AMMI Analysis of Genotype x Environment Interaction for Grain Yield in Drought-Tolerant Maize (*Zea mays* L.)

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Abstract: Eight drought tolerant maize lines and their 28 crosses with two local hybrids were evaluated separately in 12 environments to estimate the magnitude of genotype x environment interaction (GEI) and relationships between parents and progenies in stability. An additive main effects and multiplicative interaction (AMMI) model was used to analyze the grain yield data. The first two IPCAs of the AMMI 2 analysis accounted for 56 % of the GEI sum squares in trials of the hybrids. High yielding hybrids like O, P, S, Z, U, G and one of the checks (BH140) showed minimum GEI, indicating wide adaptation of these varieties over environments. In contrast, high yielding hybrids such as A, D and J adapted to unfavorable environments and K and T to favorable environments. Most of the crosses from drought tolerant parents were better than the check (BH540) in mean grain yield and stability. Although no considerable association in stability was observed between crosses and their parents, increased stability occurred in most of the crosses due to increased stress tolerance.

Keywords: Drought Tolerance; Genotype x Environment Interaction; Yield Stability

1. Introduction

In sub-Saharan Africa, crop yield variability under rainfed conditions is likely to be of greater socio-economic importance than in any other part of the world (Heisey and Edmeades, 1999). This is mainly due to drought and low nitrogen (N) stresses, which are most frequently limiting maize production in the tropics (Betran *et al.*, 2003). In addition, the typical practice of low input farming systems should be considered due to increased population pressure and poverty in the region. All these phenomena are common in Ethiopia, where environmental conditions vary considerably, and means of modifying the environment are far from adequate. Under these conditions, genotypes that provide high average yields with minimum genotype by environment interaction (GEI) have been gaining importance over increased yields (Ceccarelli, 1989; Gauch and Zobel, 1997; Kang, 1998).

The relative magnitude of GEI provides information concerning the likely area of adaptation of a given genotype. It is also useful in determining efficient methods of using time and resource in a breeding program (Ceccarelli, 1989; Kang, 1998). Various biotic and abiotic stresses have been implicated as causes of GEI, which is considered as an inheritable trait. Consequently, improving genotype resistance/tolerance to different stresses to which they would likely be exposed might minimize GEI (Kang, 1998). Selection under managed drought stress at flowering is suggested as an effective means of increasing tolerance to a number of stresses occurring near flowering. Thus mid-season, drought tolerant genotypes that perform well under variable moisture regimes (Chapman *et al.*, 1997) and N levels (Bänziger *et al.*, 1999) are expected to give a better yield with increased stability across variable growing conditions compared to conventionally developed genotypes. However, there is limited information about their GEI across different environments, and relationships between lines and their crosses with regard to this trait.

On the other hand, it has to be taken into consideration that data from multilocation trials are imprecise, complex and noisy (Kang, 1998). The conventional method of partitioning total variation into components due to genotype, environment, and GEI conveys little information on the individual patterns of response (Zobel *et al.*, 1988). To increase accuracy, additive main effects and multiplicative interaction (AMMI) is the first model of choice when main effects and interaction are both important. Thus, the objectives of this study were to estimate the magnitude of GEI among the hybrids developed from drought tolerant lines compared to conventional (local) hybrids as well as relationships between the crosses and parental lines based on AMMI stability values.

2. Material and Methods

A diallel cross without reciprocals was made among eight drought-tolerant maize lines (CML440, CML442, CML202, Mex101 (DTPWC8F31-1-1-1-B), Mex102 (DTPWC8F266-1-1-1-B), Mex103 (DTPWC8F347-1-3-1-B) CML443 and CML445) from CIMMYT during 2001/2002 at the Grain Crops Institute at Potchefstroom, Republic of South Africa. In Ethiopia, these lines and their 28 crosses with two local hybrids (BH540 and BH140) were evaluated separately in two trials planted side by side in 12 environments (Table 1). The off-season trials (well-watered normal density (WN), drought

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stressed normal density (DN), well-watered high density (WH), and drought-stressed high density (DH)) were conducted only at Melkasa, where a furrow irrigation system was used to apply about 40 mm of water (estimated by partial flume) every seven days. However, for DN and DH, watering was suspended from 15 days prior to anthesis until 25 days after anthesis when one additional irrigation was applied. A randomised complete block design with four replications was used for each trial. Each plot consisted of four 4.2 m rows with a spacing of 75 cm between rows. Intra row spacing was 15 and 30 cm between hills for high plant density and normal density respectively. Two seeds hill^{-1} were planted, and plots were later thinned to obtain the required plant density. Fertilizer was applied as recommended for each location, and trials were kept free of weeds.

In the text, the names of the hybrids are replaced by alphabetical codes (Table 3). Observations were recorded on grain yield plot^{-1}, which was reported in ton hectare^{-1} (t ha^{-1}) at 15% moisture content. An analysis of variance (ANOVAs) was performed for the grain yield of each trial (data not shown). The AMMI analysis of the log-transformed yield data (based on Bartlett's test) was performed separately for each type of genotype (lines and hybrids) using AGROBASE (1998) software. However, the hybrid trials results were mainly discussed, while results from the lines trials used only to estimate association with their crosses. The AMMI model first arranges additive effects for the main factors; that is, genotypes and environments, using the additive analysis of variance procedure. Subsequently it arranges multiplicative effects for genotype by environment interaction (GEI) by principal component analysis (PCA) (Zobel *et al.*, 1988). The statistical significance of analysis of variance, and the optimum number of interaction principal component axes (IPCA) to be retained in the model were determined using the F-test as given by the analytical software mentioned above. AMMI's stability value (ASV) was calculated in order to rank genotypes in terms of yield stability using the formula suggested by Purchase *et al.* (2000) as shown below.

AMMI stability value (ASV) =

$$\sqrt{\left[\frac{SSIPCA1}{SSIPCA2}\left(IPCA1score\right)\right]^2+\left[IPCAscore2\right]^2}$$

Where: SS = Sum of squares; IPCA1 = Interaction Principal Component Analysis axis 1
IPCA2 = Interaction Principal Component Analysis axis 2

In general, an absolute AMMI stability value (ASV) was determined using a procedure that combines IPCA1 and IPCA2. By using Pearson correlation coefficient (r) between inbred lines and crosses, the association in stability was estimated by regressing F_1 hybrid ASV on mid-parent values. In addition, the AMMI- adjusted mean grain yield (t ha^{-1}) for each cross was estimated from original data to demonstrate mean performances.

Table 1. The 12 environments used for evaluation of parental lines and 30 hybrids independently.

Environment No.	Code	Location	Year	Season	Moisture source/status	Plant density
1.	WN [a]	Melkasa	2002	Off-season	Irrigation, well-watered	Normal
2.	DN [a]	Melkasa	2002	Off-season	Irrigation, stressed during flowering	Normal
3.	WH [a]	Melkasa	2002	Off-season	Irrigation, well-watered	High
4.	DH [a]	Melkasa	2002	Off-season	Irrigation, stressed during flowering	High
5.	NB2[b]	Bako	2002	Main season	Rain fall, adequate	Normal
6.	NM2[b]	Melkasa	2002	Main season	Rain fall, adequate	Normal
7.	NB3[c]	Bako	2003	Main season	Rain fall, adequate	Normal
8.	NM3 [c]	Melkasa	2003	Main season	Rain fall, adequate	Normal
9.	HB2[b]	Bako	2002	Main season	Rain fall, adequate	High
10.	HM2[b]	Melkasa	2002	Main season	Rain fall, adequate	High
11.	HB3 [c]	Bako	2003	Main season	Rain fall, adequate	High
12.	HM3 [c]	Melkasa.	2003	Main season	Rain fall, adequate	High

[a] *Environments of 2002 off-season trials at Melkasa, WN= well-watered normal plant density; DN= drought-stressed normal density; WH= well-watered high density; DH= drought-stressed high density*

[b] *Environments of 2002 main season trials, NB2= Normal plant density at Bako; NM2=Normal density at Melkasa; HB2= high density at Bako; NM2= Normal density at Melkasa*

[c] *Environments of 2003 main season trials, NB3= Normal density at Bako; NM3=Normal density at Melkasa; HB3=High density at Bako; HM3=High density at Melkasa*

3. Results and Discussion

The AMMI analysis for grain yield showed that environments, genotypes, and GEI were highly significant ($P<0.001$) and accounted for 79.96, 3.03 and 17.01% of the treatment combination sum of squares (E+G+GEI SS) respectively (Table 2). The results indicated that specific and wide adaptations were equally important as suggested by Gauch and Zobel (1997). Although the GEI sum of square was about five times larger than that for genotypes, environmental effects dominated the analysis. As indicated by the F-test, the first three interaction PCA axes were highly significant. The IPCA1, IPCA2 and IPCA3 declared 33, 23 and 14 % of the observed hybrids by environment variation sum of squares respectively. Although IPCA3 was significant it was discarded due the difficulty of obtaining reliable information from its relatively small contribution to the interaction. Thus, since the first two IPCAs accounted for 56 % of the GEI sum of squares, the AMMI 2 model was the best fit for the hybrid trials. The residual 44 % that included IPCA3 was discarded.

High variability among environments, both in the main and interaction effects were demonstrated with a distinct pattern as indicated in Fig. 1 (biplot). All high potential environments were evenly distributed in the second (WN, NM2, HM2, HM3, WH, HB2) and third quadrants (NB2, NM3), while low yielding environments were sparsely scattered in the fourth (DH, and top soil eroded fields HB3 and NB3) and first quadrants (DN). As expected, the severely stressed environment (DH) showed the lowest yield and also the highest interaction with genotypes.

Table 2. AMMI analysis for grain yield of 30 hybrids evaluated in 12 environments.

Source	df	Sum squares	Mean squares
Total	1439	47.057	
Treatment combinations	359	34.76	0.097
Environments (E)	11	27.793	2.527**
Replicates within E	36	2.379	0.066
Genotype (G)	29	1.053	0.036**
Genotype x E	319	5.914	0.019***
IPCA1	39	1.938	0.05***
IPCA2	37	1.372	0.037***
IPCA3	35	0.802	0.023***
IPCA Residual	208	1.803	0.009
Error	1044	9.918	0.01
C.V (%) = 2.63;	R^2 = 78.92;	Log (mean yield) = 3.709	

***, ***, significant at P = 0.01 and P = 0.001, respectively*

Considerably less variation in mean yield was exhibited among hybrids compared to the environments used for evaluation (Figure 1). Based on mean performance (main effects), four groups of hybrids were evident from the biplot. Group 1 consisted of hybrids W, C_1, X, K, V, Q, H_2, I, F, H, Y, U, L, Z, E and B, which had mean yields closer to the grand mean but varied in interaction (IPCA1) scores. Hybrids W, C_1, X, K, V, E and B exhibited greater interaction with environments, of which W, C_1, X, K and V showed positive interaction with drought-stressed (DN) and most high yielding environments but negative interaction with DH and most environments at Bako. The reverse held true in the case of E and B hybrids. When IPCA1 was plotted against IPCA2 (Figure 2), their interaction scores remained as high as in Figure 1, and ranked above nineteenth in ASV values (Table 3), reflecting an unstable yield over environments. Others like H_2, F, H, I, Y and U were close to zero, while Q and Z showed medium interaction. Similarly, when IPCA1 was plotted against IPCA2, most of them appeared close to zero. However, H, I, Q, F and L ranked second to fifteenth in ASV values, indicating good yield stability across environments but were found to be unacceptable in most areas due to their poor mean yields. Thus, in Group 1, only H_2, U and Z were superior both in mean yield and stability. Hybrids O, S, C_2, P, H_1, A, J, T, R and M were included in Group 2, which relatively better than Group 1 in mean yield, of which O, S, C_2, P, and H_1 had IPCA1 scores close to zero. However, when the IPCA1 scores were plotted against the IPCA2 scores (Figure 2), only O, P, C_2 and H_1 remained close to zero. Thus, considering both mean yield and ASV values O, P, S, C_2 and H_1 were superior in both terms over environments. A top cross hybrid BH140 (C_2) was one of them, mainly due to an improvement made by CIMMYT for reduced plant height in one of its parents (Tuxpeño Sequia C_{18}). Consistent with the current study, Fischer *et al.* (1983) has indicated short maize plants as being more tolerant to drought at flowering than taller plants.

Group 3 consisted of the highest yielding (> 6.0 tha^{-1}) hybrids G and D, which showed the same pattern when IPCA1 was plotted against IPCA2. Accordingly, G and D were the best crosses in drought-stressed environments DN and DH respectively. Contrary to stability, it was also suggested that emphasis should be given to specific adaptation to extreme drought stress in semi arid climates (Haussmann *et al.*, 2000). Thus, hybrids G and D are preferable in areas facing recurrent drought stress, since a reliable minimum grain yield is more important to subsistence farmers than high yields in rarely favorable seasons. In Group 4, low yielding hybrids C and N are included, as these hybrids revealed diverse reaction. The cross N showed the lowest mean yield, stability and growth period of the tested hybrids.

Based on a combination of both mean grain yield and ASV values, hybrids O, P, C_2, S, H_1, H_2, Z, U and G were relatively superior in descending order, due to a combination of both mean yield and ASV values. Based on two sorghum populations, Zavala-Garcia *et al.* (1992) suggested that a combined index using a stability index and genotype means increased selection efficiency. Hybrids Y, I, Q, F and H were superior only in their ASV (stability) and may not be recommended for direct use in production due to their poor mean yield. However, these five crosses can be used for breeding purposes in areas with erratic rainfall patterns. In line with the observations in this study, Kang (1998) and Tollenaar and Lee (2002) pointed out that reduced GEI (increased stability) occurred due to increased stress tolerance. They also suggested that increased stability occurred due to the selection of genotypes under both stress and non-stress conditions. High yielding hybrids such as A, D, G and J, were specifically adapted to unfavorable environments that included drought stress and eroded topsoil. These hybrids were relatively poor in high yielding environments but top yielding in the unfavorable environments as emphasized in another study (Haussmann *et al.*, 2000). In contrast, the other high yielding hybrids K and T were narrowly adapted to well-managed conditions but not suitable for resource-constrained farmers, particularly in areas with unpredictable rainfall patterns and eroded topsoil. Of the 30 hybrids, X, W, N, B and C_1 were the most unstable over environments, while N and B were also the poorest in mean yield. BH540 (C_1) was improved for high rainfall areas at Bako but proved to be one of the most inferior in the present study, both in mean yield and stability. This study agreed with Betran *et al.* (2003) who suggested that good performance across stress levels can be achieved in tropical maize hybrids, especially when developed from drought tolerant lines.

The estimated relationship between crosses and mid parents based on their ASV values showed that there was no significant association ($r_{F1ASV.MPASV}$ = -0.004). This indicated that the magnitude of GEI (ASV) of the crosses was not dependent on the parental lines *per se*. Considering ASV values, CML445, CML440, CML442 and Mex103 appeared to be superior lines over various environments (data not shown). However, the performances of the crosses developed from stable lines (CML442 x CML445 and Mex103 x CML440) were not stable (Table 3). On the other hand, all the lines except Mex102 were involved in the nine superior crosses (O, P, C_2, S, H_1, H_2, Z, U and G) but lines with poor stability were more involved in these crosses than the stable lines. This also confirmed the suggestion made above because GEI expression controlled non-additive gene effects (Kang, 1998). However, good yield stability in lines may be important for F_1 seed production if it is practiced under erratic rainfall conditions.

