainly due to varying level of forest trees associated with coffee, the nature of coffee tree regeneration and resource level of growers. In general, based on the level of human intervention (management practices), the coffee system in Ethiopia is categorized in to four as forest, semi-forest, Garden and plantation coffee systems (Demil, 1999; Paulose and Demil, 2000; Workafes and Kassu, 2000; Taye and Tesfaye, 2001). The forest coffee type is genetically heterogeneous and serves as a source of gene pool to improve coffee varieties for disease and insect pest resistance/tolerance, productivity and quality through breeding. In general, crop production systems can affect insect pests population build up directly or indirectly. In Ethiopia, over forty-seven species of insect pests were recorded in plantation and garden coffee production systems (Million and Bayisa, 1986; Million, 1987, 2000).

Coffee is produced in more than 80 countries worldwide and it is by far Ethiopia's most important export crop in the national economy as it accounts for 41% (FAO, 2006) and 35% (Tadesse *et al*., 2008) of the total agricultural export earnings; and 10-20% of the total government revenue (FAO, 2006). Insect pests are among the number of factors considered to limit coffee production and productivity. Among the coffee berry damaging insects, Antestia bug cause 9% yield loss and 48% coffee bean darkening (Million, 1988) and coffee berry borer cause up to 60% damage on dry left-over berry (Million, 2001; Esayas *et al.,* 2003), in all-case damage assessment focussed on plantation coffee production system. On the other hand, there is a

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complete lack of data on insect pests of coffee in the afromontane rainforest of southwestern Ethiopia from where *C. arabica* **was** originated and distributed to the world. Insect pest status information is a vital and prominent issue for further research work in such area.

The diversity and the economic value of the Ethiopian coffee gene pool and its forest habitat as well as the institutional framework of forest users have been studied (CoCE I, 2007; Chemeda *et al.,* 2008). The *in-situ* conservation of wild coffee is an extremely useful approach in biodiversity conservation as the conservation of coffee genetic diversity is connected with the conservation of forest species diversity (CoCE I, 2007). However, the status of coffee berry damaging insects and their parasitoids has not been surveyed, nor described and no scientific information thereof is available in such a genetically diversified ecosystem. So, a detailed study was essential in order to supplement *in-situ* conservation of the genetically diversified forest coffee pool and associated flora and fauna for sustainable use. Therefore, this study was initiated to investigate and document coffee berry insect pests and their parasitoids; and estimate the associated incidence in relation to coffee berry developmental phenology in the afromontane rainforests of southwestern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Areas

The study was conducted in the afromontane rainforests of Yayu (Geba-Dogi), Berhane-Kontir and Bonga Forest Coffee Populations (FCPs) in the 2007/2008. The Yayu FCP (PI) is found in the western part of the Oromia Regional State along the Geba and Dogi Rivers, whereas the Berhane-Kontir (PII) and Bonga (PIII) FCPs are situated in the Southern Nations Nationalities and People's Regional State, SNNPS (Figure 1). These forest sites have served as a focal point for biodiversity conservation in general and strategic diagnostic research as FCPs in particular. In general, they are benchmark areas for the Ethiopian Government as the National Forest Priority Areas (NFPAs) and are declared forest coffee conservation areas too. Altitudes, geographical co-ordinates (latitudes and longitudes), slopes and aspects of the study areas and sites are shown in Table 1.

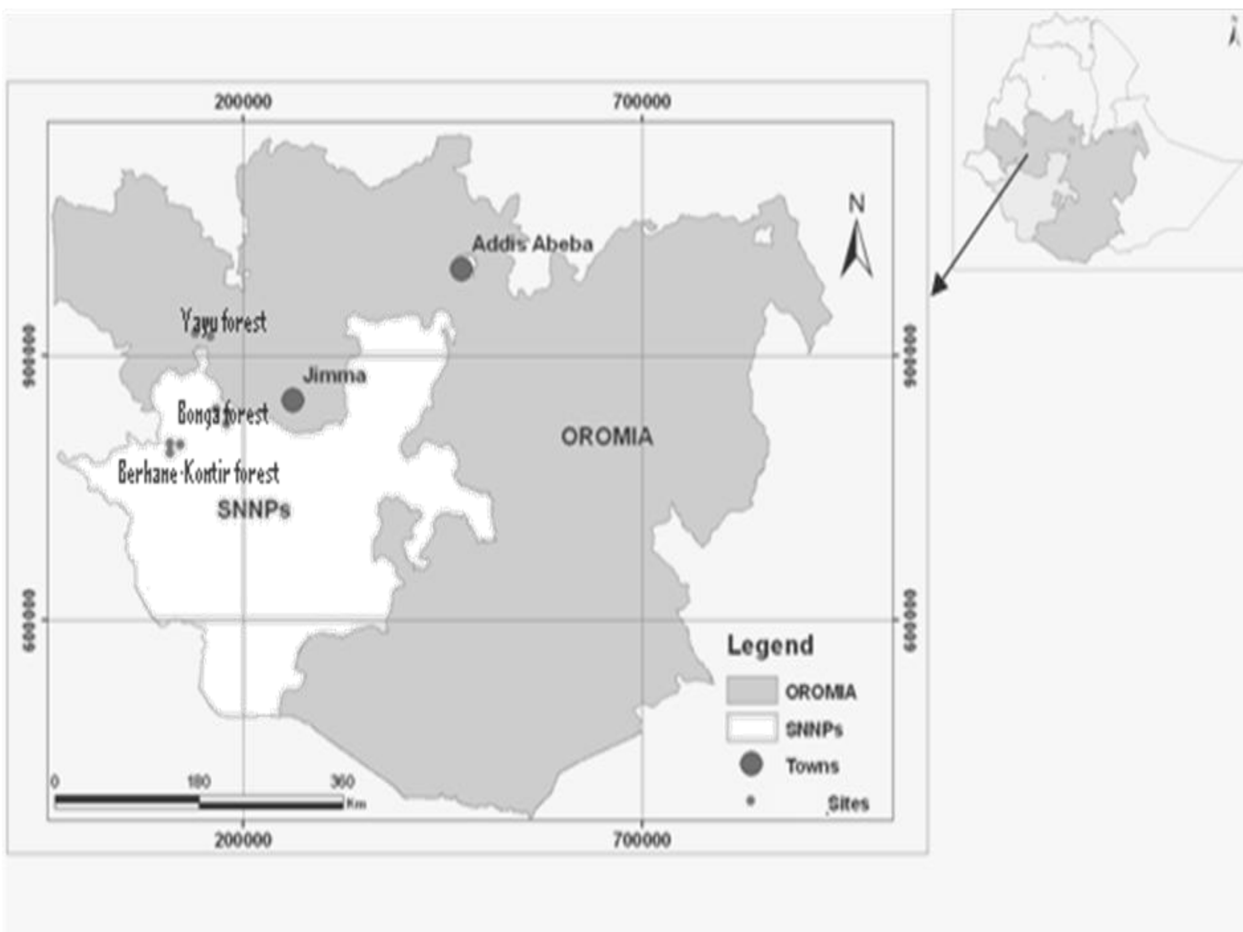


Figure 1. Map of Ethiopia showing regions with forest areas of montane rainforests of southwestern Ethiopia.

Table 1. Description of the study sites in the afromontane rainforests of southwestern Ethiopia.

Forest population	Forest site*	Elevation (masl)	Coordinates		Slope (%)	Slope aspect
			Latitude (N)	Longitude (E)		
Yayu (PI)	Yayu-1 (SI)	1493	08⁰ 24' 11"	35⁰ 47' 44"	10	East
	Yayu-2 (SII)	1491	08⁰ 23' 98"	35⁰ 47' 40"	16	West
	Yayu-3 (SIII)	1496	08⁰ 23' 10"	35⁰ 47' 62"	20	West
Berhane-Kontir (PII)	BeKo-1 (SI)	1051	07⁰ 07'43"	35⁰ 26' 16"	15	North
	BeKo-2 (SII)	1084	07⁰ 07' 16"	35⁰ 26' 29"	13	Northeast
	BeKo-3 (SIII)	1134	07⁰ 06' 52"	35⁰ 26' 33"	20	East
Bonga (PIII)	Alemgano-1 (SI)	I744	07⁰ 20' 01"	35⁰ 13' 39"	5	East
	Alemgano-2 (SII)	1739	07⁰ 20' 31"	35⁰ 13' 32"	10	East
	Yabito (SIII)	1894	07⁰ 19' 04"	'35⁰ 03' 31"	8	Northwwest
	JARC	1753	07⁰ 47' 03"	036⁰ 00' 00"	-	-

**JARC = Jimma Agricultural Research Center wherein laboratory based experiment was conducted, masl = Meters above sea level*

2.2. Assessment of Insect and their Parasitoids

A study on coffee berry insect pests and their natural enemies was conducted in the Afromontane rainforests of southwestern Ethiopia. For every FCP, 3 representative sites labelled as SI, SII and SIII; each with 100 m x 100 m area were selected for the study. This classification was made based on general uniformity of coffee trees (5-7 years old), shade status and elevation of the FCP sites.

The study/sampling plots environmental features were described using GPS for coordinates and elevation; and clinometers and compass were used to find the slope gradients and aspects, respectively. To obtain representative insect samples during different coffee fruit phenological stages, the study was made 4 times in all selected forest populations. From each site, 40 coffee trees were randomly taken and every encountered insect feeding on the coffee plant was collected using different methods including hand collection, aspirator and sweep net. Sampling was made at different times of the day at 6 am, 10 am, 12 am, 4 pm and 6 pm to widen the chance of catching all coffee berry damaging insects. All insect samples collected were labelled and the co-ordinates, altitudes, slopes, date of collection and developmental stage of the pest were registered. Specimens were brought to the Entomology Laboratory of the Jimma Agricultural Research Center (JARC) either for preservation or for further rearing to adults or parasitoid emergence using parts of the host plant as a source of food to determine their identity on the basis of adult characteristics. Daily emerged natural enemies were collected, coded and preserved separately for identification purpose. Finally, all insect specimens and parasitoids were identified at the Biosystematics Department of the International Center for Insect Physiology and Ecology (ICIPE), Nairobi, Kenya.

2.3. Experimental Tree Selection and Damage Assessment

From the three sites of each FCP, 16 coffee trees were randomly picked and tagged for berry damage assessment. Further, each coffee tree was stratified into three-canopy layer and a pair of branches from each layer was selected for data collection at different coffee berry phenological development stages as described by Alemseged *et al.* (1997).

Coffee berry moth incidence and berry damage assessment at green berry stage was made by counting total and damaged berries from lower, middle and upper canopies of selected branches. Whereas, assessment for fruit fly incidence on ripened coffee berries was conducted using destructive sampling method from each sampling tree and canopy branch. Three hundred ripened berries were sampled every time and sampling was made twice a week for two consecutive months during the harvesting period. The collected berries were dissected the same day by removing the skin with a scalpel. The number of fruit fly larvae in the mucilage and between the beans was scored against each berry to determine the percentage of the fruit fly infestation along with the number of larvae per infested berry in each FCP and site.

To determine the level of damage caused by *H. Hampei,* 200 left-over dried coffee berries were collected from 30 random coffee trees for each site following the methods of Remond and Cilas (1997) and Baker (2000). Beisdes, fallen berries were unruffled from the ground around all sampled trees of the montane rainforests' coffee areas, kept in labelled paper bags, and then brought to the Entomology Laboratory of the JARC. Finally, the entire berries were dissected with a surgical blade to confirm the damage by *H. hampei* under the microscope. The percentage of damaged berries was computed by dividing the cumulative damaged berries to the total berries collected.

2.4. Data Analysis

The percentage of damaged berry data was computed using the SAS package –V8 for windows from the SAS Institute Inc. Cary NC/USA. Nested design of Proc Mixed was used to analyze variation in infestation across the FCPs. Whenever significant differences were detected for means at 5% probability level, means were separated using the Tukey's Honestly Significant Difference Test. The SPSS statistical software program, version 13, was employed to all descriptive statistics. Correlation between level of damage on dried left-over and fallen coffee berries, and regression for relationships between altitudinal changes and percentages of infestation of dried coffee berries (fallen and left-over) in various FCPs were tested using the MINTAB software.

3. Results

3.1. Coffee Berry Insect Pests and their Parasitoids

The study revealed that on *Coffea arabica* in montane rainforests of southwestern Ethiopia, 15 insect species in 10 families under five orders were recorded and identified (Table 2). Of the identified insects, *Ceratitis fasciventris* (Bezzi) and *C. Anonae* (Graham) were new records for Ethiopia. Not all collected insects occurred commonly within every forest coffee ecosystem. Based on the number of recorded site and rate of recurrence, insect in forest ecosystems of southwestern Ethiopia were classified into two groups: sporadic and frequently occurring insect pests of coffee. Sporadic character were recorded once or twice within one or two FCPs, while the frequently observed insect pests caused detectable damage symptoms and were recorded for more than two times in every FCP. Of the insect pests of coffee berries, *C. fasciventris, C. anonae, Trirhithrum coffeae, H. hampei* and *Prophantis smaragdina* were among the frequently recorded coffee berry insect pests in all of the FCPs. Natural enemies, predominantly parasitoids of commonly occurring insect pests of coffee including Antestia bug, coffee berry borer and fruit flies have been collected and identified to the family level and in some cases to species level (Table 3).