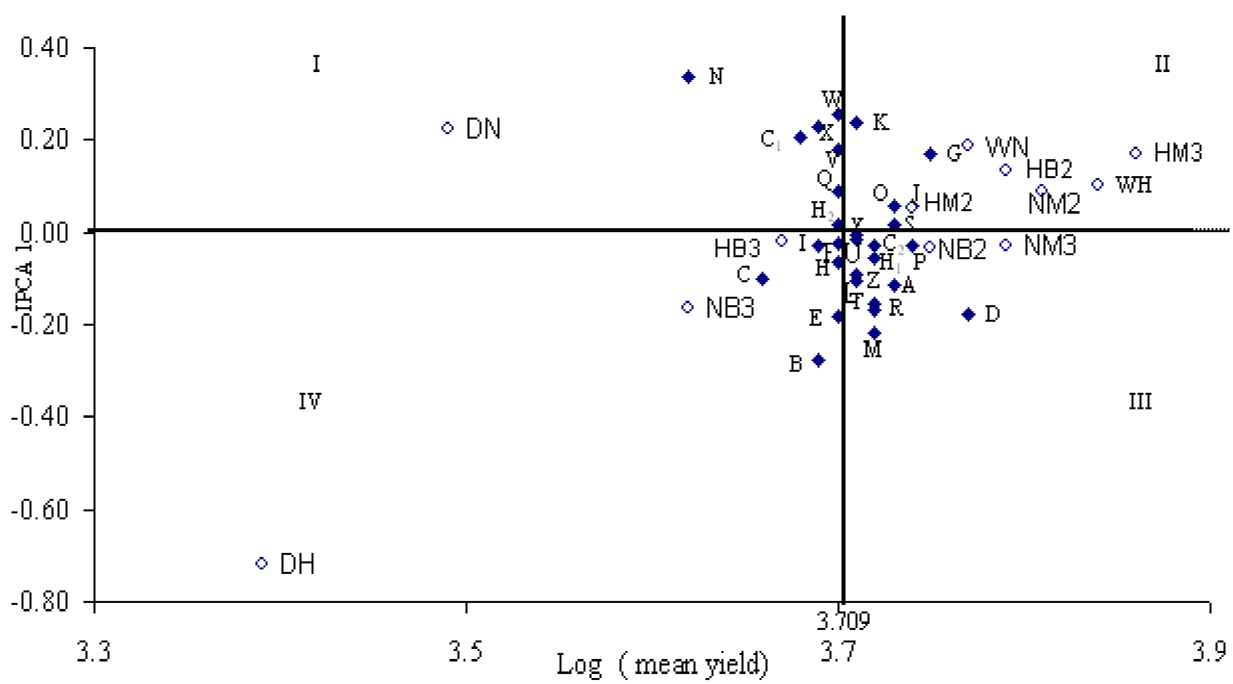

Figure 1. AMMI model 2 biplot of the 30 hybrids (◆) evaluated in 12 environments (o).

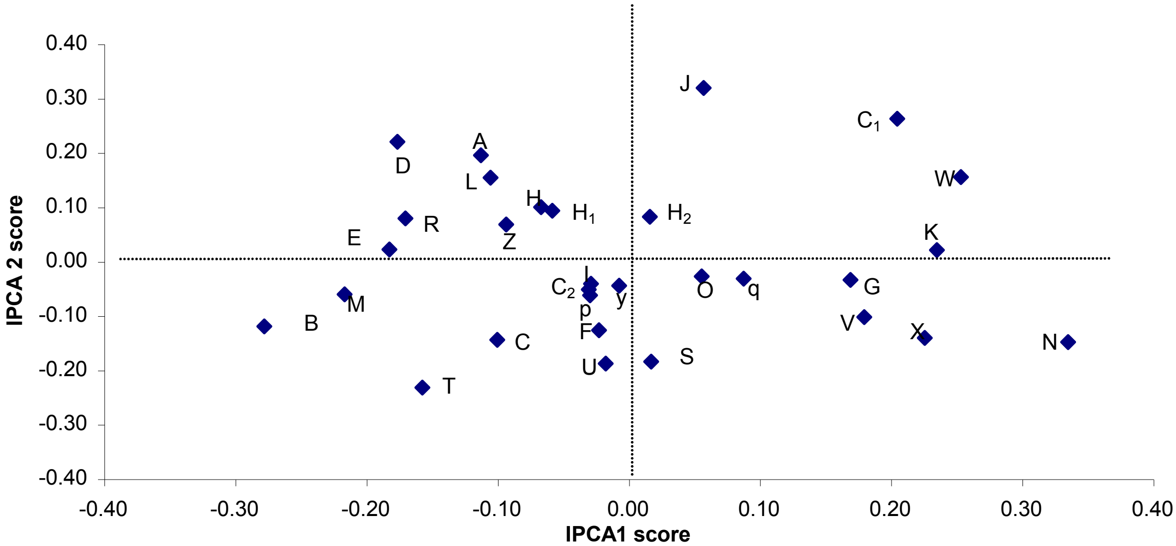

Figure 2. IPCA1 and IPCA2 scores of maize hybrids plotted against one another.

Table 3. AMMI adjusted mean grain yield (t ha^{-1}) based on raw data, and ASV and ranking orders of the 30 hybrids evaluated across 12 environments.

		Mean		ASV				Mean		ASV	
Hybrid Name	Code	t ha^{-1}	rk*	Value	rk	Hybrid Name	Code	t ha^{-1}	rk*	Value	rk
Mex101xMex102	A	5.79	4	0.251	17	Mex103xCML202	P	5.79	5	0.076	4
Mex101xMex103	B	5.14	27	0.410	29	Mex103x CML443	Q	5.40	21	0.129	8
Mex101xCML440	C	4.88	29	0.203	14	Mex103xCML445	R	5.53	13	0.252	18
Mex101xCML442	D	6.30	1	0.331	24	CML440xCML442	S	5.77	7	0.187	12
Mex101xCML 202	E	5.29	24	0.258	19	CML440xCML202	T	5.68	8	0.321	22
Mex101xCML443	F	5.28	25	0.131	9	CML440x CML443	U	5.52	14	0.191	13
Mex101xCML445	G	6.06	2	0.242	16	CML440xCML445	V	5.38	22	0.275	20
Mex102xMex103	H	5.23	26	0.136	10	CML442xCML 202	W	5.50	16	0.390	27
Mex102xCML440	I	5.09	28	0.058	2	CML442x CML443	X	5.50	17	0.350	26
Mex102xCML442	J	5.88	3	0.328	23	CML442xCML445	Y	5.44	20	0.047	1
Mex102xCML202	K	5.78	6	0.333	25	CML202x CML443	Z	5.54	12	0.147	11
Mex102x CML443	L	5.44	18	0.213	15	CML202xCML445	H_1	5.63	10	0.123	7
Mex102xCML445	M	5.44	19	0.311	21	CML443x CML 445	H_2	5.52	15	0.084	5
Mex103xCML440	N	4.69	30	0.497	30	BH540 (Check 1)	C_1	5.31	23	0.390	28
Mex103x CML442	O	5.66	9	0.084	6	BH140 (Check 2)	C_2	5.61	11	0.068	3
						LSD (0.05)		0.347			

* *rk = rank*

4. Conclusions

Most crosses from drought tolerant parents were better than the conventional hybrid (BH540) in mean grain yield and stability. Selection for drought tolerance through simultaneous evaluation of parental lines under both stress and non-stress conditions can be considered as the main cause for reduced GEI. However, some hybrids like K and T were narrowly adapted to well-managed conditions, which is not affordable for resource-constrained farmers. In this study, considerable relationships were not observed between lines and their crosses in stability, indicating independence between them for this trait.

5. Acknowledgments

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Genotype x Environment Interaction and Yield Stability of Maize

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Abstract: Maize cultivars vary in their response to variable environmental conditions. Twenty maize cultivars were tested at nine locations in Ethiopia (1100 – 2240 masl) in randomized complete block design with three replications for two years to study the nature and magnitude of genotype x environment (G x E) interaction and phenotypic yield stability of the cultivars. Analysis of variance and stability analysis were computed. Variances due to genotypes, years, locations, genotype x year, genotype x location and genotype x year x location interaction were significant ($P<0.01$). Most of the cultivars had significant deviation mean square (S^2di), implying that these cultivars had unstable performance across the testing environments. However, Additive Main Effect and Multiplicative Interaction (AMMI) analysis showed Gibe-1 (mean yield, 7.40 t ha^{-1}) had relatively stable performance across the environments. None of the cultivars were the best for grain yield in all environments. BH-660 (mean grain yield, 8.14 t ha^{-1}) had a relatively good performance in the mid- to high-altitude (1650 – 2240 m above sea level) areas whereas BH-140 (mean grain yield, 6.65 t ha^{-1}) had a good performance in the low-mid to mid-altitude (1100 – 1650 m above sea level) areas, indicating the possibility of developing specific cultivars adapted to mid- and high- or low-mid and mid-altitude areas. However, the top yielding cultivars at each maize agro-ecology were specifically adapted, indicating that, for high yield potential in each maize agro-ecology, a specific breeding program is necessary.

Keywords: Environment; Cultivar; Interaction; Stability; *Zea mays*

1. Introduction

Changes in relative rankings appear to be an inevitable consequence of growing a set of plant genotypes in even a few locations or seasons. This is especially true in tropical regions where, not only are environmental fluctuations greater, but crops also lack the protection conferred by purchased inputs; thus for plant breeders, large genotype by environment (G x E) interactions impede progress from selection and have important implications for testing and cultivar release programs (Smithson and Grisley, 1992).

In fact, G x E interaction is as much a function of the genotype as they are of the environment and so are partly heritable (Hill, 1975). Statistically, G x E interactions are detected as significantly different patterns of response among the genotypes across environments and biologically, this will occur when the contributions (or level of expression) of the genes regulating the trait differ among environments (Basford and Cooper, 1998).

As it is a common phenomenon in the East of Africa (Birhane and Bentayehu, 1989), Ethiopia is a country of great environmental variation (EMA, 1988). Where environmental differences are greater, it may be expected that the G x E interaction will also be greater. As a result, it is not only average performance that is important in genotype evaluation programs but also the magnitude of the interactions (Fehr, 1992; Gauch and Zobel, 1997). Stability of performance is also of special importance in Ethiopia and similar countries where environmental conditions vary considerably and means of modifying the environment are far from adequate. Benti *et al.* (1996) studied G x E interaction and grain yield stability of twelve maize composites and three locally-adapted Kenyan hybrids at six locations in Ethiopia with altitude ranges of 1100 – 1750 meters above sea level (masl) with sufficient rainfall for two years and found G x E interaction. Wende *et al.* (2004) also studied the G x E interaction of ten locally-developed maize cultivars at five locations (1650 – 2240 masl) in Ethiopia for three years and reported G x E interaction. However, it is not possible to get information on the performance of the maize cultivars across the altitude ranges of 1100 – 2240 masl, the major sub-humid maize growing areas of Ethiopia. Thus, this study intended to study the nature and magnitude of G x E interaction and grain yield stability of twenty maize cultivars at nine locations (1100 – 2240 masl) in Ethiopia for two years.

2. Materials and Methods

Twenty different maize cultivars of East African and CIMMYT origin were tested at nine locations situated between 7^0 09' N and 11^0 16' N latitudes and 36^0 00' E and 42^0 02' E longitudes in the 1997 and 1998 main cropping seasons. The altitude and annual rainfall of the locations ranged from 1100 – 2240 meters above sea level (masl) and 900 – 1595 mm respectively. The testing locations were: Pawe (1100 masl), Bako (1650 masl), Awassa (1700 masl), Jimma (1750 masl), Areka (1800 masl), Arsi-Negelle (1960 masl), Alemaya (1980 masl) and Adet (2240 masl). The locations represent three of the four major maize-producing mega-environments in Ethiopia; *viz.* low (low-mid) altitude sub-humid zone, mid-altitude sub-humid zone and high altitude sub-humid zone (Birhane and Bantayehu, 1989; Benti *et al.*, 1993).

The cultivars were planted at each location in randomized complete block design with three replications. The experimental unit was a two row plot 5.1 meters long, spaced 75 cm apart and with a plant-to-plant

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distance of 30 cm. All trial management practices were based on the recommendations of each location. Field weight was recorded from all ears in the harvest area. Then grain yield per hectare was calculated using average shelling percentage of 80% and adjusted to 12.5% moisture.

Analysis of variance for each environment and combined analysis of variance over years and locations were computed for grain yield. Bartlett's test, as cited in Gomez and Gomez (1984), was also computed to assess homogeneity of variances prior to combined analysis. The statistical significance of analysis of variance was determined using the F-test.

The stability of yield performance for each cultivar was calculated by regressing the mean yields of individual cultivar on environmental index and calculating the deviations from regression as suggested by Eberhart and Russell (1966). However, regression coefficient (bi) was considered as an indication of the response of the cultivar to varying environments while mean square for deviations from regression (S^2di) was used as the criteria of stability as suggested by some authors (Gupta *et al.*, 1974; Becker and Leon, 1988). In addition, the G x E interactions were analyzed using Additive Main effect and Multiplicative Interaction (AMMI) analysis (Crossa *et al.*, 1990; Gauch, 1992) to assess similarity and dissimilarity among testing environments and interaction patterns.

The regression coefficients (bi) were tested for significant difference from unity using t-tests while the significance of the deviations from regression (S^2di) from zero was tested by the F-test. The SAS computer program (SAS, 2001) and the AGROBASE software computer program (Agronomix software INC. and AGROBASE, 2000) were used for the analysis of the data.

3. Results and Discussion

Analysis of variance for grain yield revealed significant differences ($P < 0.01$) among the cultivars in each environment. Variances due to genotypes (G), years (Y), locations (L), genotype x year, genotype x location and genotype x year x location were significant ($P<0.01$) (Table 1). The significance of the interaction effects showed that the cultivars had inconsistent performance across the years and locations. A similar result was reported by Lothrop (1989) in which he indicated that environmental changes cause G x E interaction for grain yield.

The partitioning of variance components showed that 53.64% was due to Y x L interaction, 13.84% was due to location, while 8.06% was due to the genotypes (cultivars) (data not shown). This indicated that environment was the greatest source of variation. AMMI analysis also showed that the G x E interaction was significant ($P<0.01$) and the best-fit model was AMMI2 (Table 1). Interaction Principal Component Analysis score (IPCA1) was significant ($P<0.01$) and explained 29.06% of the G x E interaction sum of squares. Similarly, the Interaction Principal Component Analysis score (IPCA2) was significant ($P<0.01$) and explained 22.82%. This showed that the two IPCAs accounted for the larger portion (51.88%) of the total interaction.

AMMI biplots for grain yield (Figure 1) showed distinct patterns for the testing environments. The high-yielding environments, Alemaya 1997 (AL97), Hirna 1997 (HR97), Awassa 1998 (AW98), Adet 1998 (AD98), Pawe 1998 (PW98) and Bako 1997 (BK97), were in quadrants two and three while the low-yielding environments, Hirna 1998 (HR98), Alemaya 1998 (AL98), Adet 1997 (AD97), Areka 1998 (AR98) and Awassa 1997 (AW97) were in quadrants one and four. AMMI biplots showed that AD98 and AL97 were the most favorable environments for realizing the yield potential of the cultivars while HR98 was the poorest yielding environment. This showed that the performance of the cultivars varied from season to season in some locations.

The result of this experiment showed that the elevation rainfall distribution during the growing period (data not shown) had a great impact on the performance of maize cultivars. For example, Alemaya and Hirna were among the high yielding environments in 1997 whereas they were among the poor yielding environments in 1998 (Figure 1). This could be attributed to the continuous moisture stress after emergence due to shortage of rain in eastern Oromia in 1998. The stress occurred during the vegetative growth period while there was good distribution of rain during the grain filling period. This implied that the data obtained from the two locations in 1998 may not represent the actual yield potential of the normal years. The year effect was also observed at Adet and Awassa in 1997 (Figure 1). Thus, cultivars were exposed to different environments at the same location in different years. Similar results were reported by other authors (Fox and Rosille, 1982; Becker and Leon, 1988). This indicated the necessity of testing elite maize cultivars at least for two years before recommending them for commercial production, especially in areas where rainfall distribution is unreliable.

The mean grain yield of the cultivars across the 18 environments (year-location combination) ranged from 5.71 t ha^{-1} in Beletech RC-2 to 8.14 t ha^{-1} in BH-660 (Table 2). The ranking of the cultivars varied across the seasons in some locations and altitudinal ranges (data not shown). For example, BH-540 was among the low-yielding in 1997 at Alemaya, while it was the highest yielding in 1998, indicating G x Y interaction. BH-660 was the top-yielding at high altitude and had relatively good performance at mid-altitude testing locations. However, it was out-yielded by BH-530, BH-140 and Gibe-1 at Pawe, low-mid altitude sub-humid zone. Although, BH-530 was the top-yielding at Pawe, it was one of the low-yielding cultivars at the other testing locations, mid- and high-altitude sub-humid zones, whereas BH-140 and Gibe-1 had relatively good performances at low-mid and mid-altitude testing locations. This indicated that the rank of the cultivars varied from one testing location to another testing location, confirming the presence of G x L interaction. Similarly, Wende Abera *et al.* (2004) found

Table 1. Combined analysis of variance and AMMI analysis for grain yield of 20 maize cultivars tested at nine locations over two years in Ethiopia (1997-1998).

Source	df	Mean square
Year (Y)	1	127.54 **
Location (L)	8	80.89**
Y x L	8	313.61**
Replication (L x Y)	36	1.88**
Genotype (G)	19	19.84**
Y x G	19	2.71**
L x G	152	2.05**
Y x L x G	152	1.65**
Error	684	0.49
AMMI		
G x E	323	1.90**
IPCA1	35	4.22**
IPCA2	33	3.52**

***- Significant at P< 0.01.*

crossover interaction in maize cultivars tested in the mid - and high-altitude areas of Ethiopia (1650 – 2240 masl). This showed that for high yield potential, a specific breeding program is necessary for the low- and high-altitude maize growing areas of Ethiopia. This is similar to the report of Rathore and Gupta (1994) who stated that the presence of crossover interaction is substantial evidence in favor of breeding for specific adaptation.

The superior performance of BH-660 at high elevations could be attributed to its genetic background as its parental lines are developed from Kitale Synthetic- II and Eucador-573, which are adapted to high-altitude transition zones (Benti *et al.*, 1993). On the other hand, BH-530 with CIMMYT tropical maize germplasm in its genetic background (Benti *et al.*, 1997) had a better performance at the lower elevations.

Analysis of responsiveness as measured by regression coefficients (bi) indicated that most of the cultivars had average responsiveness (Table 2). The high-yielding cultivars, BH-660 and Gibe-1 were more responsive (bi >1) to favorable environmental conditions than the other cultivars. The better response of Gibe-1, as compared to the other open-pollinated cultivars, indicated the possibility of developing open-pollinated cultivars with high mean grain yield under favorable environmental conditions. The old composites, Alemaya composite, UCB and Bako composite, had regression coefficients below unity (bi<1), indicating their average responsiveness to favorable environmental conditions. In addition, their grain yield means were less than the grand mean, which indicated their inferior performance compared to Gibe-1.

The simple correlation coefficient between mean yields and regression coefficients was calculated and it showed a positive relationship (*r* = 3) indicating the possibility of breeding responsive cultivars along with high grain yield. Abebe *et al.* (1984) also found a positive relationship between mean grain yields and regression coefficients in sorghum.

Most of the cultivars had significant deviation mean square from linear regression (S^2di), implying that these cultivars were unstable across the environments (Table 2). BH-530 had the highest S^2di. The high yielding cultivars, BH-660 and Gibe-1 also had significant S^2di, implying unstable performance across the testing environments. In general, when the three adaptability parameters, i.e. mean yield, regression coefficient and deviation mean square from the linear regression were considered, none of the cultivars exhibited general adaptability. Additive Main effect and Multiplicative Interaction (AMMI) analysis also showed differences among the cultivars in their stability performance for grain yield across the testing environments (Table 2).

The closer the IPCA scores (Interaction Principal Component Analysis scores, IPCA1 and IPCA2) to zero, the more stable the cultivars are across the environments (Crossa et al., 1990; Purchase, 1997). When the IPCA scores were considered, Gibe-1 had relatively stable performance across the environments among the high-yielding cultivars (Figure 1).

However, the good performance of BH-660 in the mid- and high-altitude areas and good performance of BH-140 and Gibe-1 in the low-mid and mid altitude areas indicated the possibility of developing maize cultivars adapted to mid- and high-altitude or low-mid and mid-altitude areas. Crossa *et al.* (1990) have also reported similar observations about the performance of specific maize genotypes across altitude ranges.

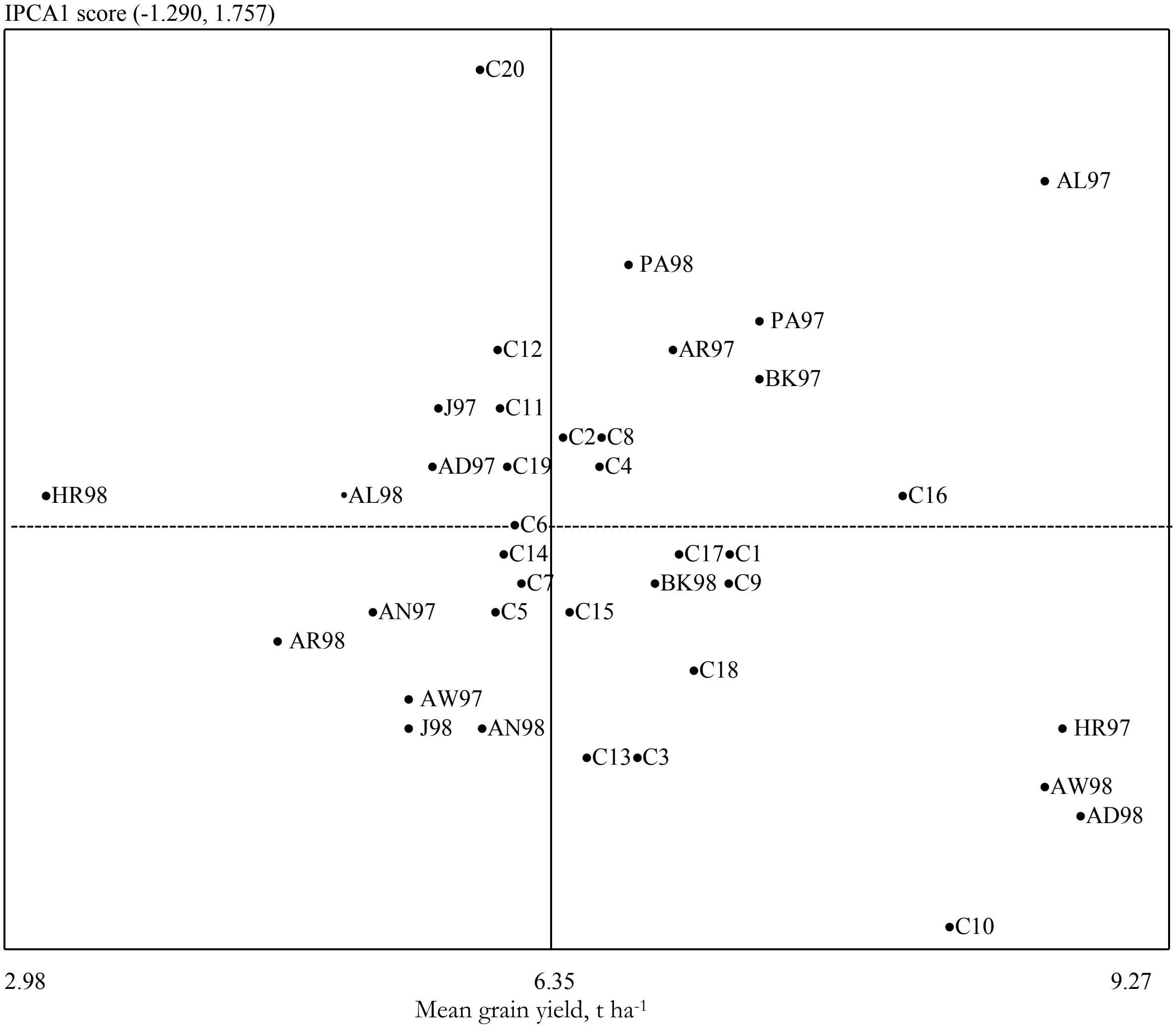

Figure 1. AMMI biplot for grain yield of 20 maize cultivars tested across 18 environments of Ethiopia (9 location, 2 years). Dots on the biplot indicate the correct spot. C=Cultivar, AL=Alemaya, AD=Adet, J=Jimma, BK=Bako, AN=Arsi-Negele, AW=Awassa, HR=Hirna, AR=Areka, PA=Pawe.

The present results demonstrate that, even in areas with sufficient rainfall, elevation has a great impact on the performance of maize cultivars in Ethiopia. It also showed that some specific cultivars, which are adapted to mid- and high- or low-mid and mid-altitude areas, could be developed. However, for high yield potential, a specific breeding program is necessary for each maize-producing agro-ecology of Ethiopia.

The results also indicated that, in some areas, distribution of rainfall during the growing period is the determining factor for the performance of maize cultivars. Thus, in those areas with abnormal distribution of rain in some years, the testing of maize cultivars across the years may help in selecting cultivars which give good yield during the years with even distribution of rain and relatively good performance in a year of uneven distribution of rain.

Table 2. Mean grain yield, regression coefficient (bi), mean square of deviation (S^2di) and Interaction Principal Component Analysis scores, IPCA1 and IPCA2, of 20 maize cultivars tested at 18 environments in Ethiopia (1997-1998).

	Cultivar	Yield (t ha^{-1})	bi	S^2di	IPCA1	IPCA2
1	Alemaya Comp. RC-2[3]	6.88	1.04	34.64**	-0.03	-0.70
2	Alemaya Comp.[2]	6.18	0.85	13.53*	0.40	0.50
3	UCB RC-2[3]	6.45	0.71	58.61**	-0.71	1.04
4	UCB[2]	6.31	0.89	24.85**	0.18	0.39
5	Beletech RC-2[3]	5.71	0.95	41.15**	-0.22	-0.54
6	Beletech S_1C_1 RC-2[3]	6.05	1.02	9.96	0.05	-0.22
7	Beletech[2]	5.99	1.09	17.46*	-0.17	-0.40
8	Late RC-5[3]	6.33	0.98	15.23*	0.32	-0.11
9	Synthetic RC-3[3]	6.67	1.21	52.36**	-0.18	-1.17
10	BH-660[1]	8.14	1.12	101.70**	-1.29	-0.29
11	EAH-75[2]	5.79	1.07	45.02**	0.49	0.15
12	Bako Comp.[2]	5.81	0.89	48.60**	0.58	0.64
13	Kuleni[2]	6.38	0.83	17.19*	-0.65	0.57
14	INT-A[3]	5.87	1.03	13.09	-0.09	-0.10
15	INT-B[3]	6.18	1.12	12.72	-0.27	-0.53
16	Gibe-1[2]	7.40	1.21	30.79**	0.13	0.23
17	BH-140[1]	6.65	1.03	31.83**	-0.05	0.48
18	BH-540[1]	6.76	0.87	52.80**	-0.45	0.94
19	A-511[2]	5.78	1.13	7.26	0.20	-0.21
20	BH-530[1]	5.80	0.96	158.87**	1.76	0.09
	Mean	6.35				
	CV %	11.03				

**, ** - Significant at $P< 0.05$ and $P< 0.01$, respectively.*
[1] *- hybrids*
[2] *– open-pollinated cultivars*
[3] *- breeding populations*

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Phenotypic Diversity in the Hararge Coffee (*Coffea arabica* L) Germplasm for Quantitative Traits

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Abstract: A field experiment was conducted at Awada Agricultural Research Sub-Center, Ethiopia, to study the magnitude of phenotypic diversity among Hararge coffee (*Coffea arabica* L.) germplasm accessions based on quantitative traits. A total of 104 entries consisting of 100 accessions from Hararge and 4 standard cultivars were evaluated using nested design. Analyses of variance showed significant differences among the accessions for all the traits considered, indicating the presence of high genetic variability among the Hararge coffee germplasm accessions. Cluster analysis grouped the entries into 6 groups of different sizes, ranging from 5 entries in cluster VI to 44 in cluster III. The maximum inter-cluster distance was obtained between clusters II and VI while the minimum was observed between clusters I and III. Clusters I and V, I and VI, II and IV, II and V, II and VI, III and VI, IV and V and V and VI were significantly divergent. The first four principal components constituted 78.5 percent of the total variation prevalent within the germplasm accessions, while 38.5 percent was represented by the first principal component. The length of the longest primary branch, stem diameter, average length of primary branches, total number of internodes per plant and total number of primary branches per plant were the five important characteristics that contributed most to the total variation in the first principal component, implying that there is high potential to improve these traits through selection. The study revealed the presence of high genetic diversity among Hararge Coffee germplasm accessions and the possibility of developing improved varieties through selection and hybridization.

Keywords: Cluster Analysis; *Coffea arabica*; Genetic Diversity; Germplasm; Hararge; Quantitative Traits

1. Introduction

Ethiopia is well-known for being the home of arabica coffee which is highly-regarded for its very fine quality, unique aroma and flavor. The coffee types that are acclaimed for having such unique characteristics include Sidamo, Yirgachefe, Hararge, Ghimbi and Limu (Workafes and Kassu, 2000). Since Ethiopia is the primary center of origin and genetic diversity for *C. Arabica,* there is high genetic variability for yield and yield components, disease and pest resistance, and other traits. This is substantiated by the fact that, within Hararge region itself, including the major coffee-producing districts such as Habro, Chercher, Wobera, Garamuleta, Harar Zuria and Gursum, which are known for the production of the best quality coffee (Bridge and Eyassu, 1968), there is high variability of yield and other characteristics. Furthermore, survey results in the past indicated the presence of considerable variations among coffee types such as Abadiro, Kubania, Shimbure, and Bunaqalla (Bayetta, 1987).

For any crop improvement program, a breeder depends on the variability present in the germplasm collections in order to advance in production, bring about stability in different biotic and abiotic stresses or changes in crop characteristics and meet breeding interest (IBPGR, 1987). In cognizant of this fact and in order to alleviate the production problems, concerted efforts were undertaken to collect coffee germplasm during 1998 from different coffee-growing areas in Hararge, eastern Ethiopia by Jimma Agricultural Reasearch Center (JARC) in Ethiopia and, as a result, more than 900 accessions were collected and maintained at the center.

Several workers have estimated the extent of genetic diversity present from the different sources of arabica coffee germplasm collections. For instance, a study by Catter (1992) on second progeny arabica coffee collections of Ethiopian origin indicated the prevalence of a high level of variability in morphological, agronomic and biochemical characteristics. The genetic diversity analysis conducted by Lashermes *et al.* (1996) by employing RAPD markers on cultivated and sub-spontaneous accessions of arabica coffee confirmed the narrow genetic base of commercial cultivars (3 typica and 3 bourbon types). On the other hand, they also reported the existence of large genetic diversity within the sub-spontaneous material, which consisted of 11 samples representing the different coffee growing areas in Ethiopia. Furthermore, they have suggested the existence of east-west differentiation in the Ethiopian coffee germplasm.

Though there are indications of genetic variations in Hararge Coffee, such as the presence of a number of vernacular names (Bayetta, 1987), no systematic study has been carried out to quantify and verify the level of genetic diversity. In addition, it is necessary to extract detailed information about the individual accessions employed in the study so that they can be used in the ongoing breeding program. This was the impetus to conduct the present study, with the objective of estimating the genetic diversity among Hararge coffee germplasm accessions for quantitative traits and of facilitating their use in breeding programs.

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2. Materials and Methods

The experiment was carried out at the Awada Agricultural Research Sub-Center, Ethiopia in the 2002 cropping season. Awada is characterized as a mid-altitude area with an altitude of 1750 meters above sea level, respective annual mean minimum and maximum rainfall of 858.1 mm and 1676.3 mm and annual mean minimum temperatures of 11.0^{0}C and maximum 28.4^{0}C. The major soil types at the research center are Eutric Nitosol and Chromotic Cambisols that are highly suitable for coffee production.

A total of 928 Hararge coffee accessions collected from 16 districts in the Eastern and Western Hararge Zones of eastern Ethiopia were planted in July 2000 for maintenance. One hundred accessions taken at random were considered for this study along with 4 coffee berry disease resistant cultivars as standard checks. A detailed description of the accessions is given in Table 1. Each of the accessions was planted in a single row of six plants using an augmented design with 29 blocks, where each block had 36 accessions including the 4 standard checks. A spacing of 1.5 m between plants and 2 m between rows was used. All field management practices were applied to all plots uniformly as recommended (JARC, 1996). Four plants were taken at random from each accession and labeled for data collection on different growth characters listed in table 2. Jima Agricultural Research Center's coffee breeding and genetics conventional methods were employed for data collection (Mesfin, 1982 and Bayetta, 2001).

Table 1. Details of germplasm accessions used in the study.