3.2. Extent of Coffee Berry Damage

3.2.1. Damage by Coffee Berry Moth, *Prophantis Smaragdina*

Prophantis smaragdina was the most frequently observed insect and prevalent at endosperm enlargement stage. Studies at this stage indicated that the percentage of incidences ranged between 0.65% at Yayu to 11.62% at Berhane-Kontir FCPs. The analysis of variance showed that there was a significant ($P < 0.05$) difference among the FCPs (3.00±1.165%c at Yayu, 7.49±1.575%a at Berhane-Kontir and 5.21±1.268%b at Bonga areas).

Table 2. Insect pests associated with forest coffee berries in south western Ethiopia.

Order	Family	Common name	Scientific name	Occurrence	FCP**
Hemiptera	Pentatomidae	Antestia bug	*Antestiopsis intricata* (Ghesquiere & Carayon)	Sporadic	1 and 2
Homoptera	Diaspididae	Black thread scale	*Ischnaspis longirostris* (Signoret)	Sporadic	2 and 3
Lepidoptera	Lycaenidae	Berry butterfly	*Duodryx lorisona coffeae*	Sporadic	2 and 3
Homoptera	Aphididae	coffee aphid	*Toxoptera aurantii* (Boyer de Fanscocombe)	Sporadic	2 and 3
Coleoptera	Scolytidae	Coffee berry borer	*Hypothemus hampei* (Ferriere)	Frequent	1, 2 and 3
Lepidoptera	Pyralidae	Coffee berry moth	*Prophantis smaragdina* (Butler)	Frequent	1, 2 and 3
Hemiptera	Miridae	Coffee capsid	*Lamprocapsidea coffeae* (China)	Sporadic	1 and 2
Homoptera	Stictococcidae	Coffee cushion scale	*Stictococcus formicarius* Newstead	Sporadic	2 and 3
Diptera	Tephritidae	Coffee fruit flies	*Trirhithrum coffeae* Bezzi	Frequent	1, 2 and 3
Diptera	Tephritidae	-	*Ceratitis fasciventris (*Bezzi)*	Frequent	1, 2 and 3
Diptera	Tephritidae	-	*Ceratitis anonae* (Graham)*	Frequent	1, 2 and 3
Homoptera	Coccidae	Green scale	*Coccus alpinus* De Lotto	Sporadic	2 and 3
Homoptera	Coccidae	Helmet scale	*Saissetia coffeae* (Walker)	Sporadic	2 and3
Homoptera	Diaspididae	Hussel scale	*Lepidosaphes bekii* (Newman)	Sporadic	2 and 3
Homoptera	Diaspididae	Rufous scale	*Selenaspidus articuslatus* (Morgen)	Sporadic	2 and 3

** = Insect pests of coffee reported for the first time from Ethiopia; ** = FCP = Forest Coffee Populations where 1 =: Yayu, 2 = Berhane-Kontir and 3 = Bonga*

Table 3. Parasitoids of coffee berry insect pests collected from afromontane rainforests of south western Ethiopia.

Host (Common name)	Stage of host attacked	Parasitoids		Species	FCP**
		Order	Family		
Antestia bug	Egg	Hymenoptera	Scelionidae	CNI	1 and 2
			Eupelmidae	CNI	
Coffee berry borer	Larval	Hymenoptera	Bethylidae	*Prorops nasuta* *	1 and 2
Fruit flies	Larval	Hymenoptera	Braconidae	*Psyttalia* spp. (Opiine subfamily)	1, 2 and 3

** = Coffee insect pest parasitoid for the first time reported from Ethiopia, CNI = Could not be identified, ** = FCP = Forest Coffee Populations where 1 =: Yayu, 2 = Berhane-Kontir and 3 = Bonga*

3.2.2. Damage by Fruit Flies, *Ceratitis* spp. and *Trirhithrum coffeae*

The damage caused by fruit flies (*C. anonae*, *C. fasciventris* and *T. Coffeae)* on Arabica coffee berries population at all the locations and sites varied significantly (Table 4). The level of damaged berries (incidence percentage) ranged from 31.3-69.0, 61.7-79.7 and 78.0-88.0% at Yayu, Berhane-Kontir and Bonga, respectively. The means of damaged berries (incidence percentage) recorded at the respective aforementioned locations were 52.12, 71.08 and 82.73%. Similarly, the number of fruit fly larvae per infested ripen coffee berries varied between and within the FCPs. The means of number of larvae per infested berry were 1.26, 1.44 and 1.76 at Yayu, Berhane-Kontir and Bonga, respectively (Table 5).

Table 4. Percent of ripen coffee berries infested with fruit fly larvae in afromontane rainforest Arabica coffee populations of southwestern Ethiopia.

Forest population	Forest site	Damaged berries (%) (range and mean)*
Yayu (PI)	SI	50.70-69.00 (61.57±12.94)bc
	SII	42.30-60.00 (51.15±12.52)ab
	SIII	31.30-56.00 (43.65±17.47)a
	Mean	52.12
Berhane-Kontir (PII)	SI	69.30-72.30 (70.77±2.12)c
	SII	71.00-79.70 (76.13±6.15)cd
	SIII	61.70-69.00 (66.33±5.16)c
	Mean	71.08
Bonga (PIII)	SI	83.00-87.00 (85.10±2.83)d
	SII	78.00-81.00 (79.77±2.12)cd
	SIII	79.70-88.00 (83.33±5.87)d
	Mean	82.73

**Means within a column followed by same letter(s) are not significantly different according to Tukey's test at P > 0.05. Figures in parenthesis are mean ± standard error of mean (SE).*

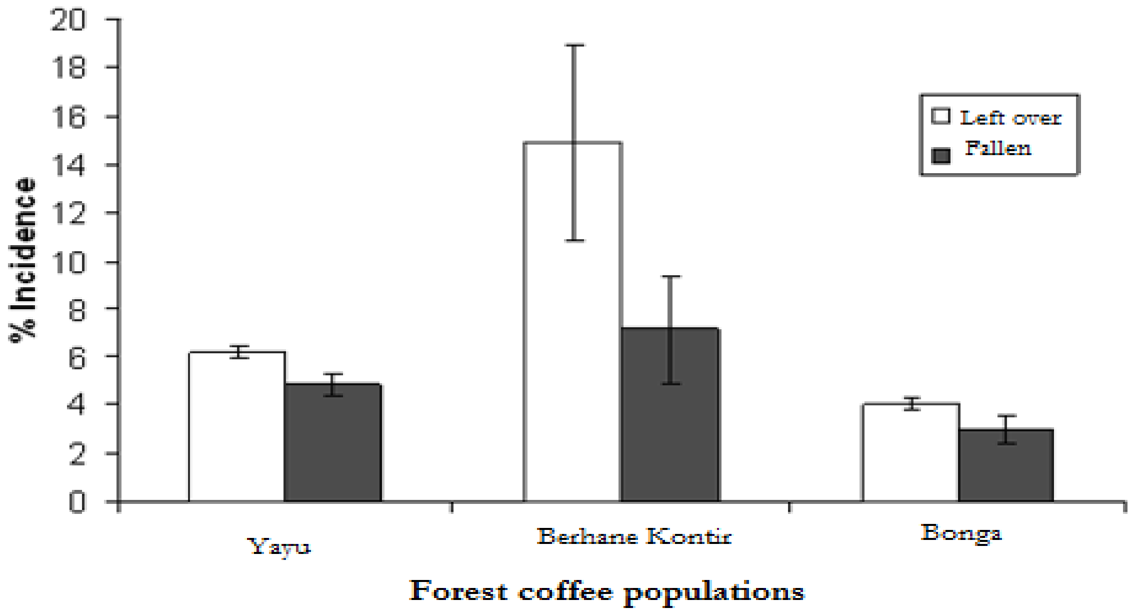
Table 5. Average fruit fly larvae density per infested coffee berry in montane rainforest of south western Ethiopia.

Forest population	Forest site	Mean ± SE (Standard error of mean)
Yayu (PI)	SI	1.34±0.08
	SII	1.39±0.11
	SIII	1.05±0.09
	Mean	1.26±0.09
Berhane-Kontir (PII)	SI	1.35±0.07
	SII	1.66±0.08
	SIII	1.30±0.07
	Mean	1.44±0.07
Bonga (PIII)	SI	1.90±0.08
	SII	1.83±0.08
	SIII	1.54±0.06
	Mean	1.76±0.07

3.2.3. Damage by Coffee Berry Borer, *Hypothenemus hampei*

Mean percent incidence of *H. hampei* on left-over dried berries ranged between 9.50-22.27, 6.00-6.90 and 3.63-4.50% at Berhane-Kontir, Yayu and Bonga with mean incidence of 14.91±4.02, 6.49±0.25 and 4.04±0.25%, respectively. Besides, fallen berries showed comparatively low incidence which ranged from 4.00-5.50% (Yayu), 4.49-11.67% (Berhane-Kontir) and 2.00-3.92% (Bonga) FCPs, with an average incidence of 4.83±0.44, 7.15±2.26 and 2.96±0.55% in that order (Figure 2). The mean percent incidence of *H. hampei* across the study areas was 4.98% for fallen berries and 8.48% for left-over dried coffee berries. Across FCPs, 88.89% of fallen berries and 77.78% of left-over dried coffee berries showed an incidence of less than 10%. In general, significantly high incidence was revealed at the Berhane-Kontir FCP followed by Yayu and Bonga for both left-over dried and fallen coffee berries, though wider range of infestations were recorded among sites of the same FCP.

The result of a simple correlation study between intensity of damage on left-over dried coffee berries and fallen berries collected from the same FCP showed a high and positively significant correlation ($r = 0.96$). A significant ($P < 0.05$) negative regression was detected between mean percentage incidences of left-over dried coffee berries and the variation in altitude across the study areas ($r = -0.79$) (Figure 3). Analogous results were also observed for the fallen coffee berries ($r = -0.63$, $P < 0.05$).



Error bars = Standard Error of Means
Figure 2. Incidence (Mean $\pm$ SE) of coffee berry borer at three Afromontane rainforests in southwestern Ethiopia

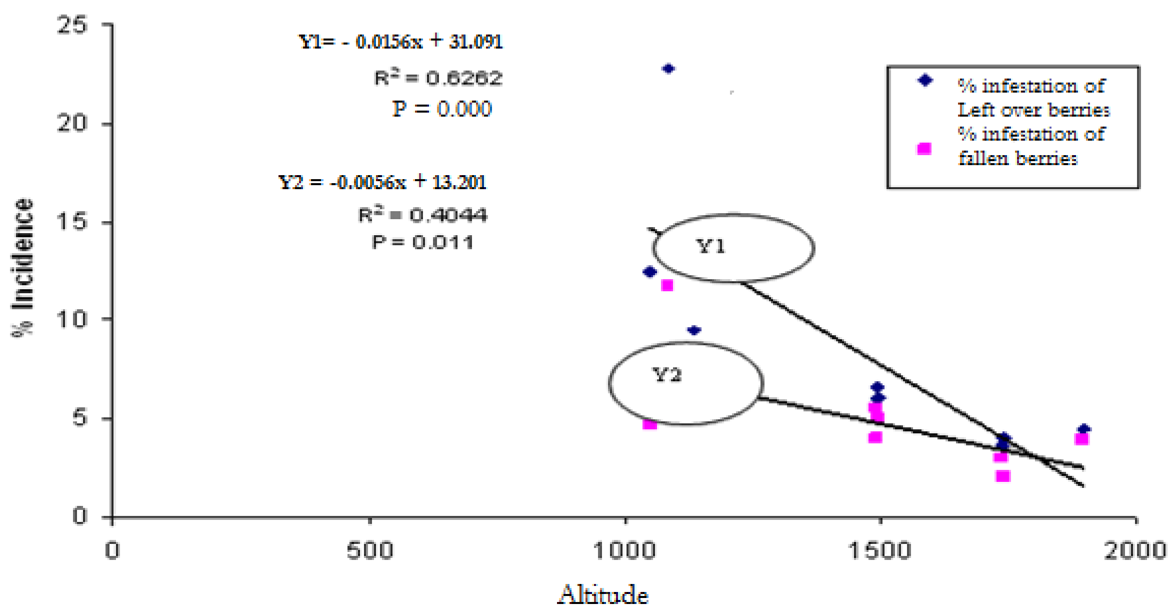


Figure 3. Regression for relationships between altitudinal range and percent incidence of coffee berry borer in the montane rainforests of southwestern Ethiopia

4. Discussion

Fifteen insect pest species in 10 families under five orders were recorded from the montane rainforests of southwestern Ethiopia. Among these, two species of insect pests and two parasitoids were reported for the first time in Ethiopia. Tadesse (2003) and Fayera (2006) opined that there is no research information regarding insect pests on coffee in the montane rainforest ecosystem. However, this study revealed that there exists more than a dozen of insect pests attacking coffee trees in the FCP of montane rainforest areas. Thus, the present study on the occurrence, incidence and distribution of coffee insect pests and their parasitoids in the montane rainforests of southwestern Ethiopia is the first of its kind in the country. The insect pest populations were high, however, their incidence was relatively low compared to other production systems, probably due to the efficient role of natural enemies (Million and Bayissa, 1986; Million, 1987) in such undisturbed ecosystem.