Serial No	Accession No.	Origin		Altitude range (masl)
		Zone	District	
1	21298, 22098, 22898, 23498, 27098, 26798, 27498, 25298, 28898	East Hararge	Bedeno	1500-1900
2	35198,35398,37598,36798, 45998		Dedder	1400-1550
3	15398,13998,13098,16898,14298, 17598,20098,20898,11898,16698, 17398,18498,		Girawa	1500-1900
4	1998,4298,5398,5498		Gursum	1600-1800
5	7098		Jarso	1300-1900
6	8898,9598,9198,10598,9998,8598		Kombolcha	1500-1700
7	29798,30998,31398,31698,33398		Meta	1500-2000
8	48998,47398,49698,50398,51198, 48198,54398,55098,51698,46698	West Hararge	Boke	1550-1700
9	67298,67598,69098,71398,66798,69298		Chiro	1600-1900
10	92798,98798,94298,99998,98598, 97998,94398		Darolabu	1300-1900
11	45998		Doba	-
12	81798,88798,87198,86198,88898, 88398,90398		Habro	1600-1800
13	55798,56498		Hardim	-
14	64198,64498,64098,62198,63198, 63498,58798,59398,60798,57498		Kuni	1700-1900
15	73098,74298,75678,80998,75898, 76598,77598,77898,79098		Mesela	1500-1800
16	41298,42698,40198,44498,44598, 42498,38298		Tulo	-
17	F-59	Kaffa	Bonga	1650
18	74140, 74165	Illubabor	Metu	1550-1750
19	75227	Jima	Gera	1900

Analysis of variance was computed using nested design for each quantitative character in order to see the variability among accessions for each trait. Since the experiment was treated as nested design for the purpose of analysis, hierarchical classification was used for the partitioning of the variation into different sources of variations. The ANOVA was constructed by considering the experimental units (the four coffee trees within each accession) as factor B nested within levels of factor A (the 104 coffee accessions) (Sokal and Rolf, 1969). The data on quantitative characters was standardized to a mean of zero and a variance of unity before cluster and principal component analyses were made to avoid differences in scales used to measure different traits.

Clustering was performed by average linkage method and the number of clusters was determined by examining the pseudo F statistic and the pseudo t^2 statistic using the SAS software package (SAS Institute, 2001). Genetic diversity between clusters, as standardized Mahalanobis D^2 values between clusters and principal components based on correlation matrix, were calculated using the same software employed in cluster analysis. The D^2 values obtained for pairs of clusters were considered as the calculated values of Chi-square (X^2) and were tested for significance both at 1% and 5% probability levels against the tabulated values of X^2 for 'P' degree of freedom, where P is the number of characters considered (P=14 in the present case) (Singh and Chaudhary, 1996). The important traits in each principal component that significantly contributed to the variation observed were identified as suggested by Johnson and Wichern (1988).

3. Results and Discussion

3.1. Analysis of Variance

Mean squares due to treatments were highly significant for all the 14 characters considered, suggesting the presence of high variability among the accessions (Table 2). In view of this, it may be reasonable to state that there is a good chance of improving Hararge coffee accessions through selection and breeding. The prevalence of such a high variability in an autogamous species like *C. arabica* appears to be significant. This may be attributed either to evolutionary tendencies, as the species is indigenous to Ethiopia, or to the natural mutations occurring to the population of the crop (Avice and Hamric, 1997; Hedrick, 2000).

Table 2. Mean squares from the analysis of variance for 14 quantitative traits.

Characters	Mean squares (MS)		Broad sense heritability values
	Treatments (MT)	Error (ME)	
Plant height (cm)	912.903**	178.046	50.8
Internodes length of stem (cm)	0.989**	0.297	36.9
Internode length of branch (cm)	15.478**	0.418	90.0
Number of internodes of stem	21.630**	5.855	40.3
Number of internodes on the longest primary branch	18.408**	7.986	24.6
Total number of internodes per plant	22106.285**	7492.994	32.8
Canopy diameter (cm)	696.938**	131.200	51.9
Stem diameter (cm)	0.465**	0.199	25.1
Leaf area (cm)	177.327**	46.202	41.5
Number of primary branches	87.553**	23.878	40.0
Angle of primary branches from the main stem (in degrees)	27.262**	10.252	29.3
Number of secondary branches	8375.144**	2355.480	39.0
Length of the longest primary branch (cm)	299.536**	73.424	43.5
Average length of primary branches (cm)	111.770**	34.231	36.2

*** Significant at 0.01 probability level*
MS=mean squares, MT=mean squares of treatments and ME= mean squares of error.
Note: degrees of freedom for treatments and error for all the 14 characters were the same i.e. 103 and 312, respectively.

3.2. Cluster Analysis

The 104 coffee germplasm accessions were grouped into 6 clusters (Table 3). The size of cluster varies from 5 accessions in cluster V to 44 accessions in cluster III. Clusters I, II, and IV contained accessions mainly from the Western Hararge districts whereas clusters III and V had an almost equal number of accessions from both east as well as West Hararge districts. The five accessions in cluster VI were from the two districts of West Hararge, out of which 4 originated in Kuni and only one in Chiro District. Three of the coffee berry disease (CBD) resistant cultivars (75227, 74165 and 74140) used as checks were grouped in cluster I where middle- to high-altitude accessions from Western Hararge districts was most frequent. The fourth check, F-59, was grouped in cluster II, confirming the fact that this cultivar was distinctly different from the rest of the standard checks in morphology and geographical origin. Lin and Binns (1985) and Lin *et al.* (1986) also highlighted the advantages of hierarchical cluster analysis in identifying useful germplasm, particularly by including reference cultivars.

It was evident that the accessions from the Eastern Hararge districts showed close similarity (Table 3) with regard to their clustering patterns. For instance, the germplasm accessions from Gursum, Bedeno and Dedder Districts were found to be distributed in clusters II and III. On the other hand, accessions from Kombolcha, Girawa and Meta were scattered in clusters I, II and III where the majority of their accessions were grouped in cluster III. In general, cluster III represented 58.5 per cent of the germplasm accessions from Eastern Hararge districts. Similarly, more than 65 per cent of the germplasm accessions from Darolabu, Mesela and Tulo Districts of Western Hararge were concentrated in cluster III.

Accessions from Habro and Boke Districts appeared in the same clusters i.e. clusters I, II, and III, even though the majority of their accessions appeared in the first two clusters. The germplasm accessions of Girawa, Bedeno, Kuni, Chiro, Mesela and Habro Districts were distributed in four different clusters, which suggested that the germplasm accessions from these districts were relatively more variable. In respect to the remaining districts, the accessions were distributed in 2 or 3 clusters, probably reflecting less variation among germplasm accessions within a particular district.

The overlapping of clustering patterns with regard to the germplasm accessions in the majority of the districts could be explained as lack of differentiation among districts, probably arising partly due to gene flow (Amsalu and Endashaw, 1999). In general, it may be possible to state that germplasm accessions from the Western Hararge districts were relatively more variable in their clustering patterns compared to those from the Eastern Hararge districts (Table 3). This pointed out that in future Hararge coffee germplasm exploration endeavors, due emphasis must be given to the Girawa, Bedeno, Kuni, Chiro, Mesela and Habro districts.

3.3. Distance Analysis

Based on Mahalanobis's D^2 statistics, highly significant inter-cluster distances were obtained. Cluster II showed the maximum and significant genetic distance (102.12) from cluster VI. Furthermore, the inter-cluster distances between clusters I and V, I and VI, II and IV, II and V, II and VI, III and VI, IV and V, and V and VI in that order were found to be highly significant (Table 4). These distances indicated that germplasm in the above paired clusters are significantly (p = 0.01) divergent from each other. Since the magnitude of heterosis largely depends upon the degree of genetic diversity among the parental lines, the progenies of those germplasm accessions belonging to the pairs of distant clusters could be very useful in a hybridization program for obtaining a wide spectrum of variation among the segregates. Crossing of parental lines extracted from germplasm accessions belonging to different clusters of wide Mahalanobis distance (D^2) could maximize opportunities for transgressive segregation as there is a higher probability that unrelated genotypes would contribute unique desirable alleles at different loci (Peters and Martinelli, 1989). Therefore, it may be possible to conclude that the germplasm accessions from cluster II and cluster VI could offer relatively better potential parental lines that, when intercrossed, could produce hybrids with maximum heterotic value, even though other clusters with significant genetic distances are also good sources of parental lines.

Table 3. Distribution of the 104 coffee genotypes over six clusters based on quantitative traits.

Zone	Cluster						Total accessions
	I	II	III	IV	V	VI	
East Hararge	6	6	24	2	3	-	41
West Hararge	11	13	20	7	3	5	59
*South west Ethiopia	3	1					4
Total	20	20	44	9	6	5	104

**Represented standard checks*
Note: This table was extracted from the dendrogram

Table 4. Inter-cluster distances among 104-coffee genotypes.

	Cluster I	Cluster II	Cluster III	Cluster IV	ClusterV	Cluster VI
Cluster I	-					
Cluster II	14.91634	-				
Cluster III	10.78772	16.56251	-			
Cluster IV	14.25636	47.83423**	22.36447	-		
Cluster V	38.84501**	66.12385**	18.28813	29.39752**	-	
Cluster VI	47.52314**	102.12226**	68.19061**	16.35693	59.78586**	-

*** = Significant at $p < 0.01$ ($X^2 = 29.141$)*

3.4. Principal Component Analysis

The first four principal components represented 78.5 per cent of the total variation (Table 5). Principal component 1 accounted for more than one third of the variation. The length of the longest primary branch, stem diameter, the average length of primary branches, the total number of internodes per plant and the total number of primary branches per plant were the most important factors contributing to the total variation of the first principal component. In the second principal component, the internode length of the stem, the leaf area, the total number of internodes per plant, the number of internodes on the stem, the number of primary branches per plant and the average internode length of primary branches made a significant contribution.

In light of the results obtained from principal component analysis, it may be possible to deduce that the maximum variation (38.5%) of principal component 1 was based on quantitative characters such as the length of the longest primary branch, the stem diameter, the total number of internodes per plant and the total number of primary branches per plant. This perhaps emphasizes the significance of these characteristics to the appraisal of genetic diversity.

Table 5. Eigenvalues, total variance, cumulative variance and eigenvectors for the 14 quantitative traits.

Characters	PC 1	PC 2	PC 3	PC 4
Plant height	-0.283	0.160	0.483	0.080
Inernode length of stem	-0.086	0.485	0.309	-0.077
Internode length of branch	0.027	-0.281	0.209	-0.633
Number of internodes of stem	-0.288	-0.299	0.364	0.150
Number of internodes on the longest primary branch	-0.264	-0.191	-0.399	0.133
Total number of internodes per plant	-0.343	-0.310	-0.010	0.172
Canopy diameter	-0.310	0.133	-0.160	-0.322
Stem diameter	-0.358	0.097	-0.129	0.023
Leaf area	0.039	0.462	0.143	0.006
Number of primary branches	-0.313	-0.285	0.313	0.050
Angle of primary branches from the main stem	0.083	0.077	0.070	0.626
Number of secondary branches	-0.229	0.136	-0.398	-0.006
Length of the longest primary branch	-0.365	0.213	-0.086	0.019
Average length of primary branches	-0.354	0.217	-0.064	-0.136
Eigenvalues	5.383	2.669	1.8642	1.079
%Total variance	38.50	19.10	13.30	7.70
%Cumulative variance	38.50	57.50	70.80	78.50

Note: PC1, PC2, PC3 and PC4 are the first four principal components with Eigenvalues greater than unity

Table 6. Grouping of Hararge coffee accessions into different diversity classes.

Cluster	Number of Accessions	Accessions included in the cluster
I	20	56498,55098,88398,45998,13998,59398,30998,13098,9198,74198, 74198,88798,20898,48998,46698,74298,75227,51198,5169816898
II	20	1998,54398,66798,81798,90398,10598,49698,99998,88898,11898, 64498,48198,80998,55798,57498,F-59,50395,21298,15398,8598
III	44	27098,17398,42498,35198,33398,23498,22898,42698,98798,41298, 35398,76598,9598,8898,92798,29798,87198,9998,37598,94398, 20098,71398,7098,97998,98598,22098,47398,31398,17598,25298, 26798,75898,75698,73098,5398,14298,4298,67598,5498,40198, 77598,18498,44498,79098
IV	9	86198,69298,94298,31698,64198,63198,69098,28898,62198
V	6	44598,38298,36798,77898,27498,16698
VI	5	63498,60798,58798,67298,64098

Table 7. Cluster means for the 14 quantitative traits of 104 coffee germplasm accessions.

Traits	Cluster					
	I	II	III	IV	V	VI
Plant height	128.00	122.85	129.36	151.53	128.58	147.25
Inernode length of stem	4.74	5.17	5.11	5.26	4.79	4.96
Internode length of branch	6.34	5.26	4.79	4.84	4.76	4.57
Number of internodes of stem	21.63	18.63	19.97	24.17	20.92	24.70
Number of internodes on the longest primary branch	20.85	18.14	20.57	21.61	23.54	25.25
Total number of internodes per plant	452.06	340.39	412.07	524.89	492.58	621.60
Canopy diameter	101.06	96.01	110.80	115.50	124.83	115.18
Stem diameter	3.22	3.04	3.48	3.71	3.64	3.80
Leaf area	47.78	54.02	50.80	49.25	46.98	47.30
Number of primary branches	39.01	32.86	36.48	44.19	38.89	44.40
Angle of primary branches from the main stem	63.81	63.37	64.65	63.28	63.58	64.50
Number of secondary branches	76.90	66.51	139.22	112.08	204.29	112.65
Length of the longest primary branch	77.36	71.21	82.19	88.58	85.08	89.75
Average length of primary branches	53.65	50.29	56.76	59.97	59.00	59.95

4. Conclusion

It must be acknowledged that Hararge coffee has limited geographical significance. In view of this, the germplasm accessions considered in the present study represented collections from the Eastern and Western areas of Hararge and these were appraised at pre-bearing stage only. It is however, necessary for different characteristics to be studied with additional accessions over several bearing years. Furthermore, other traits of interest and molecular techniques may be very useful in order to confirm the present encouraging result that indicated the presence of considerable variations within Hararge coffee populations and provides immense potential for the development of improved varieties from the local landraces in the area.

If further studies are undertaken, consideration of yield and pest reactions must receive due attention. To this end, the study pointed out that Western Hararge appeared to be the target area for the future intensive germplasm exploration endeavors of Hararge Coffee. In the meantime the evaluation of Hararge coffee germplasm collections for yield, quality and disease resistance must continue to provide improved cultivars for coffee growers in the region in the shortest time possible to minimize the risk of losing smallholder coffee orchards challenged by the severe competition with chat (*Catha edulis*). In fact, this program could be attached to the "Local Landrace Development Program for Arabica coffee" launched by Jimma Agricultural Research Center. The local landrace development approach is advantageous with regard to maintaining the typical quality of Hararge Coffee and may avoid adaptation problems faced by the released coffee berry disease-resistant cultivars of Southwest Ethiopian origin. Moreover, local cultivars are generally preferred by the smallholder local farmers over improved cultivars introduced from other areas.

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Combining Ability of Transitional Highland Maize Inbred Lines

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Abstract: Information on the combining ability of highland maize (Zea mays L.) germplasm is of great value for future hybrid development programs. Such a study has been poorly exploited in the highland areas of Ethiopia, due to limited research efforts in previous years. This study was conducted to determine the combining ability of highland maize inbred lines. The crosses were made from five lines and three testers using line by tester. The resulting crosses and their parents were evaluated at Kulumsa and Ambo in 2003, following recommended cultural practices. The combined analysis of variance showed that the mean squares due to genotypes were significant for all traits, except for thousand kernel weight and shelling percentage. B.T.Z.T.R.L.137-B-2-1-B X 142-1-e followed by B.T.Z.T.R.L-71-B-3-3-B X 142-1-e and B.T.Z.T.V.C-283-B-1-1-B X 144-7-b were the three top-yielding crosses. B.T.Z.T.V.C-283-B-1-1-B and B.T.Z.T.V.C-43-B-2-2-B manifested a high positive SCA effect with F-7215, implying these two lines combine well with F-7215. B.T.Z.T.R.L.137-B-2-1-B manifested negative SCA with F-7215, indicating that they could have a similar genetic background. The mean squares due to GCA of lines, testers and SCA of crosses were significant for ear height, ear length and grain yield B.T.Z.T.R.L.137-B-2-1-B and 142-1-e had high GCA for grain yield. The maximum SCA effect for grain yield was obtained from B.T.Z.T.R.L.137-B-2-1-B X 142-1-e and B.T.Z.T.R.L-71-B-3-3-B X 142-1-e. Generally, the magnitude of mean squares due to GCA of lines was higher than that of the SCA in most of the cases, indicating that additive gene actions were more important than non-additive with regard to inheritance of the traits studied.