Species of fruit fly parasitoids including the brown and black *Psyttalia* spp. and unidentified species under the opiine sub-family were reared from the samples in the assessed areas. In Ethiopia, Million and Bayisa (1986) reported that *C. rosa* paratisized by *Opius* sp. nr. *africanus* and *Opius* sp. nr. *desideratus* were collected from different coffee plantations. Correspondingly, Clausen (1978) mentioned as largest diversity of parasitoids attacking fruit infesting tephritid flies found in the opiine braconid sub-family. Opiines have long been known as a biological control agent against tephritid pests (Clausen *et al.,* 1965; Wharton, 1989). Species of the genus *Psyttalia* are among the most common parasitoids reared on fruit infesting flies in Africa (Clausen *et al.,* 1965; Clausen, 1978; Wharton, 1989). Wharton (1997a, b) and Billah (2004) stated of the existence of 11 *Psyttalia* species in Africa, with a few potentially undescribed species being reared from various fruits sampled in Kenya. The two most important species in terms of historical use as biological control agents are *P. concolar* (Szepligenti) and *P. humilis* (Silvestri) described from Tunisia and South Africa, respectively, in Clausen *et al. (*1965).

Prorops nasuta was found in Berhane-Kontir and Yayu FCPs attacking *H. hampei* at larval stage. The parasitoid was recorded for the first time in Ethiopia. However, Million (2001) reported that there were parasitoids attacking *H. hampei* in different parts of the country and forwarded as research gap for parasitoid collection and identification. *P. nasuta* is indigenous to Africa, but the parasitoid was introduced to Latin American countries, where *H. hampei* is the most economically important pest of coffee. Murphy and Rangi (1991) mentioned that *P. nasuta* was considered as a classical biological control agent in Brazil by introducing it from Uganda in 1929 and in 1962 from Peru. Since that time, the wasp became established in the field and artificially dispersed. In Kenya, *H. hampei* was parasitized by *P. nasuta* and *Heterospilus coffeicola* Schmied and *P. nasuta* alone caused 18% parasitism Mugo *et al.* (1997).

Prophantis smaragdina was relatively the most frequently observed insect pest at the expanding coffee berry phenology with the mean incidence of 5.07% across FCPs. Million and Bayisa (1986) reported that *P. smaragdina* was the commonly found insect pest attacking green coffee beans. Similarly, Crowe (2004) reported that this pest was a minor pest of Arabica coffee for many years in East and South Africa including Ethiopia. However, recently the damage due to this pest has become serious especially on intensively managed coffee plantations.

The mean incidence of fruit fly attack was 52.12% at Yayu, 71.08% at Berhane-Kontir and 82.73% at Bonga FCPs. Coffee fruit fly larvae infestation in ripen coffee berries was prevalent in all assessed FCPs. The mean incidence ranged between 31.3 and 88.0% across forest coffee ecosystems. In line with this, research conducted around Tepi revealed that infestation ranged from 55.2 to 58.1% (Esayas, 2005). Abasa (1973) stated that there was a seasonal emergence of fruit flies in a coffee plantation at Ruiru/Kenya, and up to 85% infestation occurred during the peak season at ripening stages. Three fruit fly species were recorded from studied FCPs, where *C. fasciventiris* was the most dominant one followed by *T. coffeae* and *C. anonae*. Similarly, research results showed that *C. arabica* is a host plant to fruit fly species like *C. fasciventiris, C. anonae* and *C. rosa* (Copeland *et al.,* 2006). On the other hand, Esayas (2005) reported three species of Tephritids fruit flies Viz. *C. rosa, T. coffeae* and *C. capitata* infesting Arabica coffee. The most probable reason for the difference between the present finding and the previous findings could be; attributed to the fact that before revision of the sub-genus *Ceratitis (Pterandrus)* Bezzi (Diptera: Tephritidae), *C. fasciventris* was categorized under *C. rosa* as a sub-species. Therefore *C. fasciventris* was reported as *C. rosa* (de Meyer and Freidberg, 2006). Mekuria *et al.,* (1995) also reported that more than three species of fruit flies infested coffee berries in Ethiopia, *C. rosa* and *T. coffeae* were the dominant species. In surveys conducted in Kenya by Gabson (1970) and Mukiama and Muraya (1994) results showed that *C. capitata, C. rosa* and *T. coffeae* infested coffee in that country.

The mean incidence of *H. hampei* was low as it accounted for only 8.38 and 4.98% incidence on dried left-over and fallen berries, respectively. In Kenya, infestation level of up to 80% during the peak season was reported with similar magnitude of crop losses with a reduction in quality of the remaining yield (Masaba *et al.,* 1985). Up to 80% of berries were also attacked in Uganda, Ivory Coast and Brazil, 90% in Malaysia, 96% in Congo and Tanzania (Waterhouse and Norris, 1989). In New Caledonia up to 87% berry infestation in full sun light coffee plantations was reported (Giordanengo, 1992). Surveys in southwestern Ethiopia indicated that the highest mean percentage infestation (60%) was recorded at Tepi (Esayas *et al.,* 2004). The author also found that in the Yeki and Godere Districts on large coffee plantations and at research centers like Melko (JARC), Mettu and Tepi the level of infestation was considerably high. Similarly, Million (2001) reported maximum berry infestations from Tepi research sub-center with up to 73% damage. The most probable reason for the low infestation in FCPs could be due to relatively low ecological disturbance, in which the *H. hampei* and its natural enemies live in a relatively balanced way, where natural enemies can perform well. Monocultures are notoriously vulnerable to pest out-breaks (Gibson and Jones, 1977) and the results of some studies suggested that structural and floristic complexity reduce the probability of severe pest out-breaks in plant communities (Andow, 1991; Altieri and Nicholls, 1999; Grimble and Laidlaw, 2002; van Mele and van Lenteren, 2002).

Regression analysis showed that the incidence of *H. hampei* and altitude had significant negative relationship. This finding is in agreement with Soto-Pinto *et al.* (2002). They stated that a step-wise regression analysis showed a significant and negative estimate parameter for the relationship between berry borer and altitude ($r = -0.63$; $P < 0.05$), suggesting that at higher elevation, berry borer could be less problematic. Similarly, Esayas *et al.* (2004) reported that altitude among other factors limited the distribution of the borer as indicated by a significant and negative correlation between altitude and infestation level (r = -0.60; P < 0.05). Hence, coffee berry borer infestation in the coffee growing areas is more severe in lower the altitude than in the higher altitudes.

5. Conclusion

In conclusion, most of the insect pests collected and identified were minor pests in the forest coffee ecosystems. In other coffee production systems or other countries, however, they may cause very serious damage when conditions allow. In the FCPs of southwestern Ethiopia, insect pest infestation was found to be less important due to the fact that they had been well controlled by their natural enemies. Incidence varied from one forest coffee area to another and within the FCPs depending on environmental condition, genetic diversity of Arabica forest coffee and the abundance of natural enemies. The over all result of this study indicated that no coffee tree was free from insect pest attack and at least one insect pest species was associated with the host. The damage, however, was mostly negligible and very low. The present research result suggest that additional control measure for berry damaging insects in the rainforest coffee may not urgently be recommended, but the finding complements other research findings that recommended to conserve remnant forests and its biodiversity in the southwestern part of the country.

Insects in general and Lepidoptera in particular are indicators of ecological diversity, so more detailed studies of insect abundance in each FCP should be conducted including the contribution of insects in coffee pollination. Furthermore, detailed studies of the genetic variability of *H. hampei* and its natural enemies should be undertaken to know factors responsible for the low population of the world wide important insect pest of coffee.

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Effect of Concentrate Mix Supplementation to Urea-Treated and Ensiled Maize Stover on Feed Intake, Digestibility and Nitrogen Balance of Hararghe Highland Sheep

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Abstract: The effects of feeding different levels of concentrate mixture to sheep fed urea treated maize stover basal diet on feed intake, digestibility, and nitrogen balance were evaluated at Haramaya University. The experiment was conducted in a randomized complete block design using twenty male Hararghe Highland sheep with a mean initial body weight (BW) of 17.2 ± 1.74 (mean ± SD) kg. The animals were grouped into five blocks based on their initial BW and randomly assigned to four treatments within the block. The levels of supplementation were 0 g (control, T1), 150 g (low, T2), 250 g (medium, T3) and 350 g (high, T4) of the concentrate mix prepared from brewers dried grain, peanut cake and wheat bran at a ratio of 1:1:3 on dry matter basis, respectively. Hundred kg (dry matter basis) of chopped maize stover was treated with 4 kg of urea dissolved in 100 liters of water and ensiled for 21 days before used as a basal diet. The urea treated maize stover (UTMS) was offered *ad libitum* and water and mineral block were available to the experimental animals all the time throughout the experiment. Intake trial was conducted for 90 days. Digestibility and nitrogen balance trials were carried out for 7 days following 3 days of adaptation to the metabolic cage and carrying of the fecal collection bag following 15 days of adaptation. Urea treatment improved the crude protein (CP) content of maize stover by about 33% (from 5.8 to 7.7%). The UTMS intake was lower ($P < 0.05$) for the sheep in T4 (665 ± 16 g DM day^{-1}) than in T1 (768 ± 16 g DM day^{-1}) and T3 (754 ± 16 g DM day^{-1}). Daily DM intake per kg $W^{0.75}$ was higher ($P < 0.01$) for T3 (105.7 ± 1.7 g day^{-1}) and T4 (104.1 ± 1.7 g day^{-1}) than T1 (91.9 ± 1.7 g day^{-1}). Total CP intake per kg $W^{0.75}$ (7.8, 10.4, 12.7, and 13.8 (SEM = ± 0.16), for T1, T2, T3, and T4, respectively) increased with increasing level of supplementation ($P < 0.01$). Crude protein digestibility was lower ($P < 0.05$) in non-supplemented sheep (0.42 ± 0.04) than the supplemented sheep (0.65, 0.71, and 0.70 (SEM = ± 0.04) for T2, T3 and T4, respectively). Nitrogen intake during digestibility trial (6.4, 11.2, 14.4, and 17.5 (SEM = ± 0.3) g day^{-1} for T1, T2, T3 and T4, respectively) increased with increasing levels of supplementation ($P < 0.001$). Nitrogen retention was positive and higher in the supplemented groups (8.2, 7, and 4.4 (SEM = ± 0.63) for T4, T3, and T2, respectively) than in T1 (-0.02 ± 0.63 g day^{-1}), which has a negative nitrogen balance ($P < 0.01$). The result indicated that supplementation improved feed intake, digestibility and nitrogen balance, but feeding sole urea treated maize stover failed to support sufficient nitrogen intake which might have resulted in body reserve mobilization to meet the maintenance requirement of the animal.

Keywords: Concentrate Mix; Digestibility; Hararghe Highland Sheep; Maize stover; Nitrogen Balance; Urea Treatment

1. Introduction

Small ruminants are important protein sources and cash income for many farmers in the tropics and sub-tropics. Among the small ruminants, sheep contribute a substantial amount to the farm household income, mutton and non-food products, such as manure, skin and coarse wool. However, the productivity of indigenous sheep breeds is low as compared to temperate breeds due to limited genetic capacity and mainly environmental factors. Among the environmental factors, the main bottleneck for the small holder livestock production in numerous tropical countries like Ethiopia is the inadequate supply and low level of feeding due to serious shortage of feedstuffs.

Currently, crop residues are becoming the most important feed resources, because of the expansion of cropping land, and it is particularly utilized during the dry season (Alemayehu, 2004). The scenario holds true in Hararghe highlands where limited areas of permanent grazing land are available and livestock depend upon crop residues and stubble grazing during the dry season. Quality of these crop residues is limited due to their deficiency in crude protein (CP), metabolisable energy (ME), minerals and vitamins. Indeed, a major limiting factor to the utilization of straw is its bulkiness and low concentration of digestible nutrients.

In Ethiopia, there is a scope for improvement in small ruminant productivity by employing better feeding, reproductive, and health care management practices (Kassahun, 2000). The efficiency of growth to attain the desired market weight, and the economic return from sheep production can be enhanced through better feeding practices. One of the feeding management practices is improving the nutritive value of low quality feed resources. Among the technologies available to improve nutritive value of poor quality roughages, such as crop residues are ammonia treatment and supplementation with agro-industrial by-products (Ben Salem *et al*., 2004). There are consistent responses in performance of animals to supplementation with concentrate, but the effects are more pronounced when the poor quality roughages are chemically treated (Liu and Meng, 2002). For better utilization of urea treated roughages, some amount of protein supplementation should be present in the feed, part of which can be provided by energy sources, and frequently some oil meals are used in preparing the formula feeds (Ensminger, 2002).

In the Hararghe highland, different agro-industrial by-products are available in the market and urea treatment is possible. However, information available on the effects of

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supplementing urea treated maize stover with concentrate mixtures of agro-industrial by-products on nutrient utilization and sheep performance is scanty and variable, hindering the wider use of the technology. Therefore, the experiment was conducted with the aim to determine the effects of supplementing different levels of concentrate mix on feed intake, digestibility and nitrogen balance of Hararghe Highland sheep fed urea treated maize stover.