Keywords: Combining Ability; Gene Action; Heterotic Pattern; *Zea mays*

1. Introduction

Maize is cultivated in all major agro-ecological zones in Ethiopia up to 2400 m.a.s.l. The high altitude moist areas including the highland transition and true highland, is next to mid-altitude in maize area and production. In highland areas, maize is the first crop grown and is a popular "hunger breaking crop" when it is harvested and consumed green (Twumasi *et al*., 2002). It is estimated that high altitude covers 20% of the land devoted to maize cultivation and 30% of small-scale farmers in the area depend on maize production for their livelihood. However, highland maize improvement research in Ethiopia has generally lagged behind that of other agro-ecologies. Attempts were made to develop suitable varieties for the highland areas of the country and, as a result, some parental lines and populations were developed. (Twumasi *et al*., 2002).

The development of appropriate maize varieties for highland areas would increase maize production and productivity in these areas. Such varietal development necessitates the use of effective selection methods for grain yield and other desirable traits. A suitable means to achieve this goal is the use of line-by-tester analysis, a system whereby the progeny performance can be statistically separated into components related to general combining ability (GCA) and specific combining ability (SCA) and thus elucidating the nature of gene action (Kempthorne, 1957). Combining ability analysis is one of the powerful tools in identifying the better combiners which may be hybridized to exploit heterosis and to select better crosses for direct use or further breeding work (Singh and Chaudhary, 1985).

The use of line-by-tester analysis would easily provide information about the combining ability of parents and also helps to estimate the type of gene action involved in the expression of grain yield and related traits (Zambezi, 1986). Although such genetic studies have been made in maize for other potential areas, little effort has been made to gather information for highland areas. Therefore, this study was initiated with the objective of determining the combining ability of transitional highland maize inbred lines.

2. Materials and Methods

The experiment was carried out at the Kulumsa and Ambo Research Centers during the 2003 cropping season. Geographically, Kulumsa lies at 8^{0}5'N latitude, 39^{o}10'E longitude with an altitude of 2200 m.a.s.l and is located in a tepid to cool, moist plain agro-ecological zone. The average rainfall at the research center is 830mm per annum. The mean maximum and minimum temperatures are 23.2^{o}c and 10^{o}c, respectively. The soils are luvisol/eutric nitosols with good drainage. Ambo is located at 8^{o}57'N latitude, 38^{o}7'E longitude and at an altitude of 2225 m.a.s.l. It is in a moist, tepid to cold mid-highland agroecological zone. The area receives an average annual rainfall of 850mm. The soil type of the experimental field is vertisol.

The experimental materials consisted of twenty-four genotypes which include five lines, three testers (142-1-e, 144-7-b and F-7215), fifteen test-crosses and a check

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(Table 1). The parental lines and testers were obtained from CIMMYT- Mexico, where they were developed to enrich highland germplasm as they are well-adapted to the highlands (up to 2200 m.a.s.l), mature early and are capable of surviving frost that usually comes late in the season, and screened for adaptation at Ambo. The testers' characterstic show large genetic differences between test crosses and are used to evaluate a series of lines which were parents of some of the released maize hybrids in Ethiopia and Eastern Africa.

Table 1. Designation and pedigree of lines and testers of maize.

Designation	Pedigree
L_1	B.T.Z.T.R.L-71-B-3-3-B
L_2	B.T.Z.T.V.C-283-B-1-1-B
L_3	B.T.Z.T.V.C-43-B-2-2-B
L_4	B.T.Z.T.R.L-137-B-2-1-B
L_5	B.T.Z.T.R.L-8-B-2-1-B
T_1	142-1-e (Ecuador-573)
T_2	144-7-b (Ecuador-573)
T_3	F-7215 (Kitale-Syn.II)
BH-660 (Check**)**	(F-7215 x A-7033) x 142-1-e

The test crosses were generated by a LxT mating design at Ambo in 2001/2. Since this design has an advantage over diallel procedure. To determine the performance of lines in hybrid combinations, a single diallel procedure is not practical because a large number of crosses is required for only a few lines. Therefore, for a preliminary hybrid evaluation, the breeder needs to determine the relative GCA of new lines using common testers. Moreover, the use of testers with common heteroic classes provides the best means of allocating inbred lines into different groups.

The experiment was laid out in randomised complete block design with two replications. A spacing of 75 cm between rows and 30 cm between plants was used. Thirty-four plants were grown by planting two seeds in each hill and then thinning to one seedling per hill four weeks after emergence. All other crop management practices were carried out as per the recommendations for each location. Data were collected according to days to tasseling, days to silking, days to maturity, grain yield, plant height, ear height, number of ears per plant, ear length, ear diameter, 1000 kernel weight, number of kernel rows per ear, number of kernels per row and shelling percentage. Grain yield per hectare was calculated using a shelling percentage of 80%, adjusted to 12.5% moisture.

The analysis of variance was computed, first for each location separately (data not shown), and then combined across locations using SPAR-1 and AGROBASE-99 computer software packages. The combined analysis across locations was computed for characters that showed significant difference among the genotypes at either of the locations after testing for homogeneity of error variance by using variance ratio. The environments were considered as random, while the genotypes were considered as fixed effects. Furthermore, line-by-tester analysis for combining ability was executed for traits that exhibited significant differences among crosses (Dabholkar, 1992).

The mathematical model for combining ability analysis of combined analysis is:

$Y_{ijk} = \mu + r_k + g_i + g_j + S_{ij} + l_k + (gl)_{ik} + (gl)_{jk} + (sl)_{ij} + e_{ijk}$

Where, Y_{ijk} = The value of a character measured on cross of line i by tester j in k^{th} replication

μ = Population mean

r_k = Effect of k^{th} replication

g_i = General combining ability (gca) effect of i^{th} line

g_j = General combining ability (gca) effect of the j^{th} tester

S_{ij} = Specific combining ability (sca) of i^{th} line and j^{th} tester such that S_{ij} equal to S_{ji}

l_k = Effect of l^{th} location

(gl) = GCA x location interaction effect of i^{th} line

(gl) = GCA x location interaction effect of j^{th} tester

$(Sl)_{ijk}$ = SCA x location interaction of i^{th} line and j^{th} tester

e_{ijk} = Experimental error for ijk^{th} observation

3. Results and Discussions

3.1. Analysis of Variance and Genotypic means

The combined analysis of variance showed highly significant ($P \leq 0.01$) mean squares due to genotypes for all characters studied, except for thousand kernel weight and shelling percentage. Mean squares due to parents were significant for days to maturity, ear height, ear length and the number of kernels per row, showing that the parents had differences for these traits (Table 2). The mean of testers was higher than that of lines in yield and other traits, except shelling percentage (Table 4). This revealed that lines were relatively earlier in tasselling and maturity than the testers. Significant ($P \leq 0.01$) differences were observed among crosses for ear height, ear length and grain yield, indicating varied performance of different cross combinations. L_4xT_1 followed by L_1xT_1 performed better in grain yield and most other traits. On the other hand, the difference between parents versus crosses was siginificant for all traits except days to maturity and shelling percentage (Table 2). Parental genotypes are late in tasselling and silking compared to their F_1 hybrids. Thus, crosses are more vigorous, mature earlier and produce a high yield than their parents. Generally, crosses involving L_4 as parent showed a better performance in most of the traits followed by L_3 crosses.

The interaction between genotypes and location (G x L) was highly significant ($P \leq 0.01$) for grain yield and shelling percentage, indicating that the performances of the genotypes were not consistent for these two traits. Significant interaction effects of parent x location were observed for thousand kernel weight. This revealed that the parents showed general adaptation across the locations for most of the traits considered in this study. However, a non-significant interaction effect of crosses with location (Crosses x Loc) was observed for all traits, indicating that crosses performed uniformly across locations. The parents vs. crosses component interact significantly with location for traits like ear length and 1000 kernel weight. Generally, the traits which showed significant GxL interaction had a differential genotypic response to variable environmental conditions and this resulted in change in the ranks of genotypes and limited the identification of superior genotypes for both locations. This revealed the location specificity of the genotypes tested.

3.2. Combining Ability

In the combined analysis of variance, mean squares due to GCA of lines, testers and SCA of crosses were significant for ear height, ear length and grain yield, indicating the role of additive and non-additive gene action in the inheritance of these characters (Table 2). This has breeding implications, since hybridization methods such as multiple crossing and/or reciprocal recurrent selection, which exploit both additive and non-additive gene effects simultaneously, could be useful in genetic improvement of the characters studied. However, for most of the traits, the variance ratio (∂^2GCA/∂^2SCA) was greater than unity revealing the predominace of additive gene action in the inheritance of these traits. Several studies involving the inheritance of various quantitative traits in maize have revealed the importance of additive gene actions (Stangland *et al.*, 1983, Shewangizaw, 1985; Zambezi *et al.*, 1986 and Vasal *et al.*, 1992). This showed that parents with good GCA and per se performance were used to predict the performance of crosses. Hence, these parents can be crossed to develop high-yielding composites that can be used directly or for further breeding work (Allard, 1960).

Estimates of GCA and SCA effects for various traits combined over location are presented in Table 3. For grain yield, none of the lines revealed significant GCA effect, implying that the inbred lines were not developed based on their GCA for yield. However, high positive and desirable GCA effects were revealed by L_4 and L_5 indicating the potential advantage of the lines for the development of high-yielding hybrids. For ear height, L_1 and L_3 showed GCA effects in a negative direction, implying the tendency of the lines to reduce ear height. L_4 was the poorest combiner for ear height and ear length as it showed positive and negative significant GCA effects respectively. L_3 showed a positive and highly significant GCA effect for ear length suggesting that this line was a good combiner for increasing ear length. Mandefro and Habtamu (1999) reported similar results for these traits. Estimates of the general combining ability effects of testers showed that T_3 exhibit negative and significant GCA effects while T_1 manifested positive and significant GCA effects for all traits studied. Moreover, T_2 showed a positive and significant GCA effect for ear length and grain yield. The result suggested that T_3 had a tendency to reduce ear placement and decrease ear length and grain yield while the reverse is true for other testers. Those parents in crosses which have a negative general combining effects for plant and ear height, appeared to be good general combiners in reducing the problem of lodging due to wind and other stresses. Hence, parents such as L_3, L_1 and T_3 could serve the purpose of breeding for lodging tolerance.

In this study, crosses manifested considerable variation in SCA effect for different traits. For grain yield, SCA estimates revealed that L_4xT_1 was the best specific combiner as it showed positive and significant SCA. Three other crosses, L_1xT_1, L_2xT_2 and L_2xT_3, were also good as specific combiners. Thus, these crosses could be selected for their specific combining ability to improve grain yield. Similarly, Yoseph (1998), Girma (1991) and Shewangizw (1985) reported on the significance of SCA effects and concluded that the predominance of non-additive genetic variance exists in the case of yield. Seven crosses showed a positive SCA effect while one cross, (L_3xT_3), manifested a significant SCA effect in an undesirable direction for ear length. Thus, L_2xT_3 (0.71) and L_3xT_3 (-0.76) were the best and worst specific combiners for this trait. Eight of the 15 crosses exhibited negative SCA effects out of which L_4xT_3 and L_5xT_1 showed a negative and significant SCA effect for ear height, indicating the crosses have a good specific combination for shorter ear placement (Table 3).

Heterotic combinations between inbred lines and testers for grain yield showed that all the lines except L_4, manifested positive SCA with T_3, indicating that these lines combined well with the Kitale heterotic pool, themselves belonging to the Ecuador gene pool. L_4 exhibited negative SCA with T_3 and can be assigned to the Kiatle heterotic pool (Table 3). This revealed that the testers manifested the tendency of discriminating lines into heterotic groups. Generally, most of the parents involved in the selected crosses were high x high general combiners. In such cross combinations, practising selection in advanced populations or using such lines in multiple crosses enable an improvement in grain yield potential.

Table 2. Line by tester ANOVA pooled over locations for yield and other traits of maize.

Sources of Variation	df	Mean Squares							
		DM	EH	EL	KRE	NKR	GY	TKW	SHP
Location	1	3372.3**	0.19**	6.69	9.98*	58.72	7065200.0	12159.80*	1121.0*
Replication/Loc	4	9.74	0.007	1.06	0.76	50.85	54316.6	1526.90	157.39
Genotypes	22	75.97**	0.41**	42.06**	2.14**	223..9**	23178972.2**	9891.10	276.2
Parents	7	156.61**	0.27**	32.5**	1.76	90.48**	3890830.0	1426.10	223.09
Parents vs Cross	1	13.27	6.18**	662.69**	22.18**	4254.7**	436816700.2**	16908.0**	263.20
Crosses	14	31.88	0.08**	65.43**	0.98	21.06	6832448.0**	3219.70	169.80
Lines(gca)	4	39.20	2.01**	4.75*	0.64	28.15	3320213.3**	21089.21	262.29
Testers(gca)	2	12.43	0.16*	28.52**	0.61	10.16	30284830.0*	236.28	51.58
Lines x testers(sca)	8	30.02	0.03*	1.49*	0.54	13.86	2434862.0*	2684.99	188.10
Genotype x Loc	22	27.50	0.03	1.76	0.74	13.17	17331893.9**	7661.59	1533.6**
Parents x Loc	7	17.30	0.01	1.89	1.18	14.16	1678846.0	4780.50*	482.70
Parent vs cross x loc	1	2.15	0.0008	7.64*	0.19	33.23	1306128.0	51297.0**	435.40
Crosses x Loc	14	34.40	0.02	1.33	0.56	11.23	1790866.0	5985.30	213.80
Lines x Loc	4	62.81	0.00078	2.12 **	0.12	11.60	19809920.1**	16519.1**	541.4**
Testers x Loc	2	33.10	0.0100	0.68	0.94	6.52	58086.4	2070.50	73.09
(Lines x testers) x Loc	8	20.20	0.00026	0.94	0.67	12.33	2128998.0**	1697.08	85.36
Pooled Error	132	22.98	0.018	1.51	0.65	12.98	1746192.0	1635.60	163.40

**, ** Significant at 0.05 and 0.01 prob. level., respectively, df = degree of freedom, Loc = location, DM = Days to maturity, EH= Ear height, EL = Ear length, KRE = Number of kernel rows per ear, NKR = Number of kernels per row, GY= Grain Yield, TKW = Thousand Kernel weight, SHP = Shelling percentage*

Table 3. Estimates of general and specific combining ability effects for yield and other traits across locations of maize in 2003.

Parent	General combining abilities			Specific combining abilities								
	EH	EL	GY	EH			EL			GY		
				T1	T2	T3	T1	T2	T3	T1	T2	T3
L_1	-0.10	0.19	-260.67	-0.01	0.02	-0.01	-0.22	-0.27	0.49	785.93	-1084.97*	299.05
L_2	0.00	0.27	60.86	-0.03	-0.05	0.07	-0.55	-0.15	0.71	-859.54*	454.39	405.15
L_3	-0.05	0.49**	-124.57	0.02	0.03	-0.05	0.58	0.18	-0.76*	-700.71	325.09	375.62
L_4	0.08*	-0.76**	190.41	0.11*	-0.02	-0.09*	0.58	-0.12	-0.46	957.94*	263.41	-12221.40**
L_5	0.04	-0.19	133.97	-0.09	0.02	0.08	-0.39	0.36	0.02	-183.61	42.08	141.53
T_1	0.06*	0.47**	884.23**									
T_2	0.04	0.82**	520.15*									
T_3	-0.10*	-1.29**	-1404.38**									
SE. (M)	0.02	0.16	207.98									
S.E. (F)	0.03	0.22	294.13									
SE(d)gi-gj (line)	0.18	0.73	87.21									
SE(d)gi-gj (tester)	0.15	0.61	73.56									
SE				0.04	0.04	0.04	0.32	0.32	0.32	415.96	415.96	415.96
SE (Sij-Skl)				0.25	0.25	0.25	1.05	1.05	1.05	0.82	0.82	0.82

**, ** = *, ** Significant at 0.05 and 0.01 prob. level, respectively, S.E. = Standard error, EH = Ear height, EL = Ear length, GY = Grain Yield*

Table 4. Mean of different traits of maize pooled over five locations.