2. Materials and Methods

2.1. Study Area

The experiment was conducted at Haramaya University which is located 515 km east of Addis Ababa. The site is located at an altitude of 1950 m above sea level at 9.0° N and 42.0° E. The mean annual rainfall and temperature of the study area is 790 mm and 16 °C, respectively (Mishra *et al.*, 2004). The major feed resource for livestock in the area is crop thinning and residues of mainly maize and sorghum. Wheat bran, brewers dried grain, and noug seed cake are the most widely used supplement agro-industrial by-products in the area, particularly in areas closer to towns (Tsigereda, 2010).

2.2. Animals and Management

Twenty male Hararghe Highland Sheep with intact milk teeth and a mean initial body weight of 16.3 ± 1.45 kg (mean ± SD) were purchased from *Kulubi* and *Lange* markets. They were quarantined for three weeks to acclimatize the animals to the environment and to monitor for any health problem. The basal diet used for the experiment was urea treated maize stover (UTMS). The concentrate mixtures (CM) were prepared from peanut cake (PNC), brewers dried grain (BDG) and wheat bran (WB) at a ratio of 1:1:3, respectively. Higher proportion of WB was used to provide higher energy source for rumen microbes in order to efficiently utilize the urea in the treated maize stover. All animals were offered UTMS *ad libitum* but the CM in two equal portions at 0800 hours and 1600 hours according to the treatment. The UTMS offer was adjusted once every week based on previous week intake allowing a 30% refusal rate. All animals had free access to water and mineral blocks throughout the experimental period.

2.3. Urea Treatment of Maize Stover

Maize stover was chopped using tractor mounted chopper. Hundred kilogram dry matter (DM) of the chopped stover was treated with a solution of 4 kg urea in 100 liters of water (Sundstøl and Coxworth, 1984; Dolberg, 1992). The application of urea solution to the stover was made on a plastic sheet placed on a floor. Twenty five liters of the prepared urea solution was uniformly sprayed using garden watering cans and mixed with 25 kg DM of the chopped stover, and rubbed with hand to ensure proper penetration of the solution. The treated stover was placed in a pit with a dimension of 2m x 2m x 2m, and its floor and sides lined by a polyethylene sheet. The treated stover was placed in the pit and trampled with human foot to ensure proper packing. Following similar procedure, layers of such treated stover were placed until the pit was full. After filling, the pit was covered with plastic sheet and compacted with soil and stone and was left to incubate. After twenty one days, the pit was opened and aerated for a day in order to remove excess ammonia (Zhang and Qiaojuan, 2002).

2.4. Experimental Design and Treatments

The experiment was conducted in a randomized complete block design with four treatments and five replications. The sheep were blocked based on their initial body weight into five blocks of four animals each. Each animal within each block were randomly assigned to one of the four dietary treatments. The four dietary treatments were, UTMS alone and UTMS supplemented with 150, 250 and 350 grams of the CM expecting the basal diet to fulfill the maintenance requirement, and the lowest level of concentrate mix supplementation to provide additional nutrients to support 50 g average daily gain. The concentrate mix was formulated according to the growth requirements of the sheep based on the recommendations of the National Research Council (NRC) and by considering the expected body weight gain of sheep (NRC, 1985).

2.5. Digestibility and Nitrogen Balance Trial

The experiment duration consisted of 7 days of digestibility and nitrogen balance trials, and 90 days of growth trial followed by carcass evaluation at the end of the experiment. Data of live weight change and carcass were published elsewhere (Hirut *et al.*, 2011). The animals were kept in individual pens and offered the respective treatment diet for fifteen days to adapt them to the feed. Following this, the animals were moved to individual metabolic cages equipped with feeding and watering troughs.

The digestibility and nitrogen balance trials were conducted before the growth trial by using all experimental sheep. The animals were adapted to the metabolic cages as well as the carrying of fecal bags for three days, and were followed by collection of feces and urine for seven consecutive days. Feces were collected into a fecal collection bag harnessed on the animal. Urine was collected into a bucket placed underneath the metabolic cage through a hole on the floor of the metabolic cage. During urine collection, one hundred ml of H_2SO_4 (10%) was added to each urine collection bucket daily to trap the nitrogen that may escape as NH_3 from the urine. The total amount of feces and urine voided were collected and weighed every morning starting at 0800. About 20% sample of the total feces and urine collected daily were taken into a plastic bottle and kept in a deep freezer adjusted at -20 °C.

At the end of the experiment, the samples were bulked per animal and kept until required for analysis. The refusal of the UTMS were collected every day, pooled per treatment, and then bulked over the seven days of digestibility trial. Finally, the sub-samples of urine, feces and feeds were taken and transported in ice box filled with chilled ice bags to ILRI laboratory Addis Ababa for chemical analysis. Apparent DM and nutrient digestibility coefficient (DC) of the treatment diets were calculated as a proportion of nutrient intake not recovered in feces on dry matter basis using the following formula:

$$DC = \frac{\text{(Total amount of nutrients in feed consumed-Total amount of nutrients in feces voided)}}{\text{Total amount of nutrients in feed consumed}}$$

2.6. Feed Intake Measurement

Following the digestibility and nitrogen balance trial, the sheep were weighed and re-blocked based on their initial body weight into five blocks. The mean initial body weight of the sheep was 17.2 ± 1.74 (mean ± SD). Feed intake was evaluated for 90 days. The basal diet and concentrate mixture were offered in a separate feeding trough. The concentrate mixture was offered after about 30 minutes of UTMS feeding. The amounts of feed dry matter offered and refused were recorded daily for each experimental animal to determine daily feed dry matter intake. Daily feed dry matter intake was calculated as a difference between the feed dry matters offered and refused. Feed samples were taken following similar procedures indicated under section 2.5.

2.7. Chemical Analysis

The sample of feed offered, refused and feces were analyzed for DM, ash and nitrogen (N) according to the procedures of AOAC (1990). The crude protein (CP) content was estimated as N*6.25. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were analyzed by the method of Van Soest and Robertson (1985). Organic matter was calculated by subtracting the ash content from the DM.

2.8. Statistical Analysis

The data was subjected to analysis of variance in a randomized complete block design using the general linear model procedure of SAS (1998). The treatment means were separated using Tukey honestly significant difference test. The model for data analysis was:

$$Y_{ij} = \mu + t_i + b_j + e_{ij},$$

where Y_{ij} = response variable; μ = overall mean; t_i = treatment effect; b_j = block effect; eij = random error.

3. Results

3.1. Chemical Composition of the Experimental Feeds

Although sensory evaluation test by employing recommended procedures were not conducted, the researchers observed that the treated stover has a strong pungent smell with brownish yellow color and soft texture with no mould appearance. Urea-treatment increased CP content of the stover from 5.8 to 7.7%. There were also slight increments in ADF, ADL and ADL-ash, but NDF decreased by about 12.7% (Table 1). The UTMS refusals contained lower CP than in the UTMS offer in all treatments, whereas NDF, ADF and ADL were higher in feed refusal than the offer in all treatments.

3.2. Feed dry matter and Nutrient Intake

The daily UTMS DM intake of T1 and T3 were higher ($P < 0.05$) than that of T4 (Table 2). Urea treated maize stover DM intake decreased by 6.4, 1.8 and 15.4% for T2, T3 and T4, respectively as compared to that consumed by T1. However, the total DM intake was lower ($P < 0.001$) in T1 than in T3 and T4, and T2 has statistically similar dry matter intake with all treatments. The concentrate mix DM intake of T2, T3 and T4 accounted for about 17.5, 25.6 and 35.7% of the total DM intake, respectively. Substitution of UTMS with concentrate mix was not different between treatments, although T3 has numerically lower substitution rate. The total OM intake followed similar trend with DM intake. The total OM intake was higher ($P < 0.01$) for T3 and T4 than T1. The CP intake was significantly ($P < 0.01$) different among the treatments in the order of T4 > T3 > T2 > T1. The CP intake was 8.0, 10.5, 11.6 and 13.1% of the total DM intake for T1, T2, T3 and T4, respectively. Feed dry matter and nutrient intake during the seven days of digestibility trial (Table 3) followed similar trend with that during the 90 days of growth period intake (Table 2).

Table 1. Chemical composition of concentrate mixtures, untreated and urea treated maize stover.

		Urea treated maize stover					Concentrate ingredients			
			Refusal							
Nutrients	UMS	Offer	T1	T2	T3	T4	WB	PNC	BDG	CM
DM (%)	91.5	95.6	96.5	96.5	96.9	96.6	90.4	90.8	90.2	89.8
OM (%)	93.1	89.0	91.3	92.0	90.4	89.6	94.1	94.0	94.8	93.9
CP (% DM)	5.8	7.7	6.5	7.0	6.8	7.1	16.3	62.5	27.4	23.8
NDF (% DM)	86.6	73.9	77.8	77.7	76.7	75.2	55.5	27.3	79.9	53.5
ADF (% DM)	49.1	53.6	57.3	58.0	56.5	51.7	14.6	12.8	27.1	16.9
ADL (% DM)	4.7	5.4	7.6	7.5	7.6	7.1	3.5	4.1	6.8	4.6
ADL-ash (% DM)	1.6	3.6	0.9	1.9	1.6	1.8	0.1	0.4	2.1	0.7

DM = Dry matter; OM = Organic matter; CP = Crude protein; NDF = Neutral detergent fiber; ADF = Acid detergent fiber; ADL = Acid detergent lignin; UMS = Untreated maize stover; T1 = UTMS alone; T2 = UTMS + 150 g CM; T3 = UTMS + 250 g CM; T4 = UTMS + 350 g CM; WB = Wheat bran; PNC = Peanut cake; BDG = Brewers dried grain; CM = Concentrate mix.

Table 2. Dry matter and nutrient intake of Hararghe Highland Sheep fed a basal diet of urea treated maize stover and supplemented with different levels of concentrate mix during the growth period.

Parameter	T1	T2	T3	T4	SEM	SL
Basal DMI (g/head/d)	767.5^{a}	721.8^{ab}	753.7^{a}	665.0^{b}	15.69	*
Supplement DMI (g/head/d)	0	134.6	224.4	314.1	-	-
Total DMI (g/head/d)	767.5^{b}	856.4^{ab}	978.1^{a}	979.1^{a}	16.79	***
DMI (g/kg $W^{0.75}$)	91.9^{b}	96.5^{ab}	105.7^{a}	104.1^{a}	1.72	**
OMI (g/kg $W^{0.75}$)	83.3^{b}	88.0^{ab}	97.0^{a}	95.8^{a}	1.58	**
CPI (g/kg $W^{0.75}$)	7.8^{d}	10.4^{c}	12.7^{b}	13.8^{a}	0.16	**
CPI (% TDMI)	8.0^{d}	10.5^{c}	11.6^{b}	13.1^{a}	1.41	**
NDFI (g/kg $W^{0.75}$)	69.5	69.7	74.0	70.8	1.34	ns
ADFI (g/kg $W^{0.75}$)	41.8	39.8	40.9	38.3	0.92	ns
ADLI (g/kg $W^{0.75}$)	3.0^{b}	3.5^{ab}	4.0^{a}	4.0^{a}	0.10	**
Substitution rate	-	0.34	0.1	0.29	0.09	ns

[a, b, c, d] *Means within a row not bearing a similar superscript letter significantly differ; * = (P < 0.05); ** = (P < 0.01); *** = (P < 0.001); DMI = Dry matter intake; OMI = Organic matter intake; CPI = Crude protein intake; NDFI = Neutral detergent fiber intake; ADFI = Acid detergent fiber intake; ADLI = Acid detergent lignin intake; SEM = Standard error of means; SL = Significance level; ns = Not Significant.*

3.3. Nutrient Digestibility

Supplementation improved only CP digestibility (Table 3). The CP digestibility was lower ($P < 0.05$) for the non-supplemented sheep than all the supplemented groups. Digestible CP intake (DCPI) increased with increasing levels of CP intake with the lowest recorded in T1 (17 g day^{-1}) as compared to the other treatments ($P < 0.001$).

3.4. Nitrogen Balance

There was difference between treatments in nitrogen intake ($P < 0.001$), fecal nitrogen ($P < 0.05$), total nitrogen excreted ($P < 0.05$), nitrogen balance ($P < 0.01$) and nitrogen retained as percent of nitrogen intake ($P < 0.01$) (Table 4). Sheep supplemented with high level of concentrate mix recorded higher ($P < 0.01$) nitrogen retention than those in T1 and T2. Feeding UTMS as a sole diet resulted in a negative nitrogen balance. Nitrogen intake was significantly ($P < 0.001$) different among the treatments in the order of T4 > T3 > T2 > T1. Nitrogen absorbed and retained expressed as percent of nitrogen intake was higher ($P < 0.01$) in the supplemented sheep than those fed only UTMS. Fecal nitrogen loss was the lowest ($P < 0.05$) in T1 as compared to T4.

Table 3. Apparent DM and nutrient digestibility of Hararghe Highland Sheep fed a basal diet of urea treated maize stover and supplemented with different levels of concentrate mix.

Parameters	Experimental treatments				SEM	SL
	T1	T2	T3	T4		
Digestibility coefficients						
DMD	0.54	0.56	0.56	0.48	0.04	ns
OMD	0.66	0.64	0.63	0.57	0.03	ns
CPD	0.42^{b}	0.65^{a}	0.71^{a}	0.70^{a}	0.04	*
NDFD	0.76	0.71	0.68	0.63	0.02	ns
ADFD	0.77	0.72	0.69	0.63	0.02	ns
Intake during digestibility period (g day^{-1})						
DMI	592^{b}	722^{ab}	776^{a}	838^{a}	31.79	*
DDMI	320	399	434	407	30.69	ns
OMI	520^{b}	640^{ab}	698^{a}	760^{a}	28.85	*
DOMI	339	406	443	437	24.50	ns
CPI	40^{d}	70^{c}	90^{b}	109^{a}	1.80	***
DCPI	17^{d}	45^{c}	64^{b}	76^{a}	2.24	*
NDFI	425^{b}	494^{ab}	519^{ab}	551^{a}	24.31	*
DNDFI	320	349	356	350	21.26	ns
ADFI	305	323	320	323	17.97	ns
DADFI	235	231	221	204	15.14	ns

[a, b, c, d] *Means within a row not bearing a similar superscript letter significantly differ; * = (P < 0.05); *** = (P < 0.001); ns = Non-significant; DMI = Dry matter intake; OMI = Organic matter intake; CPI = Crude protein intake; NDFI = Neutral detergent fiber intake; ADFI = Acid detergent fiber intake; DDMI = Digestible dry matter intake; DOMI = Digestible organic matter intake; DCPI = Digestible crude protein intake; DNDFI = Digestible neutral detergent fiber intake; DADFI = Digestible acid detergent fiber intake; SEM = Standard error of means; SL = Significance level.*

Table 4. Nitrogen balance of Hararghe Highland sheep fed a basal diet of urea treated maize stover and supplemented with different levels of concentrate mix.

Parameter	NI (g/d)	Fecal N (g/d) lose	Urinary N (g/d) lose	Total N (g/d) lose	NR (g/d)	NR/NI
T 1	6.4^{d}	3.5^{b}	2.9	6.4^{b}	-0.02^{c}	-0.03^{b}
T 2	11.2^{c}	4.0^{ab}	2.8	6.8^{ab}	4.4^{b}	0.4^{a}
T 3	14.4^{b}	4.1^{ab}	3.2	7.4^{ab}	7.0^{ab}	0.5^{a}
T 4	17.5^{a}	5.2^{a}	4.1	9.3^{a}	8.2^{a}	0.5^{a}
SEM	0.29	0.32	0.64	0.63	0.63	0.06
SL	***	*	ns	*	**	**

*$^{a, b, c, d}$ Means within a column not bearing a similar superscript letter significantly differ; * = (P < 0.05); ** = (P < 0.01); *** = (P < 0.001); NI = Nitrogen intake; NR = Nitrogen retention; SEM = Standard error of means; SL = Significance level.*

4. Discussion

The strong pungent smell of the treated stover and no mould growth indicated the efficiency of the ensiling process. The brownish yellow color and soft texture shows the uniform application of urea solution to the stover. Zhang and Qiaojuan (2002) reported that properly ammoniated stover to be soft and fragile, brownish yellow or light brown in color, and with a light fragrance after excess ammonia has evaporated.

The CP value obtained in the current study for untreated maize stover was comparable with the values of 5.6 and 5.1% reported by Bareeba and McClure (1996) and Wambui *et al.* (2006), respectively. However, Zhang and Qiaojuan (2002) and Weldegebriel (2007) reported lower CP contents of 3.7 and 2.9%, respectively for untreated maize stover. The CP content of UTMS was comparable with that reported by previous studies (Maphane and Mutshewa, 1999; Wambui *et al.*, 2006; Zhang and Qiaojuan, 2002). However, Bareeba and McClure (1996) reported higher (14.2%) CP value in UTMS than the result obtained from the current study. Lower CP content of UTMS in the current study might be due to volatile nitrogen loss while ventilating the silo for a day in preparation for feeding to the animal. Other factors such as urea dose, moisture content of the stover, temperature and treatment time that are responsible for the effectiveness of urea treatment might have contributed to the difference in CP content of UTMS between the different experiments. Indeed, Sundstøl and Coxworth (1984) reported that two-thirds of the ammonia generated is usually evaporated to the environment in the course of urea treatment and until feeding to the animals.

The increase in CP content of the stover as a result of urea treatment was in accordance with previous similar studies (Getahun, 2006; Dawit, 2007). The reduction in NDF was in line with previous reports (Bareeba and McClure, 1996; Misra *et al.*, 2006; Weldegebreil, 2007) and it could be due to the dissolving effect of urea on the hemicellulose fraction and subsequent removal from cell wall constituents (Givens *et al.*, 1988). The slight increase of other cell wall components in UTMS is similar with the results reported by Smith *et al.* (1989) and Weldegebriel (2007). Lower CP and higher NDF, ADF and ADL contents in UTMS refusals than in the UTMS offer in all treatments indicates the selective feeding behavior of sheep on portions of feeds with better nutritive value. The concentrate mix used for the experiment contained more than 3 fold protein and lower NDF and other fibers than the basal feed (Table 1).

The lower UTMS DM intake in T4 could be attributed to the high intake of the supplement DM as a proportion of total DM intake. Topps (1997) indicated that if the level of supplementation is about 30-40% of the total DM intake of the animal, there is an increase in the intake of the basal diet. But, if it is more than this, it will have a reduction effect in the intake of the basal diet. Thus, the high level of concentrate mixture (36% of the total dry matter intake) in the present experiment seems to be too high and prevented maximum intake of the basal feed. The similar intake of UTMS of low and medium level of concentrate mix supplementation with the control sheep might have arisen from the more balanced intake of nutrients (CP and ME) that have led to a more efficient utilization of the fiber in the total diet. In the current study, substitution of UTMS with concentrate mix was lower in T3 and this might have resulted due to similar UTMS DM intake in T3 and T1. In line with this, Getahun (2006) also indicated that 200 and 300 g *Leucaena* supplementation resulted in a replacement of urea treated wheat straw at a ratio of 0.13 and 0.27, respectively.

Higher total DM intake (g kg^{-1} $W^{0.75}$) in T3 and T4 than in non-supplemented Sheep indicated that supplementation has a positive effect on daily total DM intake and it could be attributed to the ability of the medium and high level of supplementation to provide CP and energy for the cellulolytic microbes up on degradation in the rumen than the other treatments. In agreement with the present study, Bonsi *et al.* (1996) indicated that supplementation with protein sources improved total DM intake of sheep. The lowest CP intake as % DM in T1 was less than the minimum requirement for adequate microbial synthesis in the rumen (ARC, 1980). Greater values of CP intake as % DM in the supplemented treatments is attributed to concentrate mix supplementation which increases the supply of nitrogen to the rumen microbes, which can bring a positive effect by increasing microbial population and efficiency, thus enabling them to increase the rate of fermentation of the digesta, consequently feed intake increased (Van Soest, 1994). The lower digestibility of CP in sheep fed only UTMS compared to all the supplemented diet might be related to the lower CP content of the basal diet. Similarly, the intake of digestible CP in T1 was below 38 g day-1 which is recommended for growing sheep in the tropics (NRC, 1985). This indicates that concentrate feed which is rich in protein content promotes high microbial population (McDonald *et al.*, 2002) which facilitates rumen fermentation. The overall mean CP digestibility recorded in the present experiment were similar with the mean CP digestibility value (62.8%) reported by Bareeba and McClure (1996) for growing lambs fed UTMS supplemented with alfalfa at 20% of the total DM intake. But Dawit (2007) reported higher values of mean CP digestibility (74%) for Arsi Bale sheep fed a basal diet of urea treated barley straw supplemented with vetch and alfalfa hay. The variation in CP digestibility between the different studies might be due to the difference in the type, maturity and quality of the basal and supplement diet used in the particular experiment. Advanced plant maturity could also contribute to high proportion of cell wall, which has a negative role on digestibility and as a result part of the proteins might have been bound in lignocellulose and cannot be degraded by microbes (Cheeke, 1999) and the total protein in the diet may not be available to the animal.

The DM and OM digestibility in the current experiment were in a range reported by Smith *et al.* (1989) for UTMS. The mean NDF digestibility recorded in this particular study in general was slightly higher than 63.1% reported by Weldegebriel (2007) for urea treated maize stover supplemented with molasses and/or sweet potato vines. It was also higher when compared with the digestibility value of NDF (45.4%) reported by Bareeba and McClure (1996) for urea treated maize stover supplemented with 20% alfalfa. Fiber digestibility is known to influence voluntary intake (Van Soest, 1994). The better values of NDF and ADF digestibility in the current experiment may contribute to the better total DM intake.

The excretion of fecal nitrogen is more closely related to DM intake (Tegene *et al.*, 2001). Thus, the higher fecal nitrogen excretion in T4 could be due to the higher total DM, as a result the higher N intake. Moreover, it may indicate the inefficient utilization of nitrogen in T4, perhaps due to lack of sufficient energy substrate matching nitrogen available from supplementation. Getahun (2006) noted that sheep supplemented with Leucaena showed a higher nitrogen intake and nitrogen retention as the level of supplement increased. Negative nitrogen balance in sheep fed with sole UTMS is due to the low nitrogen content and poor digestibility of nitrogen in the diet. Weldegebriel (2007) also noted negative nitrogen balance when UTMS was fed to sheep without supplementation. Lower nitrogen supply to rumen microbes hinders animal performance (McDonald *et al.*, 2002). Similarly, groups fed with sole UTMS in the present experiment lost weight at the end of 90 days growth trial (Hirut *et al.*, 2011).

5. Conclusion

The result suggested that feeding sole urea treated maize stover cannot supply sufficient nitrogen for normal rumen microbial function, hence cannot support maintenance requirement of the growing animal. Supplementation of UTMS with 350 g concentrate mixture resulted in improved feed intake, digestibility, and positive nitrogen balance indicating an enhanced animal growth. Therefore, we recommend concentrate supplementation to UTMS basal diet for improved animal performance.

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Short Communication

Association of Faba Bean Rust (*Uromyces viciae-fabae*) with Environmental Factors and Cultural Practices in the Hararghe Highlands, Eastern Ethiopia

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Abstract: Disease survey was conducted in Hararghe highlands of Ethiopia during the 2009 cropping season to determine the incidence and severity of faba bean rust (*Uromyces viciae-fabae*) in major growing districts of Hararghe highlands, and its association with environmental factors and cultural practices. A total of 90 faba bean fields were surveyed in six districts. Sample plants were systematically selected in an "X" fashion. In each field, 10 plants were sampled for disease assessment. During the survey, altitude, type of cropping system, weed management practices, crop growth stage, previous crop in the field and sowing date were recorded. Significant differences among locations were indicated with respect to altitude, sowing date, crop growth stage and field management practices. The mean incidence of the disease varied from 44.6% in Bedeno to 98% in Tullo, while severity of the disease varied from 12.7% in Bedeno to 65% in Gorogutu and Kurfachale districts. Logistic regression analysis for the association of rust incidence and severity with environmental factors and cultural practices as independent variables showed rust incidence below 80% had a high probability of association with Deder district, areas with altitude above 2450 m.a.s.l. and when faba bean was planted after July 25. Rust incidence above 80% had a high probability of association with Gorogutu, Kurfachale, Tullo districts; altitudes below 2450 masl, and when faba bean was planted from the end of June up to July 25. Similarly, disease severity below 40% had a high probability of association with Bedeno district, flowering growth stage, altitude above 2450 m.a.s.l., and when weeds were managed properly. Disease severity greater than 40% had a high probability of association with Gorogutu, Kurfachale, Tullo, Deder and Metta districts, altitudes below 2450 m.a.s.l., podding and late podding growth stages, and where poor weed management was practiced. The survey revealed high occurrence and distribution of faba bean rust in the study area and the need for effective and feasible management options to be developed.

Keywords: Disease Incidence; Disease Severity; Faba Bean Rust; *Uromyces viciae-fabae;* Weed Management

1. Introduction

Faba bean (*Vicia faba* L.), occupies nearly 3.2 million hectares with production of 2.6 million metric tons worldwide in 2003 (Torres *et al.,* 2006). It is the first in area coverage (459,000 ha) among the legumes with production of 0.58 million metric tons in Ethiopia. It is cultivated on 23,061 hectares of land in Hararghe highlands (CSA, 2007). It is a multi-purpose crop that plays an important role in the socio-economic life of farming communities (Agegnehu and Fessehaie, 2006). Faba bean has an important place in the Ethiopian national diet and is consumed in various forms (Keneni and Jarso, 2002). The contribution of faba bean in improving soil fertility is well documented (Asfaw *et al*., 1994). It is a cool season pulse crop grown in the highlands (1800-3000 masl) of Ethiopia, where the need for chilling temperature is satisfied. It grows well with optimal temperature of 15-20°C and mean annual rainfall of 700-1000 mm (ICARDA, 2006).

In spite of its huge importance, the productivity of faba bean in Ethiopia remains far below the crop's potential (> 3 t/ha). The major constraints that limit the realization of full yield potential of faba bean and cause instability in yield in different parts of the world are both abiotic and biotic constraints (Agegnehu *et al*., 2006). Among the biotic constraints, fungal diseases are the major factors affecting production and productivity as well as the quality of faba bean in different parts of Ethiopia. Among the fungal diseases, rust caused by *Uromyces viciae-fabae* is the most important one worldwide including Ethiopia (Saxena, 1991). Normally, rust epidemics begin late in the season, when pod filling has started and yield losses usually range from 5 to 20%. However, when the infection starts early in the season, severe epidemics can occur and yield losses can be as high as 70% (Rashid and Bernier, 1991). Faba bean rust is widely distributed in Ethiopia (Dereje and Tesfaye, 1994) and causes yield losses of 27%.