Genotype	DT	DS	DM	PH	EH	EPP	ED	EL	KRE	NKR	GY	TKW	SHP
L_1	100.5	104.3	176.5	1.22	0.60	1.15	2.93	13.35	13.00	25.80	2376.67^{hij}	189.68	62.77
L_2	105.0	113.3	182.0	1.96	1.03	0.95	2.93	13.80	12.50	22.95	2026.73^{ij}	217.4	58.48
L_3	103.8	109.0	179.8	1.08	0.61	1.08	3.55	12.30	12.60	19.35	2311.37^{hij}	266.93	65.25
L_4	104.3	103.3	187.3	1.90	1.09	1.35	2.63	11.25	13.00	22.30	2517.26^{hij}	186.95	58.33
L_5	104.3	113.5	182.0	1.76	0.96	0.98	2.58	9.80	11.70	13.35	1412.84^{j}	209.10	64.55
T_1	102.3	104.5	192.3	2.08	1.29	1.10	3.05	17.50	12.30	27.45	3668.5^{fghij}	345.28	58.09
T_2	107.8	112.8	193.0	1.96	1.09	1.10	3.65	17.55	11.10	25.75	4484.69^{efghi}	337.88	59.98
T_3	106.5	112.5	191.0	2.04	1.23	0.90	3.35	15.85	11.90	27.03	3259.35^{ghij}	322.55	64.14
L_1 x T_1	99.0	99.8	187.3	2.60	1.51	1.55	4.93	20.00	14.10	36.03	8635.73^{ab}	300.53	80.24
L_1 x T_2	99.5	103.3	184.5	2.56	1.52	1.45	4.43	20.30	13.60	37.83	6400.75^{bcde}	281.38	76.42
L_1 x T_3	98.5	100.5	182.5	2.43	1.36	1.10	4.58	18.95	13.50	38.75	5860.24^{cdefg}	256.15	77.41
L_2 x T_1	102.0	107.8	187.5	2.54	1.56	1.75	4.28	19.75	12.75	37.15	7311.79^{abcd}	282.25	69.92
L_2 x T_2	100.8	107.5	183.5	2.57	1.52	1.63	4.83	20.50	13.20	41.08	8261.64^{abc}	262.88	75.56
L_2 x T_3	99.3	103.3	190.5	2.43	1.5	1.45	3.55	19.25	12.75	37.08	6287.87^{bcdef}	316.70	68.95
L_3 x T_1	99.3	100.5	186.5	2.63	1.56	1.75	5.10	21.10	13.70	35.73	7285.19^{abcd}	299.93	80.84
L_3 x T_2	101.8	105.3	190.3	2.53	1.54	1.68	5.10	21.05	13.10	33.65	7946.92^{abc}	284.70	64.11
L_3 x T_3	100.8	102.5	187.0	2.18	1.33	1.23	5.15	18.00	14.10	33.10	6072.91^{bcdef}	316.00	66.96
L_4 x T_1	99.3	101.5	183.0	2.85	1.77	1.93	4.63	9.85	13.40	37.13	9258.82^{a}	251.05	79.72
L_4 x T_2	100.5	105.3	186.3	2.64	1.62	1.75	4.00	19.50	12.70	40.60	8200.22^{abc}	314.90	78.19
L_4 x T_3	101.0	105.3	183.3	2.34	1.42	1.23	3.93	17.05	13.65	37.58	4790.92^{efgh}	264.65	87.52
L_5 x T_1	103.3	107.0	190.3	2.48	1.53	1.70	4.23	19.45	12.90	39.83	8060.83^{abc}	312.30	74.13
L_5 x T_2	100.0	103.0	188.5	2.75	1.63	1.88	3.95	20.55	12.90	37.30	7922.45^{bcdf}	284.05	66.75
L_5 x T_3	102.0	105.8	183.3	2.56	1.55	1.38	4.00	18.10	13.05	36.30	6097.36^{bcdef}	267.23	67.61
BH660	108.0	112.5	191.5	2.53	1.45	1.23	4.28	16.90	13.00	33.50	6358.87^{bcde}	250.60	60.74
Crosses	100.5	103.8	186.3	2.54	1.53	1.56	4.50	19.56	13.29	37.28	7226.24	286.31	74.29
Parents	104.3	109.1	172.9	1.75	0.99	1.08	3.08	13.93	12.26	23.00	2757.19	259.47	61.45
Lines	103.6	108.6	181.5	1.58	0.86	1.10	2.90	12.10	12.56	20.75	2128.97	214.01	61.876
Tester	105.5	109.9	158.8	2.03	1.20	1.03	3.40	16.97	11.77	26.74	3804.20	335.24	60.74
G.mean	102.3	105.9	186.2	2.28	1.34	1.39	3.98	17.57	12.94	32.36	5700.42	275.80	69.79
CV(%)	2.4	3.6	2.6	8.57	9.77	15.50	11.98	6.86	6.07	11.58	23.22	15.04	21.50
LSD(0.05)	4.9	7.8	9.7	0.39	0.26	0.43	0.96	2.43	1.58	7.54	2663.00	83.49	12.23

DT = Days to tasselling, DS = Days to silking, DM = Days to maturity, PH = Plant height, EH = Ear height, EPP= Number of ears per plant,
ED = Ear diameter, EL = Ear length, KRE = Number of kernel rows per ear, NKR = Number of kernels per row, GY= Grain Yield,
NN = Number of nodes, TKW = Thousand Kernel weight, SHP = Shelling percentage

4. Conclusions

The results of this study have demonstrated the importance of line by tester analysis in identifying parents with general and specific combining abilities that would help to develop hybrids with desirable traits for highland areas. L_4 and T_1 for grain yield, L_3 and T_2 for ear length, L_1 and T_3 for ear height had good general combining abilitiy estimates. These parents could therefore be used to improve the respective characters. Crosses such as L_4xT_1 and L_1xT_1 for grain yield and L_5xT_1 and L_4xT_3 for ear height were good in specific combining ability and can be used to develop hybrids for future use in maize breeding programs. Generally, crosses involving L_4 as the parent showed better performance in most of the traits, followed by L_3 crosses. The testers showed a tendency of allocating lines into heterotic groups. Thus, parental inbred lines can be selected from different heterotic groups so as to develop superior hybrids in most of the traits. In conclusion, parents with good GCA and *per se* performances can be crossed to develop high yielding composites that can be used directly for recommendation or further breeding work, whereas crosses with good SCA and high mean values can be promoted for further testing.

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Leaf Area Estimation Models for Ginger (*Zingibere officinale* Rosc.)

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Abstract: The study was carried out to develop leaf area estimation models for three cultivars (37/79, 38/79 and 180/73) and four accessions (29/86, 30/86, 47/86 and 52/86) of ginger. Significant variations were observed among the tested genotypes in leaf length (L), leaf width (W) and actual leaf area (ALA). Leaf area was highly correlated with L × W, followed by L + W, L and W. Regression equations developed for the aforementioned cultivars and accessions were $Y = 13.6 + 1.204X$, $Y = 4.244 + 1.349X$, $Y = 0.516 + 1.428X$, $Y = -54.627 + 2.201X$, $Y = 1.811 + 1.421X$, $Y = -2.386 + 1.489X$ and $Y = -4.614 + 1.831X$ respectively, where Y is estimated leaf area (ELA) and X is L × W, and have R^2 ranged between 0.916 and 0.942. Simple constants (K) were also derived from L × W and have the values of 1.454, 1.458, 1.396, 1.626, 1.433, 1.586 and 1.429 for the respective genotypes. On all cultivars and accessions, the correlation coefficients (r) computed between ALA and ELA [K (L × W)] were positive and significant ($p < 0.01$). Hence both the regression models and K developed are employed equally for estimating the areas of intact ginger leaves.

Keywords: Correlation; Ginger; Leaf Area; Regression

1. Introduction

Ginger (*Zingibere officinale* Rosc.) 'Zingible' is the rhizomatous slender perennial herb (30-100 cm tall), usually grown annually, and has been cultivated in tropical Asia since ancient times. It has been known in Ethiopia since the beginning of the 13th century and cultivated in wider environments than any other spices (Borget, 1993). It is popular in the daily dishes of every Ethiopian and used alone or together with other spices for flavoring a variety of foods and local drinks.

Leaf area is an index to measure the growth, development and yield of a plant (Ramkhelawan, 1992; Rajan, 2003). It is a noble parameter in agronomic and physiological studies like photosynthetic efficiency and rate of individual leaves in a crop community (Uzun and Celik, 1999; Rajan, 2003; Pinto e*t al*., 2004). Various methods have been reported for measuring the leaf area of crops. Some well-known methods include tracing an individual leaf on paper and determining the area by planimeter or by the weight of the cut paper; using sensitized photopaper, photoelectric cells, or glass sheets divided into 1 cm^2 sections; and measuring roughly by direct calculation (Planiswamy and Gomez, 1974), and photocopying and leaf printing in a dye solution (Willims and Joseph, 1970). However, most of the methods require complex and sophisticated tools, which are costly and not easily available in most developing countries. Besides, others require leaves to be removed from the plant, which reduces the photosynthetic surface area of plants, and tiresome and time-consuming tracing on square paper. Hence, exploring simple, rapid and non-destructive methods that could estimate the area of intact plant leaves with modest precision is imperative.

The use of regression models and simple constants (adjustment factors) for estimating leaf area can provide simple, quick, accurate, reliable, inexpensive and non-destructive methods to within 0.05 accuracy (Raju *et al*., 1991; Uzun and Celik, 1999). In addition to the fact that the methods can allow the replication of measurements during the growth period, it reduces variability in experiment as compared to destructive sampling (NeSmith, 1992). They are very useful in studying plant activities, which require a non-destructive method of measuring leaf area and also when the number of available plants is limited (Pinto *et al*., 2004).

The usual procedure of the methods involves measuring lengths, widths and areas of a sample of leaves and then calculating several and/or common (pooled) regression equations and/or constants to estimate areas of subsequent leaf samples (Pouono *et al*., 1990; Ramkhelawan, 1990; Yacob *et al*., 1993; Fanthaun and Anteneh, 1995; Pinto *et al*., 2004). Developing mathematical models and/or constants eliminate the need for leaf area meters and also save time as compared to cumbersome geometric reconstructions (NeSmith, 1992; Yacob *et al*., 1993; Fanthaun and Anteneh, 1995). However, such models have not yet been established for estimating the leaf area of ginger in Ethiopia and elsewhere. The present study was, therefore, undertaken with the objective of developing the best matching regression equation and constants for estimating areas of intact ginger leaf from measurements of leaf length and leaf width and to test for homogeneity of regression equations among different ginger cultivars and accessions using the best matched model.

2. Materials and Methods

Three cultivars (37/79, 38/79 and 180/73) and four accessions (29/86, 30/86, 47/86 and 52/86) of ginger grown at Tepi Agricultural Research Sub-center, Ethiopia, with a spacing of 30 cm * 15 cm on well-prepared ridge

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and in the recommended planting time (April) were selected for leaf area measurements. Samples of 90 leaves per cultivar and accession were collected from three replications (30 leaves per replication) in September 2005. The sampled leaves represented the full spectrum of measurable leaf size and did not present any damage and deformation caused by diseases, insects or other external factors.

The collected leaf samples were immediately taken to the laboratory in paper bags for measurements of length (L), width (W), and area. The length and width of each lamina was measured along the midrib, from the apex to the base of the lamina and perpendicularly to the midrib at the widest part of the leaf respectively. Actual leaf area (ALA) of each lamina was determined by tracing an individual leaf onto square paper with a dimension of 0.25 cm^2 per square and counting the number of squares covered by the leaf and multiplying it by the dimension of a square. In this case, peripheral squares with an area greater or equal to 0.125 cm^2 were considered as full squares. The collected data was then summarized and arranged for statistical analysis using randomized complete block design with three replications to investigate the variability in leaf dimension variables. To this end, the data were subjected to analysis of variance using the SAS software program (SAS Institute, 1990). Results were presented as means and compared using Duncan's New Multiple Range Test at $p < 0.05$ probability level (Mandefero, 2005).

Correlation coefficients (r) were computed between the dependent variable, ALA, and the independent variables *viz.* L, W, L + W and L × W for individual cultivars and accession separately. Leaf dimension variables strongly related to ALA, regression equation, which is represented by $Y = a + bX$, where Y = ALA; a = Intercept; b = Regression coefficient and X = regressor highly correlated with ALA (L or W or L + W or L × W), were computed separately for each cultivar and accession. The coefficient of determination (R^2), which measures the contribution of the linear function of independent leaf dimension variables to the variation in leaf area, was also worked out. Subsequently, homogeneity tests of the various regression coefficients developed for the cultivars and accessions were carried out to determine whether a single pooled regression equation was to be used to estimate the leaf area for the studied genotypes.

Likewise, intact leaf area estimation constant (K) were computed for individual cultivar and accession using the regressor strongly correlated to the ALA following the procedure adopted by Raju *et al.* (1991), Yacob *et al.* (1993) and Fanthaun and Anteneh (1995). Finally, r were computed between ALA and estimated leaf area [K (L × W)] to investigate the reliability of estimating ALA by using simple constants. All the regression equations and correlation coefficients were computed using the Microsoft Excel computer program.

3. Results and Discussion

There were significant differences among ginger cultivars and accessions in leaf lengths, leaf widths, and actual leaf area (Table 1). The mean leaf length was found to be maximum in 30/86 followed by 29/86, 180/73, 37/79, 47/86, 38/79 and 52/86. However, the mean leaf width ranged from 2.31 - 2.63 cm with the maximum in 30/86 followed by 37/79, 180/73, 29/86 and 52/86, 38/79, and 47/86. Similarly, leaf area was found to be maximum in 30/86 and minimum in 52/86. Except for accession 30/86, which consistently register the highest leaf length, width and area, no definite trend could be observed among the remaining cultivars and accessions for the parameter tested.

Table 1. Mean leaf length, width and leaf area of ginger cultivars and accessions.

Cultivar and accession	Length (cm)	Width (cm)	Area (cm^2)
Cultivar			
37/79	23.14^{b}	2.45^{b}	81.81^{bc}
38/79	22.41^{b}	2.35^{b}	75.88^{d}
180/73	23.71^{ab}	2.44^{b}	83.29^{b}
Accession			
29/86	25.20^{b}	2.40^{b}	78.62^{bcd}
30/86	25.24^{a}	2.63^{a}	96.27^{a}
47/86	22.96^{b}	2.31^{b}	77.12^{cd}
52/86	22.20^{b}	2.40^{b}	74.67^{d}
F-test	*	*	**
SE (±)	0.39	0.05	0.66
CV (%)	4.42	3.51	3.55

Means within a column followed by the same superscript (s) are not significantly different from each other at $p < 0.05$ probability level.
, Significant at $p < 0.05$ and 0.01 probability level, respectively.*

The correlation coefficients computed between ALA and L, W, L + W and L × W were significant ($p < 0.01$) in all cultivars and accessions (Table 2). However, only the relationships between leaf area and L × W consistently gave the highest r values ranging from 0.957 to 0.970, indicating the strong relationship between these variables. The present investigation corroborates the earlier works in cacao (Pouono *et al.*, 1990), sour orange (Ramkelawn, 1990), Arabica coffee (Raju *et al.*, 1991; Yacob *et al.*, 1993), black pepper (*Piper nigrum* L.) (Fantahun and Anteneh, 1996), summer squash (NeSmith, 1995), *Zinnia* spp and 'profusion cherry' (Pinto *et al.*, 2004).

The strong correlations between the ALA and L × W in the present investigation indicate the possibility of estimating leaf area by using regression analysis pertaining to L × W compared to other independent leaf dimension variables (L, W and L + W). Accordingly, the regression equations along with the coefficient of determinations (R^2) for different cultivars and accessions are summarized in Table 3. The R^2, a measure of predictive ability of the model, ranged between 0.916 to 0.942 for different cultivars and accessions, indicating that 91.6 to 94.2% of the variability in the ALA has been explained by L × W. On the other hand, homogeneity tests of regression lines developed for the studied genotypes revealed significant ($p < 0.01$) differences between them. Hence, a single pooled regression equation based on the L × W should not be used to estimate leaf area for the studied genotypes. Each cultivar and accession should have its own regression equation. Similar results have been reported for cacao (Pouono *et al.*, 1990), Arabica coffee selections (Raju *et al.*, 1991) and black pepper (*Piper nigrum* L.) (Fantahun and Anteneh, 1996).