The disease is favored by high humidity, cloudy and warm weather conditions. *Uromyces viciae-fabae* produces numerous, small, orange-brown pustules, each surrounded by a light yellow halo that develops on the leaves. On the stem, rust pustules are larger and longer than those found on the leaves (Hanounik and Bisri, 1991). Isolated rust pustules may also appear on the pods, which can reduce seed weight. Severe infection may cause premature defoliation, resulting in reduced seed size. Urediospores of *U. viciae-fabae* germinate well in a temperature that ranges 5-26 ^{O}C, with fastest germination at 20 ^{O}C (Joseph and Hering, 1997).

Different control methods have been proposed against rust, including cultural practices, the use of chemicals and resistant varieties. Cultural practices, such as adjusting plant density, nitrogen fertilization or crop mixtures can significantly influence rust infection (Fernandez-Apricio *et*

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al., 2006). However, use of resistant varieties is recognized as the most desirable, efficient and economical management option (Bond *et al.,* 1994). Disease management using chemicals should be based on a precise knowledge of the relationship between disease severity and yield loss in case of rust (Zadoks, 1985). Foliar sprays of mancozeb, chlorothalonil and copper hydroxide have been recommended against rust in Australia (Hawthorne *et al.*, 2004). In Ethiopia, Hassen *et al.* (2010) showed that severity and rate of rust progression were significantly influenced by use of resistant varieties and fungicides. He indicated treatment of faba bean with mancozeb at the rate of 1.6 a. i. kg ha^{-1} resulted in significant reductions in rust severity and produced the highest yield. Faba bean in Ethiopia, especially in the Hararghe highlands where such information is totally lacking.

Understanding the association of disease intensity and different management practices will help to identify the most important variables and focus efforts in developing an integrated and sustainable rust management package for faba bean production (Rusuka *et al.*, 1997). Survey data are useful to gain insight into the occurrence, distribution and relative importance of diseases (Rusuka *et al.*, 1997). Even if the crop has diverse uses, very little survey work has been done for rust of faba bean.

Therefore, this study was conducted with objectives to determine (i) the incidence and severity of faba bean rust in major growing districts of Hararghe highlands, and (ii) its association with environmental factors and cultural practices.

2. Materials and Methods

2.1. Survey Area

Disease survey was conducted to assess the incidence, severity and prevalence of faba bean rust in six districts of Hararghe highlands located at latitude of 09^0 11'-09^0 21' N and longitude 041^0 01'-041^0 48' E during the 2009 main growing season. Rugged topography and mountainous landscapes characterize the Hararghe highlands (Table 1). The region has a bimodal rainfall distribution and is a typical sub-humid, high altitude agro-climatic zone. The short rainy season (*Arfassaa*) extends from April to June and accounts for about 25% of the annual rainfall, whereas the long rainy season (*Gaanna*) extends from July to October and accounts for about 45% (Belay *et al.*, 1998).

The survey was conducted in Deder, Metta, Bedeno, Kurfachale, Gorogutu, and Tullo districts of Hararghe highlands. Deder, Metta, Bedeno, Kurfachale, and Gorogutu highlands are in eastern, while Tullo district is in western Hararghe Zone of the Oromia Regional State. A total of 90 fields were assessed for disease incidence and severity from October 22 to 28, 2009.

Table 1. Characteristic features of surveyed faba bean fields in six districts of Hararghe highlands, Ethiopia.

District	altitude (masl)	Temperature range (^{o} C)
Bedeno	2540 - 2602	8 - 24
Deder	2414 - 2779	10 - 23
Gorogutu	2303 - 2534	6 - 24
Kurfachale	2135 - 2441	5 - 20
Metta	2413 - 2510	3 - 22
Tullo	2420 - 2673	1 - 29

Source: National Meteorological Services Agency, Jijjiga Branch (NMSAJB, 2009).

2.2. Sampling and the Sample Unit

Fields were sampled at intervals of 5-10 km along roads and distance between fields depending on the topography and the relative importance of faba bean cultivation within each district. Sample plants were systematically selected by making a specified number of equally spaced paces by moving through the field in an "X" fashion. Having made the pre-set number of paces (according to the size of the field), the nearest plant to the right foot was first sampled. In each field, 10 plants were sampled for disease assessment. A sub sample of twelve leaves per plant and four leaves per canopy layers (upper, middle and lower) were selected from the main stem, yielding a total of 120 leaves per field. Mean of canopy layers was determined per plant and then averaged per field for data analysis. All sample fields belonged to small, private farmers. Each field was visited once.

2.3. Crop and Disease Assessment

During the survey, altitude (m), type of cropping pattern (row versus broadcast planting), weed management practices, crop growth stage, previous crop in the field and sowing date were recorded for each sampled field to determine their relationship with the disease incidence and severity. Growers were asked information on cultural practices (time of sowing, faba bean varieties grown, previous crop, and disease control practices) employed. Altitude was recorded using a GPS.

Severity was rated using the 1-9 disease scoring scale (ICARDA, 1986), where 1 indicates no visible symptom and 9 represents disease covering more than 80% of the foliar tissue. Disease severity scores were converted into percentage severity index (PSI) for analysis (Wheeler, 1969).

$$PSI = \frac{\text{Sum of numerical ratings} \times 100}{\text{No of plants scored} \times \text{Maximum score on scale}}$$

2.4. Data Analysis

Disease incidence and severity data were classified into distinct groups of binomial qualitative data. Class boundaries were chosen so that groups contained approximately equal totals. Thus, $\leq$ 80 and > 80 were chosen for rust incidence and $\leq$ 40 and > 40 for rust severity, yielding binary dependent variables. Categorized independent variables that were used in the analysis are presented (Table 2). Contingency tables of disease intensity and the independent variables were built to represent the bivariate distribution of fields according to two classifications (e.g. district by rust incidence). An entry in a cell of a contingency table represents the frequency of fields falling into that cell (Table 3). Several contingency tables were combined into a single matrix.

The association of faba bean rust intensities with independent variables was analysed using logistic regression as described by Yuen *et al.* (1996) with the SAS Procedure GENMOD (SAS Institute Inc., 2008). The logistic regression model allows to evaluate the importance of multiple independent variables that affect the response variable. In plant pathology, the model has been used to study the effect of different variables on Sclerotinia stem rot forecasting (Twengstrom *et al.*, 1998). Logistic regression calculates the probability of a given binary outcome (response) as a function of the independent variables (McCullagh and Nelder, 1989). If the probability of the outcome is denoted as (*P*), the logistic regression model assumes that the logarithm of the odds of *P* (*P*/(*1*-*P*)), which equals logit (*P*), is a linear function of the independent variables (Yuen *et al.*, 1996). In this case, the binary outcome was the probability that faba bean rust incidence exceeds 80% and severity exceeds 40% in a given faba bean field. The GENMOD procedure gives parameter estimates and the standard error of the parameter estimates. Exponentiating the parameter estimate yields the odds ratio, which is interpreted here as the relative risks (Yuen *et al.*, 1996).

The importance of the independent variables was evaluated in three ways. First, the association of an independent variable alone with disease incidence or severity was tested. This consists of testing the deviance reduction attributed to a variable when it was first entered into the model. Second, the association of an independent variable with disease incidence or severity was tested when entered last into the model with all other independent variables. Third, variables with high association to disease intensity when entered first and last into a model were added to a reduced multiple variable model. A complete analysis of deviance table was generated for the final reduced multiple variable model, where deviance reduction (DR) was calculated for each variable as it was added to the reduced model.

The deviance (-2 x log likelihood) was used to compare single and multiple variable models. The difference between the two models, known as a likelihood ratio test (LRT), was used to examine the importance of the variable and was tested against a χ^2 value (McCullagh and Nelder, 1989) where the number of degrees of freedom in the χ^2 value corresponded to the difference in degrees of freedom between the two models.

3. Results

3.1. Disease Incidence and Severity

Rust was prevalent in all the faba bean fields surveyed. The districts varied in occurrence of rust and severity. Among the faba bean fields surveyed in six districts, the least mean incidence (44.6%) and mean disease severity (12.7%) were recorded in Bedeno district and the highest mean disease incidence (98%) in Tullo district and the highest mean severity (65%) was recorded in Gorogutu and Kurfachale districts (Table 4). The finding of the survey indicated that late planting (after July 25) resulted in less rust incidence and severity. The lowest mean (57%) faba bean rust incidence and mean severity (18.8%) were noted on faba bean crops sown after July 25.

Farmers planted faba bean as sole crop as well as intercropped with maize, wheat, barley, sorghum and field pea. Out of the total surveyed faba bean fields, 54.4% fields were intercropped with these crops and rust was also less as compared with sole faba bean fields. Faba bean fields were at three different growth stages: 20% at flowering, 27.78% at podding and 52.2% at late podding stage during the survey (Table 3). Maximum incidence and severity were recorded in fields where faba bean was at late podding stage. Faba bean fields cultivated at an altitude below 2450 masl, fields having sole faba bean and fields having poor weed management score showed the highest incidence and severity of rust as compared to their respective other variable classes (Table 4). Most of the fields surveyed (57.78%) were planted on fields where barley crop was previously grown (Table 3). The highest and lowest mean rust incidence was recorded in fields previously sown with sorghum (96%) and wheat (73.5%).

Table 2. Categorization of variables used in analysis for a survey of faba bean rust disease in six districts (n = 90) of Hararghe highlands, Ethiopia.

Variable	Variable class	No. of fields	Variable	Variable class	No. of fields
District	Metta	15	Weed management[a]	Good	32
	Gorogutu	15		Intermediate	30
	Deder	15		Poor	28
	Tullo	15	Previous crop	Barley	52
	Kurfachale	15		Wheat	10
	Bedeno	15		Maize	16
Cropping System	Sole	41		Sorghum	5
	Mixed	49		Field Pea	7
Altitude	≤ 2450	35	Rust	≤ 40	42
	> 2450	55		> 40	48
Growth Stage	Flowering	18	Incidence	≤ 80	44
	Podding	25		> 80	46
	Late pod filling	47			
Sowing Date	June-July 25	65			
	> July25	25			

[a]*Good weeding, any weed is weeded; intermediate weeding, few weeds are present; poor, no weeding and high weed infestation*.

Table 3. Independent variable by disease contingency table for logistic regression analysis of faba bean rust survey during the 2009 cropping seasons from Hararghe highlands, Ethiopia.

		Disease intensity (%)			
		Incidence		PSI	
Independent variable	Variable class	≤ 80	> 80	≤ 40	> 40
District	Metta	10	5	12	3
	Gorogutu	5	10	0	15
	Deder	11	4	11	4
	Tullo	1	14	2	13
	Kurfachale	2	13	2	13
	Bedeno	15	0	15	0
Cropping system	Sole	18	23	13	28
	Mixed	26	23	29	20
Altitude	≤ 2450	3	32	5	30
	> 2450	41	14	37	18
Growth stage	Flowering	18	0	18	0
	Podding	15	10	14	11
	Late pod filling	11	36	10	37
Sowing date	June-July 25	19	46	18	47
	> July	25	0	24	1
Weed management[a]	Good	21	11	21	11
	Intermediate	15	15	16	14
	Poor	8	20	5	23
Previous crop	Barley	25	27	20	32
	Wheat	6	4	5	5
	Maize	8	8	12	4
	Sorghum	1	4	2	3
	Field Pea	4	3	3	4

[a]*Good weeding, any weed is weeded; intermediate weeding, few weeds are present; poor, no weeding and high weed infestation. PSI = Percent severity index.*

3.2. Association of Faba Bean Rust with Environmental Factors and Cultural Practices

The association of all independent variables with rust incidence is presented in Table 5. All the independent variables, except district, altitude and sowing date, were not significantly associated with rust incidence when entered first into a logistic regression model. However, district lost significance, while growth stage gained importance when entered last into the model with addition of other variables.

Altitude (χ^2 = 14.03, 17.96) and sowing date (χ^2 = 10.05, 6.96) were the most significant and important variables associated both when entered into the model first and last. A group of three variables: district, altitude and sowing date significance were tested in a reduced multiple variable model. Analysis of deviance for these variables added one by one to the reduced model showed the importance of each variable and variable class (Table 6). The parameter estimates resulting from the reduced regression model and their standard error are presented (Table 6). Low rust incidence had a high probability of association with Deder district, altitude above 2450 m.a.s.l. and when crop sown after July 25. High rust incidence had a high probability of association to Kurfachale, Gorogutu and Tullo districts. In Kurfachale and Gorogutu districts there was about four and three times greater probability, respectively, that rust incidence would exceed 80%.