Table 2. Correlation coefficient (r) for actual leaf area (ALA) vs leaf length (L), leaf width (W), L + W and L × W for different ginger cultivars and accessions.

Cultivar and accession	Correlation coefficient (r)*			
	ALA vs L	ALA vs W	ALA vs L + W	ALA vs L × W
Cultivar				
37/79	0.491	0.702	0.606	0.957
38/79	0.857	0.731	0.895	0.961
180/73	0.800	0.801	0.862	0.970
Accession				
29/86	0.450	0.754	0.458	0.958
30/86	0.696	0.667	0.771	0.966
47/86	0.747	0.608	0.802	0.961
52/86	0.747	0.608	0.802	0.961

All 'r' values are significant at p < 0.01 probability level.

Table 3. Regression equations and coefficient of determination (R^2) of different cultivars and accessions of ginger for estimating actual leaf area (Y).

Cultivar and accession	Regression equation	R^2
Cultivar		
37/79	$Y = 13.6 + 1.204X^b$	0.916
38/79	$Y = 4.244 + 1.349X$	0.924
180/73	$Y = 0.516 + 1.428X$	0.942
Accession		
29/86	$Y = -54.627 + 2.201X$	0.918
30/86	$Y = 1.811 + 1.421X$	0.934
47/86	$Y = -2.386 + 1.489X$	0.930
52/86	$Y = -4.6143 + 1.483X$	0.925

[b]*X is the product of L and W.*

In addition to the regression equations, simple constants (K) were computed for each cultivar and accession and are given in Table 4. The K obtained for different cultivars and accessions were 1.454, 1.458, 1.396, 1.326, 1.433, 1.486 and 1.429 for 37/79, 38/79, 180/73, 29/86, 30/86, 47/86 and 52/86 respectively. However, Raju *et al.* (1991), Yacob *et al.* (1993) and Fanthaun and Anteneh (1995) stated that accurate estimates of leaf area by constants require a strong correlation between ALA and the L × W. Likewise, a high and significant correlation evident between the ALA and L × W in all cultivars and accessions (Table 2) in this study confirms the possibility of estimating ginger leaf area accurately by using these constants. A positive and significant ($p < 0.01$) r value evident between the ALA and ELA [K (L × W)] (r = 0.925 - 0.996) (Table 4) indicate that these constants can be used for estimating areas of ginger leaves accurately. Similarly, Raju *et al.* (1991) and Yacob *et al.* (1993) developed simple constants and regression equations for leaf area estimation of Arabica coffee cultivars from L × W. The work of Fantahun and Anteneh (1996) also corroborated L × W to nearly accurately estimate leaf area of black pepper (*Piper nigrum* L.) cultivars with an appropriate constant.

In conclusion, both regression equations and simple constants involving L × W compared to other independent leaf dimension variables, *viz*. L, W and L + W, are found to be equally suitable in estimating the area of intact ginger leaves without destroying the assimilatory organs and could be used as potential indicators of the yield performance of ginger planted in macro and micro climates. However, simple constants are easier than the regression equations for estimating leaf area since the calculations involved are very simple.

Table 4. Simple constants (*K*) and correlation coefficients (r) between ALA and estimated leaf area [*K* (L × W)].

Cultivar and accession	K[c]	r[d]
Cultivar		
37/79	1.454	0.976
38/79	1.458	0.979
180/73	1.396	0.996
Accession		
29/86	1.326	0.987
30/86	1.433	0.995
47/86	1.486	0.979
52/86	1.429	0.925

[c] $K = \frac{ALA}{L \times W}$

[d] *All 'r' values are significant at $p < 0.01$ probability level.*

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Yellow Rust Resistance in Advanced Lines and Commercial Cultivars of Bread Wheat from Ethiopia

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Abstract: Bread wheat (*Triticum aestivum* L.) cultivars often succumb to yellow rust (*Puccinia striiformis* f.sp. *tritici* Westend.) soon after their release for commercial production, especially in the highlands of south-eastern Ethiopia. Variety diversification may buffer the ever evolving new races of the yellow rust pathogen. The objective of this study was to characterize seedling yellow rust resistance in 21 advanced bread wheat lines and 20 cultivars from Ethiopia. Yellow rust infection types (ITs) produced on test wheat lines and cultivars from nine yellow rust races were compared with ITs produced on standard differential lines that differed for specific yellow rust resistance genes. The experiment was conducted at seedling stage under greenhouse conditions in Goettingen, Germany during 2001. The result indicated that most of the advanced bread wheat lines possess different yellow rust resistance genes when compared to the commercial cultivars. Seedling genes *Yr1, Yr2, Yr3V, Yr4, Yr6* and *Yr17* with or without *Yr9* were postulated to be present in 11 advanced lines. However, only *Yr7* and *Yr9* were postulated to be present in five of the commercial bread wheat cultivars. The newly identified resistance sources could be of great importance for enhancing the genetic base of resistance of bread wheat to yellow rust in Ethiopia.

Keywords: Race; Resistance Gene; Virulence; Yellow or Stripe Rust

1. Introduction

Yellow or stripe rust (*Puccinia striiformis* f.sp. *tritici* Westend) is a major wheat disease in the highlands of Ethiopia. It was first reported in the early 1940s, but gained importance with the expansion of high-yielding, semi-dwarf bread wheat cultivars in the mid 1980s (Hailu, 1991). Yellow rust infects the leaf, leaf sheath and spikes of the wheat plant; it can cause yield losses of 96% depending on the susceptibility of the cultivars and environmental conditions (Eshetu, 1986).

Wheat researchers in Ethiopia have been continuously breeding for disease resistance, wide adaptability and high yield, which resulted in the release of many cultivars to farmers. However, most of these cultivars were abandoned from production due to their susceptibility mainly to yellow rust disease (Ayele and Stubbs, 1995). The main reasons for periodic outbreaks of yellow rust disease in Ethiopia are the scarce information on the genetic variation of host-pathogen interactions and unreliability of current sources of resistance to the prevailing race population (Ayele, 2002). Wheat cultivars with high levels of race-specific yellow rust resistance often select virulent races, which result in loss of resistance in these cultivars.

So far, more than 37 yellow rust resistance genes have been reported worldwide and most of these confer seedling resistances (http://www.wheat.pw.usda.gov.). However, virulence genes of the pathogen which overcome many of the seedling resistance genes had already been detected individually or in many combinations (Stubbs, 1988).

In general, research on yellow rust disease should supply wheat genotypes with combinations of effective genes for resistance to the prevailing races of the pathogen.

The gene-for-gene concept (Flor, 1971) is often applied to determine the probable identity of seedling rust resistance genes in wheat cultivars (Wellings *et al*., 1988; Ayele *et al.,* 1990). Although the sexual stage of the yellow rust fungus has not yet been identified, the race specific yellow rust resistance genes apparently are assumed to conform to the gene- for- gene system (Zadoks, 1961). The low and high ITs produced by a diverse group of yellow rust races on lines under study are compared with ITs produced by the races on yellow rust differential lines that differ for specific resistance genes. Yellow rust races that produce distinct ITs on specific yellow rust resistance genes in the differential line will also produce similar ITs to those cultivars that have the same resistance genes.

In this paper, we report on the yellow rust resistance spectra of advanced bread wheat lines and commercial cultivars from Ethiopia with regard to nine different races at seedling stage.

2. Materials and Methods

2.1. Yellow Rust Isolates

Two yellow rust isolates from Ethiopia and seven from Germany were used in this study. The isolates from Germany were obtained from Biologische Bundesanstalt für Land und Forstwirtschaft, Braunschweig while the isolates from Ethiopia had originally been collected from southeastern Ethiopia during 1998/99. A mono-pustule was prepared for each isolate and multiplied on the susceptible bread wheat cultivar, 'Morocco', and analyzed

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on the standard differential sets according to Johnson *et al*. (1972).

2.2. Differential Lines

A total of 21 yellow rust standard differential lines obtained from IPO, Wageningen, The Netherlands were used to characterize the nine yellow rust isolates (Table 1). The 'world-set' and the 'European set' each comprised eight differential lines (Stubbs, 1985). Moreover, Kema and Lange (1992) proposed incorporating *Yr15* in the differential set of cultivars through extension of the 'world set', and a similar suggestion for *Yr5* by Wellings & McIntosh (1990) was adopted here. In addition, Stubbs (1988) suggested Kalyansona (*Yr*2) and Federation *4/Kavkaz (*Yr9*) and Bariana and McIntosh (1994) proposed another differential cultivar, VPM1 (*Yr*17) to be included as supplemental differential sets for yellow rust.

Table 1. Origin of nine yellow rust races and their resistance factors, which were used to study the resistance spectra of advanced bread wheat lines and commercial cultivars.

Origin	Race code [a-]	World set											European set							Supplimental set	
		Chinese 166 –*Yr*1	Lee –*Yr7*	Heines Kolben-*Yr6*	Vilmorin 23 –*Yr*3V	Moro -*Yr*10	Strubes Dickkopf-*Yr*SD	Suwon/Omar-*Yr*SU	Clement Yr9+	*Triticum* s. *album*-*Yr*5	T.dicoccoides-G25-*Yr*15	Hybrid 46 –*Yr*4+	Reichersberg 42 – *Yr*7+	Heines Peko –*Yr*6+	Nord Desprez –Yr3N	Compair-*Yr*8	Carstens V - *Yr*CV	Spaldings Prolific- *Yr*SP	Heines VII- *Yr*2+	Kalyanson –*Yr* 2	Federation *4/KVZ-Yr9	VPM 1- *Yr*17
Ethiopia	230E158	R	S	S	R	R	S	S	S	R	R	R	S	S	S	S	R	R	S	S	S	R
Ethiopia	70E150	R	S	S	R	R	R	S	R	R	R	R	S	S	R	S	R	R	S	S	S	R
Germany	237E141	S	R	S	S	R	S	S	S	R	R	S	R	S	S	R	R	R	S	S	S	R
Germany	232E137	R	R	R	S	R	S	S	S	R	R	S	R	R	S	R	R	R	S	S	S	R
Germany	169E136	S	R	R	S	R	S	R	S	R	R	R	R	R	S	R	R	R	S	S	S	S
Germany	109E141	S	R	S	S	R	S	S	R	R	R	S	R	S	S	R	R	R	S	S	S	R
Germany	104E41	R	R	R	S	R	S	S	R	R	R	S	R	R	S	R	S	R	R	S	S	R
Germany	41E168	S	R	R	S	R	S	R	R	R	R	R	R	R	S	R	S	R	S	S	R	R
Germany	6E22	R	S	S	R	R	R	R	R	R	R	R	S	S	R	S	R	R	R	S	R	R

[a] *Nomenclature according to Johnson et al. (1972).*
[b] *S= Virulence,* R = *Avirulence on differential lines*

2.3. Wheat Genotypes

Twenty-one advanced bread wheat lines and 20 commercial cultivars were used in this study (Table 2). The advanced bread wheat lines were developed through a shuttle breeding program between the Institute of Plant Pathology and Plant Protection, Goettingen, Germany and Kulumsa Research Center, Ethiopia (Solomon, 2001). The commercial cultivars were obtained from the national bread wheat breeding program at Kulumsa. The wheat genotypes and yellow rust differential lines were simultaneously tested to nine individual yellow rust isolates. The experiment was conducted in the Institute of Plant Pathology and Plant Protection, Goettingen, Germany during 2001.

2.4. Testing Procedures

From each entry, 7-8 seeds were sown in 5cm^3 jiffy pots that contained a mixture of soil, sand, and compost at the ratio of 1:1:1 v/v/v/ in the greenhouse. Seedling tests were conducted according to Stubbs (1985). About a week old seedlings with fully expanded first leaves were sprayed with a suspension of yellow rust spores with a concentration of 10^5-10^6/ml in mineral oil (FC-40, 3M Fluorinert Electronic liquid, Saint Paul, USA) onto the leaves. The treated seedlings were incubated for 24 hours in plastic cages at *ca*. 10^{o}C and 100 % relative humidity. Thereafter, the seedlings were transferred to a growth chamber to allow symptom development. Inside the chamber, the day/night regime was 16 hrs of light (18,000 lx) and 8 hrs darkness at 16-17^{o}C, and the relative humidity was *ca*. 70%. About a week after spraying, 2 g of fertilizer ($N:P_2O_5:K_2O$=15:11:15) per 100 cc was added to each set of 24 pots, and the second leaves were cut once a week after inoculation to minimize light competition.

Table 2. The reaction of advanced bread wheat lines and commercial cultivars to nine yellow rust races at seedling stage.

No.	Lines	Pedigree	230E158	70E150	237E141	232E137	169E136	109E141	104E41	41E168	6E22
a. Advanced bread wheat lines											
1	8.2.7	Arb//295/SM/3/149/SM//150/M	R[b]	R	S	R	S	S	R	R	R
2	8.3.8 (W)	HAR 1709/3/300/SM//150/M	R	R	R	R	S	R	R	R	R
3	8.3.8 (B)	HAR 1709/3/300/SM//150/M	R	R	R	R	R	R	R	R	R
4	8.3.11	ET-13/3/149/SM//150/M	S	R	S	S	S	R	S	R	R
5	8.3.12(T)	Kon/3/149/SM//150/M	S	S	S	S	S	S	S	S	S
6	8.3.12 (S)	Kon/3/149/SM//150/M	S	S	S	S	S	R	R	S	R
7	8.3.13	HAR1709/3/149/SM//150/M	S	S	S	R	S	R	S	S	S
8	11.1.23	Ton/4/Arb//24/E/3/295/SM//149/M	R	R	S	R	S	S	R	R	R
9	11.4.16-1	HAR1709/4/Arb//295/SM/3/149/SM//150/M	S	R	S	R	R	R	R	R	R
10	11.4.16-2	HAR 1709/4/Arb//295/SM/3/149/SM//150/M	R	R	S	R	R	R	R	R	R
11	11.4.16-3	HAR 1709/4/Arb//295/SM/3/149/SM//150/M	R	R	R	R	S	R	R	R	R
12	11.5.26-1	M/4/HAR1709/3/149/SM//150/M	R	R	S	R	R	R	R	R	R
13	11.5.26-2	M/4/HAR1709/3/149/SM//150/M	S	S	S	R	R	S	R	R	R
14	11.5.26-3	M/4/HAR1709/3/149/SM//150/M	S	S	S	R	S	S	R	R	R
15	11.5.32	T1/Arb/4/Kon/3/149/SM//150/M	S	R	S	R	R	S	S	R	R
16	11.5.38-1	HAR 1709/4/ET-13/3/149/SM//150/M	S	S	S	R	S	R	S	S	R
17	11.5.38-2	HAR 1709/4/ET-13/3/149/SM//150/M	S	S	S	R	S	R	S	S	S
18	11.5.39-1	HAR 1709/4/Kon/3/149/SM//150/M	R	R	S	S	S	S	S	S	R
19	11.5.39-2	HAR 1709/4/Kon/3/149/SM//150/M	R	R	S	S	S	S	S	S	R
20	11.6.21	M/4/ET13/3/EY2//2/E	R	R	S	S	S	S	S	S	R
21	11.6.24	M/4/HAR 1709/3/M//24/E	R	R	R	R	S	R	R	R	R
b. Commercial cultivars											
1	HAR1899	Cook/Vee/Dov/Seri/3/Bjy/Coc	S	S	S	S	R	S	S	S	R
2	HAR1407	Cook/Vee/Dov/Seri	S	R	R	R	R	R	R	R	R
3	HAR416	BOW #28	S	R	R	R	R	R	R	R	R
4	HAR1775	ARO Sel 60/89	S	S	S	S	S	S	S	R	R
5	HAR1522	BOW'S / BUC'S	S	S	R	S	R	R	S	S	R
6	HAR1595	F371/TRM//BUC'S'/3/LIRA'S'	S	R	R	S	R	R	S	R	R
7	HAR1868	Gov Az//Mus's'/3/R37/Ghl/2/...	S	R	S	R	R	R	R	R	R
8	HAR710	MRL'S'/BUC'S'	S	R	R	R	R	R	R	S	R
9	HAR1685	Attila 'S'	S	R	S	S	R	R	R	R	S
10	HAR604	4777(2)//FKN/GB/3/PVN'S'	S	R	S	R	R	S	R	R	S
11	HAR1709	BOW 28 X ROMANY B.C.	S	R	R	S	S	S	S	S	R
12	BATU	SUN BIRD 4	S	R	R	R	R	R	R	R	R
13	DASHEN	VEE #17	S	R	R	R	R	R	R	R	R
14	GARA	BOW'S'	S	R	R	R	R	R	R	R	R
15	HAR407	VEE #15	S	S	S	S	S	R	S	R	R
16	K6295-4A	ROMANYX GB-GAMENYA	S	S	S	S	S	S	S	S	S
17	ET13 A2	UQ105 Sel. X ENKOY)	S	S	S	S	S	S	S	S	S
18	DERESEL.	CI81541//2*FR	S	S	S	S	S	S	S	S	S
19	K6290-B	AF.MAYOXGEM) XROMANY	S	S	S	S	S	S	S	S	S
20	ENKOY	Heb. Sel./WIS245xSUP51 x (FR-FN/Y)	S	S	R	R	S	S	S	S	R

Note: In Table 2, R and S denote resistant and susceptible reactions, respectively.