Four variables: districts, altitude, growth stage and weed management were highly associated with rust severity when entered as single variable into the model. Altitude lost significance while previous crop and growth stage gained importance when entered last into the model with addition of other variables. District and weed management were the most highly associated with severity when entered as a single variable and last with other variables into the model (Table 5). The significance of district, altitude, growth stage and weed management was tested by adding these variables one by one to a reduced model. Analysis of deviance for the variables, parameter estimates and their standard errors is given in Table 7. Rust severity (≤ 40%) had a high probability of association with Bedeno district and an altitude of (> 2450 masl), flowering growth stage and in field with good and intermediate weed management system. Gorogutu, Kurfachale, Tullo and Deder districts and late podding growth stage had a high probability of association with high rust severity. There were about 226 and 2 times greater probabilities that rust severity would exceed (> 40%) in the Gorogutu district as compared to Metta and in late podding to podding, respectively.

Table 4. Mean incidence and percent severity index (PSI) of faba bean rust for different independent variables in 2009 cropping season in Hararghe highlands, Ethiopia.

		Incidence				PSI			
Variable	Variable Class	Min	Max	mean	SD	Min	Max	Mean	SD
District	Meta	65	100	83.2	13.0	24.7	55.0	36.4	8.1
	Gorogutu	60	100	91.3	13.6	40.9	100.0	65.2	15.7
	Deder	66	100	82.6	11.6	11.1	89.0	33.8	19.4
	Bedeno	15	80	44.6	22.7	11.1	18.1	12.7	2.0
	Kurfachale	75	100	97.0	8.0	26.9	80.3	65.2	16.2
	Tullo	80	100	98.0	5.6	33.2	80.7	62.3	14.9
Sowing date	June-July25	60	100	92.6	11.8	11.1	100.0	56.4	19.3
	After July25	15	80	57.0	23.6	11.1	45.2	18.8	9.6
Altitude	$\leq$ 2450	70	100	97.7	6.9	24.1	89.0	62.7	16.5
	> 2450	15	100	73.2	23.8	11.1	100.0	35.2	22.2
Cropping system	Sole	25	100	87.3	16.5	11.1	100.0	53.0	22.4
	Mixed	15	100	79.0	26.0	11.1	80.7	39.9	24.1
Growth stage	Flowering	15	80	62.5	22.2	11.1	37.9	18.5	7.9
	Podding	15	100	76.2	26.2	11.1	80.3	39.1	20.3
	Late podding	60	100	94.1	11.0	11.1	100.0	60.1	18.9
Weed management	Good	15	100	75.2	25.4	11.1	100.0	36.2	26.1
	Intermediate	15	100	83.4	22.0	11.1	80.7	43.8	21.1
	Poor	32	100	90.9	16.3	11.8	89.0	59.4	18.6
Previous crop	Barley	20	100	84.4	20.8	11.1	80.8	46.8	23.5
	Wheat	15	100	73.5	28.8	11.1	80.7	43.7	22.3
	Maize	30	100	83.4	20.3	11.1	89.0	38.6	23.0
	Sorghum	80	100	96.0	8.9	33.3	80.7	58.5	23.4
	Field Pea	15	100	73.7	32.5	11.1	100.0	50.2	34.4

Min. = Minimum value; Max. = Maximum value; SD = Standard deviation; PSI = Percent severity index.

Table 5. Independent variables used in logistic regression modeling of faba bean rust incidence and severity and likelihood ratio test (LRT) for seven variables entered first and last into a model.

		Rust incidence LRT				Rust Severity LRT			
		Type 1 analysis		Type 3 analysis		Type 1 analysis		Type 3 analysis	
Independent variable	df	DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2
District	5	48.9	<0.0001	7.22	0.205	66.2	0.0001	29.77	0.0001
Previous crop	4	3.99	0.407	7.89	0.096	3.59	0.465	10.38	0.035
Cropping system	1	0.28	0.597	2.83	0.093	0.00	1.00	0.01	0.936
Altitude	1	14.03	0.0002	17.96	<0.0001	10.1	0.001	3.27	0.07
Sowing date	1	10.05	0.002	6.96	0.0082	1.89	0.169	0.48	0.49
Growth stage	2	4.41	0.11	6.44	0.04	5.24	0.073	7.18	0.028
Weed management	2	2.94	0.23	2.94	0.23	10.9	0.004	10.91	0.004

Type 1 analysis, variable entered first; Type 3 analysis, variable entered last; df = Degrees of freedom; DR = Deviance reduction; Pr = Probability of a value χ^2 exceeding the deviance reduction.

4. Discussion

During the survey period, faba bean rust was found widely distributed in all districts with ranging degree of incidence and severity. In Tullo, Gorogutu and Kurfachale districts the severity was greater by 2–5% than Metta, Deder and Bedeno districts. It is believed that the existence of favorable temperatures that ranged from 5-24^{0}C during the growing period led to increased spore germination and rust epidemic development in most of the districts (Table 1). Rust is favored by warm temperatures (17-22^{0}C) and cloudy weather conditions (Stoddard *et al.,* 2010). Rust infection can occur following six hours of leaf wetness, so does not require extended wet periods (Hawthorne *et al.,* 2004). Unfortunately, it was difficult to find rainfall data of the districts that could better explain the association. Altitude alone and when combined with other cultural practices had a significant effect on the development of rust. Both disease incidence and severity were relatively higher below 2450 m.a.s.l. This suggests that the relatively humid and warm climate is more favorable for the disease development (Dereje and Tesfaye, 1994).

The farmers grow local cultivars of faba bean year after year in Hararghe highlands and faba production is constrained by rust because local cultivars grown by farmers are highly susceptible and resistant varieties are not yet available to satisfy the need of the producers (Hassen *et al.,* 2010). In cooler production regions, the uredospores are important means of survival between cropping seasons. Secondary spread is by means of uredospores, which can readily germinate on plant surfaces under humid conditions and dispersed by wind (Stoddard *et al.,* 2010).

Mean rust severity was 56% in fields sown between June-July 25, while it was 19% in fields planted after July 25. Hawthorne *et al.* (2004) indicated that early sowing faba bean may result in a bulky crop, which creates an environment most conducive to rust disease but later sowings reduce the disease risk in Australia. High mean disease incidence and severity were found to increase with advancement in growth stage under favorable conditions. This might be due to the defoliation or aging of the already infected leaves of the plant at this stage. It was also not easy to measure the time between flowering, podding and late-podding growth stages because the survey was conducted on one occasion within a season and the type of cropping practices and many other factors also influence the development of the disease.

Throughout the survey it was observed that there were a higher number of rust-infected plants within fields when faba bean was planted as sole compared with fields intercropped with other crops like field pea, barley, wheat, maize, and sorghum (Table 4). There was no significant difference when this factor was considered independently and combined with other factors (Table 5). Sharaiha *et al.* (1989) also reported reduced (29%) rust incidence in maize-faba bean intercropped plots under the Jordan Valley conditions. Faba bean rust incidence and severity were more in non-weeded fields than weeded or weed free fields. Some farmers did not see the need to weed their faba bean fields because they also used the weeds as animal feed. This led to a situation in which farmers tolerated high weed densities within their faba bean crop. Cultivation of faba bean in the presence of high weed populations is known to highly reduce the yield of the crop and favour the development of disease epidemics (Agegnehu and Fessehaie, 2006). In fields with dense weed populations, there was competition for space, moisture and soil nutrients as a result of which the faba bean plants were less vigorous and prone to the disease. Sahile *et al.* (2008) reported that high weed density in non-weeded fields increased chocolate spot disease of faba bean. Besides, the presence of a high weed population in a field increases the humidity within the crop canopy (microclimate) which is more favorable for *U. viciae-fabae* infection and the development of rust epidemics (Fernandez-Aparicio *et al.*, 2006).

The survey data analysed using logistic regression analysis indicated environmental and cultural variables that were associated with faba bean rust incidence and severity either singly or in combination. The regression model quantified the relative importance of the variables indicating how much the disease was increased or decreased as a function of the independent variables singly or in combination. The present study identified districts, altitude, growth stage, sowing date and weed management as important variables that influenced faba bean rust epidemic. The results of this study suggests the importance of research on weed management and other related cultural practices to supplement effective rust management options in the surveyed areas and elsewhere with similar agro-ecological settings. Moreover, extensive and consistent survey is recommended to know the intensity of the disease in similar agro-ecology of the country where the crop is widely grown.

Table 6. Analysis of deviance, natural logarithms of odds ratio and standard error of added variables in a reduced model analyzing faba bean rust incidence[a].

Added variable[b]	Residual deviance	df	LRT		Variable class	Estimate[c]	SE[d]	Odds ratio[e]
			DR	Pr > $\chi 2$				
Intercept	124.72	0				1.87	1.16	6.49
District	75.83	5	48.9	0.0001	Deder	-0.57	1.12	0.57
					Bedeno	0.22	2.26	1.25
					Gorogutu	1.02	0.82	2.77
					Tullo	0.59	1.51	1.80
					Kurfachale	1.36	1.15	3.90
					Metta	0*	0*	1
Altitude	61.76	1	14.07	0.0002	≤ 2450	0*	0*	1
					> 2450	-2.52	1.04	0.08
Sowing date	55.27	1	6.49	0.011	June-July25	0*	0*	1
					> July25	-2.88	1.71	0.06

[a]*df, degrees of freedom; LRT, likelihood ratio test; DR, deviance reduction; Pr, probability of a* χ^2 *value exceeding the deviance reduction; *, reference group;* [b]*Variables are added into the model in order of presentation in table;* [c]*Estimates are from the model with all independent variables added;* [d]*Standard error of the estimate;* [e]*Exponentiating the estimates.*

Table 7. Analysis of deviance, natural logarithms of odds ratio and standard error of added variables in a reduced model analyzing faba bean rust severity[a].

Added variable[b]	Residual deviance	df	LRT		Variable class	Estimate[c]	SE[d]	Odds ratio[e]
			DR	Pr>χ2				
Intercept	124.37	0				0.443	1.16	1.56
District	58.13	5	66.2	0.0001	Dedder	0.66	1.16	1.93
					Bedeno	-0.27	1.61	0.76
					Gorogutu	5.42	1.63	225.88
					Tullo	1.83	1.80	6.23
					Kurfachale	3.30	1.42	27.11
					Metta	0*	0*	1
Altitude	51.44	1	6.68	0.009	≤ 2450	0*	0*	1
					> 2450	-1.52	1.16	0.22
Growth stage	44.16	2	7.29	0.026	Flowering	-0.23	1.56	0.79
					Podding	0*	0*	1
					Late podding	0.70	0.96	2.01
WMT[f]	37.11	2	7.05	0.029	Good	-2.64	1.13	0.07
					Intermediate	-1.27	0.92	0.28
					Poor	0*	0*	1

*[a]df, degrees of freedom; LRT, likelihood ratio test; DR, deviance reduction; Pr, probability of a χ^2 value exceeding the deviance reduction; *, reference group; [b]Variables are added into the model in order of presentation in table; [c]Estimates are from the model with all independent variables added; [d]Standard error of the estimate; [e]Exponentiating the estimates; [f]WMT, weed management: good weeding, any weed is weeded; intermediate weeding, few weeds are present; poor, no weeding and high weed infestation.*

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Registration of *Obsa* and *Dicho* Sesame (*Sesamum indicum* L.) Varieties

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Abstract: *Obsa* and *Dicho* are the names assigned after release for sesame (*Sesamum indicum* L.) varieties with accession number Acc. EW004 and Acc. EW015, respectively. Both varieties were by far greater than the standard check, *Abasena*, in terms of grain yield (by 142.06 and 135.98%, respectively), disease resistance, tolerant to shattering and non-lodging. The average oil contents and average oil yields for *Obsa and Dicho* were 51.45 and 53.8%, and 498.4 and 503.9 kg ha^{-1}, respectively.

Keywords: *Dicho; Obsa*; *Sesamum indicum;* Variety Registration

1. Introduction

Sesame (*Sesamum indicum L.*) has early origins in East Africa and in India. Except for one, which is found in India, all the other 19 wild species of sesame are found in Africa. This suggests that sesame was domesticated in Africa, probably in Ethiopia (Onwueme and Sinha, 1991). The world production of sesame seeds gradually increased from 1.5 million tons per year in the 1960s to 3.2 million tons per year in 2005 due to an increased demand for sesame oil worldwide. Over this period, annual international trade in sesame seed increased from 150,000 tons to 800,000 tons. Africa produced an estimated 25% of the total world production and contributed nearly 40% of the world exports. Among African countries, Nigeria were the leading producer (75,000 tons year^{-1}), followed by Ethiopia (50,000 tons year^{-1}), Tanzania (41,000 tons year^{-1}) and Chad (35,000 tons year^{-1}) (Wijnands *et al.,* 2007).

In Ethiopia, the total area, production and productivity averaged for the last 11 years were 0.1 million ha, 70, 000 tons and 0.60 t ha^{-1}, respectively (CSA 1996/1997–2007/2008 as cited in Negash *et al.,* 2011). Sesame ranks first in total production from oil crops. Tigray, Oromia, Amhara and Benshangul Gumuz are the major producers in Ethiopia. The last 11 years data showed that the production of sesame is increasing in terms of area and total production while the productivity is much below 1.0 t ha^{-1}.

The major sesame producing regions in Ethiopia are situated in the low land of northwest and southwest (Wijnands *et al.,* 2007). The author indicated that northwestern regions have comparatively the highest yield per hectare. Of the total 707059 hectare land allocated for oil crop production in Ethiopia during 2007/2008 main cropping season, 185912 hectare (26.294%) was mainly covered by sesame with the national average productivity 1.0 tone per hectare, and it accounts for 70% of the export value of all oil crops. During the same season, 25.66% sesame production came from Oromia, mainly from East Wollega and West Wollega (60.45% and 12.54% of the total production in Oromia, respectively). However, the regional productivity per hectare was less than the national average, 0.62 t ha^{-1} (CSA 2008). The major problems of sesame production in western region were lack of adaptable high yielding and disease resistant varieties. Cognizant of this problem, Bako Agricultural Research center has started sesame improvement activities before decades and released two promising sesame varieties named *Obsa* and *Dicho* through national variety release system in 2010. Therefore, this paper highlights the agro-ecological adaptation, grain yield performance, disease reaction and other agronomic and management recommendation for the released varieties for further uses by producers, researchers and industries

2. Variety Evaluation

Adaptation trial of released sesame varieties were conducted at Bako, Gutin, Wama, Uke, Boneya and Dedessa from 2003-2004. But, none of them were adapted and only *Abasena* gave grain yield of about 300 kg ha^{-1} (Dagnachew, 2011). Cognizant of the fact that all released varieties performed poorly in western region, introduction and evaluation of sesame landraces were initiated in 2005/2006 on 117 sesame landraces collected from different regions. Through the routine variety trial procedures, 19 best performing genotypes were evaluated with one standard check, *Abasena*, and were promoted to multi-location variety trial in 2007 and 2009 at Dedessa and from 2008–2009 at Bako and Gutin. All genotypes performed and gave grain yield better than the standard check. Among the tested genotypes, Acc. EW004 (*Obsa*) and Acc EW015 (*Dicho*) were found resistant to bacterial blight, showed consistent performance across location and gave an average grain yield of 1068.5 kg ha^{-1} and 1062.6 kg ha^{-1} at on-station and 868.8 and 810.6 kg ha^{-1} on farmers field, respectively. These better performing varieties were evaluated by national variety release committee, preferred by farmers across location and finally released in 2010.

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3. Agronomic and Morphological Characters

Obsa (Acc. EW004) is a white seeded variety with ovoid seed shape and medium seed size (1000 grain weight of 2.56 gram). It has purple colored narrow leaf and medium plant height with comparatively short length of the first capsule bearing zone from the surface on the main stem. *Dicho* (Acc. EW015) has white-tan seed color with ovoid shape and better seed size (1000 grain weight of 2.72 gram). Thousand grain weights for the standard check, *Abasena* is 2.58 gram. Summary of major agronomic and morphological traits of both varieties (*Obsa* and *Dicho*) are presented in Table 1.

4. Yield Performance

Obsa (Acc.EW004) and *Dicho* (Acc. EW015) were local landraces collected from western region of Ethiopia by IBC (Institute of Biodiversity Conservation) decades ago. The varieties were evaluated against the standard check, *Abasena*, from 2005 to 2009 in different breeding stages at different sites. Across years and locations, both varieties were by far high yielders than the standard check. On the research field, the average grain yield for *Obsa*, *Dicho* and *Abasena* were 1068.5, 1062.6 and 399.4 kg ha^{-1}, respectively. On the farmers' field, they gave 868.8, 810.6 and 324.57 kg ha^{-1}, respectively. Though it was reported as more than 60% of sesame production in Oromia comes from Wollega zones (CSA, 2008), the average productivity per hectare of sesame has been less than 500 kg across years mainly due to lack of improved variety and disease problem. Thus, the release of these varieties can minimize the problem and boost productivity of the crop.

5. Disease Reaction

In western Oromia, particularly in eastern and western Wollega zones of sesame producing districts, its production and productivity were highly hampered by bacterial blight. However, *Obsa* and *Dicho* were resistant to moderately resistant to major diseases of sesame such as bacterial blight over locations and years.

6. Grain Yield Stability

Stability analysis in 20 sesame genotypes planted across three locations for two years following the method of Eberhart and Russel (1966) indicated that both *Obsa* and *Dicho* were moderately stable with higher mean grain yield than the remaining genotypes. Several authors indicated that the best agro-ecology for sesame adaptation and wider genetic diversity is at altitude below 1500 masl (Gemechu and Bulcha, 1992; MARD, 2008; Demissie *et al.*, 1992). Contrary to the expectation and these findings, maximum grain yield was obtained and best field performance was observed for these varieties at Bako, where the altitude is around 1600 masl than at Gutin where the altitude is 1350 masl across years.

7. Conclusion

Obsa and *Dicho* are adaptable, high yielding and disease resistant varieties with desirable agronomic traits released for western Oromia where none of the former released sesame varieties performed well. Beside the yielding ability of these varieties, their oil content is more than 50%. Therefore, the release of these varieties can have an immense effect for sesame production in western region in particular, and the country in general.

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Table 1. Adaptation, agronomic and morphological characteristics of sesame varieties, *Obsa and Dicho*.

Characteristics	*Obsa* (EW004)	*Dicho* (EW015)
Adaptation, agronomic and morphological characteristics	Bako, Dedessa, Gutin and areas with similar agro-ecology	Bako, Dedessa, Gutin and areas with similar agro-ecology
Adaptation area:		
Altitude (masl)	1250-1650	1250-1650
Rainfall (mm)	700-1100	700-1100
Fertilizer rate:		
DAP (kg ha^{-1})	0	0
Urea (kg ha^{-1})	50	50
Seed rate (kg ha^{-1})	5	5
Spacing (inter x intra row)	40 cm x 5 cm	40 cm x 5 cm
Planting date	Mid to late June	Mid to late June
Days to flowering	62-75	65-78
Days to maturity	120-137	131-142
Plant height (cm)	86-115	91-122
1000 seed weight (g)	2.56	2.72
Seed color	white	white-tan
Crop pest reaction	resistant to major diseases and pests	resistant to major diseases and pests
Average oil content (%)	51.45	53.80
Average oil yield (kg ha^{-1})	498.4	503.9
Yield (kg ha^{-1}):		
Research field	1068.5	1062.6
Farmers field	868.8	810.6
Year of release	2010	2010

Registration of *Bubu*, a Medium Maturing Improved Potato (*Solanum tuberosum* L.) Variety for the Eastern Highlands of Ethiopia

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Abstract: An improved potato (*Solanum tuberosum* L.) variety, *Bubu* (CIP-384321-3), is developed by the Root and Tuber Crops Improvement Program of the Haramaya University, Ethiopia and approved by the National Variety Release Committee in 2011. The performance of the variety was evaluated at five locations in the eastern part of Ethiopia from 2006 to 2009. The mean performance of *Bubu* over locations and years indicated that it gave 11.5% more tuber yield over the standard checks *(Harchassa and Gabissa)*. Although it is not stable for tuber yield, it exhibited high sensitivity to environmental change and a better adaptation to high-yielding environments. *Bubu* is a medium maturing variety with tuber size and shape preferred by the farmers. The taste of boiled tubers was rated as very good by the farmers. The variety is recommended for the highlands of Eastern and Western Hararghe Zones with an altitude ranging from 1650-2330 meter above sea level.

Keywords: *Bubu;* Hararghe; Potato; Stability; Tuber Yield

1. Introduction

Ethiopia is known to have favorable edaphic and climatic conditions for high quality potato production. About 70% of the agricultural land in the county is situated at an altitude range of 1800-2500 m above sea level with annual rainfall of 600 mm or more which is conducive for high quality ware and seed potato production. However, the national average yield is approximately 10.5 tons ha^{-1}, which is very low compared to the world average of 16.4 tons ha^{-1} (FAOSTAT DATA, 2004). Lack of well-adapted potato cultivars to the different agro-ecological zones of the country is the most crucial factor accounting for this low yield. To tackle this problem, the Potato Improvement Program of the Haramaya University was established in 1975 with the major objective of developing widely adaptable, high yielding and stable potato varieties with good resistance to biotic and abiotic constraints. To achieve this, the Program has been introducing potato germplasms having wider genetic base from the International Potato Center (CIP) and testing them across locations. After five years of trials, the Program managed to release one new high yielding and late blight tolerant potato variety (*Bubu*) with the consent of the National Varity Release Committee.

This variety is dedicated in memory of the late Wondimeneh Assefa who passed away untimely on April 21, 2011. He was a hardworking, dedicated, generous and loveable individual in our home institution, Haramaya University. The name given to this variety, *Bubu*, is his nickname that the author used to call him while he was with us in this world.

2. Origin and Pedigree

The variety *Bubu* (CIP-384321-3) was introduced from CIP and had gone through multi-location trials in the eastern part of the country. The selection and adaptation test results proved that it is one of the best varieties for regional release.

3. Main Morphological Characteristics of the Variety

The variety is erect in its growth habit and having an intermediate vigor and an average plant height of 66.8 cm (Table 1). Its flowers are pink in color and it requires about 41 and 99 days to flower and mature, respectively. The variety sets high number of tubers per hill with a shallow eye depth that are white in skin color and flat rounded in shape (Table 2).

Table 1. Major morphological characteristics of *Bubu* potato variety.

Variety	Growth habit	Vigor	Plant height (cm)	Flower color	Days to flowering	Days to maturity
Bubu	Erect	Intermediate	66.8	Pink	41	99

Table 2. Tuber characteristics of *Bubu* potato variety.

Variety	Tuber set/hill	Eye depth	Skin colour	Tuber shape	Tuber size distribution
Bubu	High	Shallow	White	Flat round	Medium – large

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4. Yield Performance and Stability

The variety and two standard checks (*Herchassa and Gabissa)* were tested at Haramaya Langie, Kulubi, Hirna and Alberekete in 2008 and 2009 (Tables 3 and 4). The mean performance of *Bubu* over locations and years indicated that it gave 11.5% more tuber yield over the standard checks (Table 5).

Table 3. Total tuber yield (tons ha^{-1}) of the *Bubu* variety and two standard checks tested at different locations in 2008.

	Tuber yield (tons ha^{-1})						Over the
Variety	Haramaya	Langie	Kulubi	Hirna	Arbarakate	Mean	checks
Bubu	36.91	27.10	22.32	36.55	36.91	31.96	12.14%
Harchassa	31.11	31.92	31.11	31.92	27.94	30.80	
Gabissa	32.19	25.16	26.94	25.16	21.53	26.20	

Table 4. Total tuber yield (tons ha^{-1}) of *Bubu* potato variety and two standard checks tested at different locations in 2009.

	Tuber yield (tons ha^{-1})						Over the
Variety	Haramaya	Langie	Kulubi	Hirna	Arbarakate	Mean	checks
Bubu	34.09	22.73	26.99	37.20	44.28	33.06	9.59%
Harchassa	30.07	23.57	24.67	35.84	42.74	31.38	
Gabissa	31.40	20.98	21.98	34.22	36.18	28.95	

Table 5. Two years (2008 and 2009) average total tuber yield (tons ha^{-1}) of *Bubu* potato variety and the two standard checks tested at different locations.

	Tuber yield (tons ha^{-1})						Over the
Variety	Haramaya	Langie	Kulubi	Hirna	Arbarakate	Mean	checks
Bubu	35.50	22.53	29.97	32.15	40.41	32.11	11.55%
Harchassa	30.59	24.28	27.89	33.88	35.34	30.39	
Gabissa	31.80	21.11	24.46	29.69	28.85	27.18	

According to Perkins and Jinks (1968), a genotype having a mean of a specific character higher than the overall mean, a regression coefficient (β_i) close to unity and deviation from regression coefficient (S^2d_i) of zero is considered to be superior for the character under consideration. Based on these criteria, *Bubu* was found to be unstable for tuber yield and it is on the average responsive to changing environments and better adaptable to high yielding environments (Table 6).

Table 6. Estimates of stability parameters for tuber yield (tons ha^{-1}) of the *Bubu* potato variety and the standard checks.

Variety	Mean root yield (tons ha^{-1})	Regression coefficient (β_i)†	Deviation from regression (S^2d_i)
Bubu	32.11	1.06^{ns}	45.95^{++}
Gabissa	27.02	0.93**	4.60^{++}
Herchassa	29.99	0.96**	15.66^{++}

†*ns = Not significantly different from unity at p > 0.05; ** = Significantly different from unity p < 0.01;* $^{++}$ *= Significantly different from zero at p < 0.01.*

5. Reaction to Major Disease

The average of three years reaction of the potato varieties to late blight (Table 7) indicated that *Bubu* is more tolerant to the disease as compared to both of the standard checks.

Table 7. Late blight reaction of *Bubu* potato variety in comparison with the checks.

Variety	2007	2008	2009	Mean
Bubu	2	2	2	2.0
Herchassa	4	4	5	4.3
Gabissa	3	4	5	4.0

6. Quality Attributes

Bubu is a medium maturing and high yielding potato variety with tuber size and shape preferred by the farmers. The taste of cooked tubers is classed as very good by the farmers around Haramaya area (Table 8).

Table 8. Taste and physical characteristics of boiled tubers of *Bubu* potato variety.

Variety	Cooking ability	Peeling ability	Flesh color	Flesh texture	Flavour	After boiling	
						Integrity	Darkening
Bubu	Quick	Easy	Cream	Waxy	Very good	Skin surface slightly cracked	No

7. Adaptation

Bubu is recommended for the highlands of Eastern and Western Hararghe Zones with an altitude ranging from 1650-2330 meters above sea level.

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