2.5. Disease Assessment and Data Analyses

Yellow rust assessment was made 16-17 days after spraying using a 0-9 disease-scoring scale (McNeal *et al.*, 1971). Infection types 0-6 were classified as low or resistant while 7-9 scores were considered as high or susceptible infection types (Stubbs, 1985). A race number (code) was given to each isolate according to Johnson *et al.* (1972) which was based on their reaction on the 'world' sets and 'European sets' of yellow rust differential lines.

A matching technique based on the gene–for-gene concept was applied to characterize seedling yellow rust resistance genes in advanced bread wheat lines and commercial cultivars (Browder, 1971; Wellings *et al.*, 1988). The reaction of each test genotype was compared with the reaction of the differential lines to nine individual races. Wheat genotypes which exhibited similar reaction patterns with that of specific differential lines to a range of isolates were being postulated to possess the same resistance gene(s).

3. Results and Discussion

The yellow rust races had combined virulence/avirulence formula to yellow rust resistance genes (*Yrs*); namely, 1, 2, 2^+, 3V, 3N, 4^+, 6, 6^+, 7, 7^+, 8, 9, 9^+, 17, SD, SU/5, 10, 15, CV and SP (Table 1). Virulent races to *Yr*5, *Yr1*5, *Yr*CV and *Yr*SP are not common in East Africa or Europe (Danial and Stubbs, 1992; Bayles and Stigwood, 2001). However, virulence for *Yr*10 had been reported from samples collected in central and northwestern part of Ethiopia (Ayele and Stubbs, 1995). So far, virulent races on *Yrs., 2,* 2^+*, 3N, 6,* 6^+*, 7,* 7^+*, 8, 9,* 9^+*, 10, SU, SD* have been detected singly or in many combinations in Ethiopia (Ayele, 2002). The races used in this study exhibited broad virulence patterns that represent the common virulences reported so far from Ethiopia.

The reaction of advanced bread wheat lines and commercial cultivars to nine yellow rust races is shown in Table 2. Almost all the advanced bread wheat lines exhibited different resistance spectra when compared with that of commercial cultivars. Eleven of the advanced bread wheat lines were resistant to races 230E158 from Ethiopia whereas all the commercial cultivars exhibited susceptible ITs. The aforementioned race was detected in Arsi and Bale during 1998 and overcame the resistance of most of the bread wheat cultivars including, 'Kubsa' (Ayele, 2002). Out of 41 tested entries only 8.3.8 (B) exhibited resistance while four bread wheat cultivars (K6295-4A, ET13, 'Dereselign' and K6290-B) showed susceptible ITs to all nine races employed in this study. However, with the exception 'Derselign', the rest often show low terminal severity when compared to other susceptible cultivars at adult plant growth stage (Ayele, 2002). The bread wheat cultivars HAR1685 ('Kubsa') and HAR604 ('Galama') were susceptible to race 6E22. This race was avirulent on Federation*4/Kavkaz (*Yr*9) and Clement (*Yr*9^+) which indicated that the aforementioned resistance gene may be absent in the two widely grown bread wheat cultivars.

The yellow rust resistance genes were postulated in some of advanced bread wheat lines and commercial cultivars (Table 3). Two of the advanced lines 11.5.39-2 and 11.6.21 were susceptible to 237E141, 232E137, 169E136, 109E141, 104E141 and 41E168 but resistant to the rest. The six races showed virulence for Vilmorin-23 which might indicate the presence of *Yr*3V in the above two genotypes. In East Africa, virulent races for *Yr1* and *Yr3V* have rarely been reported (Stubbs, 1988; Danial and Stubbs, 1992).

Three genotypes 8.3.8 (W), 11.4.16-3 and 11.6.24 were resistant to eight races but susceptible to one (169E136). This race was different from the others because of its combined virulence on the differential line VPM1 (*Yr17*). Thus, resistance gene *Yr*17 was proposed in the three bread wheat genotypes. Two other genotypes 11.4.16-2 and 11.5.26-2 were susceptible to races 237E141 and 232E137 while exhibited resistance to the rest. Therefore, *Yr*4^+ (Hybrid 46) and *Yr*9^+ (Clement) were postulated in the aforementioned genotypes. Virulence for *Yr9* has commonly been reported but the two resistance genes *Yr*4^+ and *Yr17* are effective with regard to the prevailing races in East Africa (Danial and Stubbs, 1992; Ayele and Stubbs, 1995). *Yr*9 was first introduced into bread wheat from Rye through 1B/1R translocations (Zeller, 1973) and is common in CIMMYT-originated bread wheat cultivars (van Ginkel and Rajaram, 1993). However, virulence for *Yr17* was detected recently in Europe (Bayles and Stigwood, 2001). The resistance gene was formerly introduced from *Triticum ventricosa* to bread wheat (Bariana and McIntosh, 1994).

The bread wheat genotype 11.5.26-2 was susceptible to 230E158, 70E150, 237E141 and 109E141 but it was resistant to the other five races. The above four races had common virulences for H. Kolben (*Yr*6), H. Peko (*Yr*6^+) and H.VII (*Yr*2^+) which might indicate the presence of *Yr*6^+ and *Yr*2^+ in 11.5.26-2. Another bread wheat genotype 11.4.16-1 was susceptible to 237E141 and 230E158. These races had common virulences for Clement (*Yr*9^+), H. Kolben *(Yr6)* and H. Peko (*Yr*6^+). Therefore, *Yr*9^+ and *Yr*6^+ combinations were proposed in 11.4.16-1.

Two bread wheat genotypes 8.2.7 and 11.2.23 showed susceptible reaction to 237E141, 169E136 and 109E141 but exhibited resistance to the rest. The three races had common virulences for Federation*4/KVZ (*Yr*9) and chinese166 (*Yr*1). Thus, *Yr9* and *Yr1* genes were postulated in the two genotypes.

Five commercial bread wheat cultivars, HAR416, TUSIE (HAR 1407), BATU, DASHEN and GARA, exhibited similar resistance spectra. They showed low infection types to all eight races but were susceptible to 230E158. The eight races lack combined virulences for *Yr*9^+ (Clement) and *Yr*7^+ (Reichersberg 42). Therefore, the above resistance genes might confer yellow rust resistance in the five bread wheat cultivars.

In general, it is not advisable to release bread wheat genotypes with *Yr*9^+*, Yr*7^+*, Yr*6^+*, and Yr*2^+unless they possess additional resistance genes conferring adult plant resistance. Some of the advanced bread wheat lines and commercial cultivars, which showed susceptible reaction at seedling stage exhibited low terminal yellow rust severities under field conditions in Ethiopia (Ayele, 2002). Such type of resistance, which slows disease development, has often been reported in the yellow rust-wheat system (Ma and Singh, 1996).

Table 3. Postulated yellow rust resistance genes in 11 bread wheat lines and five commercial cultivars after inoculation with nine races at seedling stage.

Differential lines	*Yr* gene	Yellow rust races									
		230E158	70E150	237E141	232E137	169E136	109E141	104E41	41E168	6E22	
Chinese 166	1	◦	◦	**S**	◦	**S**	**S**	◦	**S**	◦	
Kalyansona	2	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	◦	
Heines VII	2+	**S**	**S**	**S**	**S**	**S**	**S**	◦	**S**	◦	
Vilmorin 23	3V	◦	◦	**S**	**S**	**S**	**S**	**S**	**S**	◦	
Nord Desprez	3N	**S**	◦	**S**	**S**	**S**	**S**	**S**	**S**	◦	
Hybrid 46	4+	◦	◦	**S**	**S**	◦	**S**	**S**	◦	◦	
Triticum spelta var. *album*	5	◦	◦	◦	◦	◦	◦	◦	◦	◦	
Heines Kolben	6	**S**	**S**	**S**	◦	◦	**S**	**S**	◦	**S**	
Heines Peko	6+	**S**	**S**	**S**	◦	◦	**S**	◦	◦	**S**	
Lee	7	**S**	**S**	◦	◦	◦	◦	◦	◦	**S**	
Reichersberg 42	7+	**S**	**S**	◦	◦	◦	◦	◦	◦	**S**	
Compair	8	**S**	**S**	◦	◦	◦	◦	◦	◦	**S**	
Fed *4/KVZ	9	**S**	◦	**S**	**S**	**S**	**S**	◦	◦	◦	
Clement	9+	**S**	◦	**S**	**S**	**S**	◦	◦	◦	◦	
Moro	10	◦	◦	◦	◦	◦	◦	◦	◦	◦	
T.turgidum ssp.*dicoccoides* G25	15	◦	◦	◦	◦	◦	◦	◦	◦	◦	
VPM1	17	◦	◦	◦	◦	**S**	◦	◦	◦	◦	
Suwon/ Omar	SU	**S**	**S**	**S**	**S**	◦	**S**	**S**	◦	◦	
Strubes Dickkopf	SD	**S**	◦	**S**	**S**	**S**	**S**	**S**	**S**	◦	
Carstens V	CV	◦	◦	◦	◦	◦	◦	◦	**S**	◦	
Spaldings Prolific	SP	◦	◦	◦	◦	◦	◦	◦	◦	◦	
Test genotypes [a]		Infection types									Postulated gene
11.5.39-1		◦	◦	**S**	**S**	**S**	**S**	**S**	**S**	◦	3V
11.6.21		◦	◦	**S**	**S**	**S**	**S**	**S**	**S**	◦	3V
8.3.8 (W)		◦	◦	◦	◦	**S**	◦	◦	◦	◦	17
11.6.24		◦	◦	◦	◦	**S**	◦	◦	◦	◦	17
11.4.16-3		◦	◦	◦	◦	**S**	◦	◦	◦	◦	17
11.5.26-3		**S**	**S**	**S**	◦	◦	**S**	◦	◦	◦	6+,2
8.2.7		◦	◦	**S**	◦	**S**	**S**	◦	◦	◦	9,1
11.1.23		◦	◦	**S**	◦	**S**	**S**	◦	◦	◦	9,1
11.4.16-1		**S**	◦	**S**	◦	◦	◦	◦	◦	◦	9+,6+
11.4.16-2		◦	◦	**S**	**S**	◦	◦	◦	◦	◦	9+,4+
11.5.26-2		◦	◦	**S**	**S**	◦	◦	◦	◦	◦	9+,4+
HAR416		**S**	◦	◦	◦	◦	◦	◦	◦	◦	9+, 7+
TUSIE		**S**	◦	◦	◦	◦	◦	◦	◦	◦	9+, 7+
BATU		**S**	◦	◦	◦	◦	◦	◦	◦	◦	9+, 7+
DASHEN		**S**	◦	◦	◦	◦	◦	◦	◦	◦	9+, 7+
GARA		**S**	◦	◦	◦	◦	◦	◦	◦	◦	9+, 7+

Note: in Table 3, ◦ and S denote Resistance (R) and Susceptible (S) infection types, respectively.
[a] Source: Solomon (2001)

Breeding for disease resistance requires a comprehensive knowledge of the physiologic specialization of pathogens and the main resistance genes deployed in host genotypes before their advancement and release to the end users. The four yellow rust resistance genes *Yr1*, *Yr*3V, *Yr4*+ *and Yr17* identified in the nine bread wheat genotypes were different from the ones in commercial wheat cultivars from Ethiopia. Out of the advanced bread wheat genotypes, 8.3.8 (B) and 11.6.24 were released to farmers in Ethiopia, with names KBG-01 and Meraro, during 2001 and 2005 respectively. The former was resistant to the nine races and, based on F_2 segregation ratio, two complementary recessive genes were postulated (data not presented).

This study revealed that most of the advanced bread wheat lines contained different resistance spectra when compared to the commercial cultivars which appeared to lack genetic variability for resistance to the current virulent yellow rust race from Ethiopia at seedling stage. To cope with the build up of virulences, the genetic bases of resistance to yellow rust should be broadened and diversified. The advanced bread wheat lines have been identified as important sources of resistance to the prevailing races of yellow rust in Ethiopia.

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The Effect of Tillage Frequency and Weed Control on Yield of Tef (*Eragrostis tef*) in Yielmana-Densa Area, Northwestern Ethiopia

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Abstract: Tef is the major crop and has the highest share of grain production in Ethiopia. However, its productivity is limited to 896 kg/ha. An experiment was conducted on nitosols in the Yielmana-Densa area of northwestern Ethiopia in the main cropping seasons of 2002-2004. The objective of the experiment was to determine the optimum tillage frequency, time and weeding frequency for tef production in the Yielmana Densa area. The experiment was designed in a factorial split plot using tillage as a main plot and weeding as sub plot. The tillage consisted of four frequencies (seven plows, five plows, three plows and one plow + roundup) and the weeding consisted of four levels (no weeding, weeding once at tillering, weeding once at stem elongation and weeding twice at tillering and stem elongation stages of the crop). Grain yield increased linearly as tillage frequency increased. Twice weeding increased yield by 39% over un-weeded. The highest grain yield was obtained when seven times plow was combined with weeding twice which resulted in an increase of yield by 96% over the lowest yield treatment (one plow + roundup + un-weeded). However, three times plowing combined with hand weeding at tillering was found to be an economical practice with the highest marginal rate of return and net benefit. It is, therefore, recommended to small-scale farmers around Yielmana Densa as a way of promoting sustainable crop production with fewer unfavorable effects on the environment.

Keywords: Nitosols; Tef; Tillage; Weed

1. Introduction

Tef is the major staple cereal crop of Ethiopia and highly adapted to diverse agro-ecological zones, including conditions marginal to the production of most of the other crops (Hailu and Seyfu, 2001). Seyfu (1991) stated that Ethiopian farmers prefer to grow tef because of its multiple advantages, such as high market value, reduced post-harvest management cost, low risk crop and the straw provides better animal feed than other cereals. In the Amhara region tef contributes the highest share (21%) of grain production compared to other crops. However, its productivity is limited to 896 kg/ha (CSA, 2002). Because of the morphological nature of the crop, especially its short and delicate stem, small leaves and shallow fibrous root system, tef offers lower resistance to weeds. About 48 to 49 % yield loss of tef had been reported due to weed competition in western Amhara (Rezene and Zerihun, 2001). Farmers around Adet mostly practise twice hand weeding for tef from 30 to 60 days after planting. Most surveys reported that hand weeding in tef remains one of the most expensive, time- and energy consuming practice under all growing conditions (Rezene and Zerihun, 2001). Seyfu (1997) reported that the small size of tef seed poses a problem during sowing and, indirectly, during weeding as farmers find it difficult to use mechanical weeding implements and are forced to either hand weed or use chemical herbicides.

Most of the farmers in northwestern Ethiopia practice fine tef seedbed preparation with an average seven times oxen plow (Aleligne, 1988). The reason for fine seedbed preparation is to create a weed-free environment and good crop germination. However, traditional tillage (excessive tillage) had an unfavorable effect on the environment due to accelerated soil erosion (Reddy, 2000) and also increased cost of production.

An experiment conducted at Debre Zeit Research Center, Ethiopia indicated that hand weeding once at early tillering or twice at early tillering and stem elongation stage depending on the degree of weed infestation of the crop was profitable (Seyfu, 1993). However, no single weed control method gives satisfactory results and, therefore, an experiment consisting of tillage frequency, time and frequency of hand weeding was conducted in the Yilmana Densa area to determine optimum tillage frequency, time and frequency of weeding for tef production in the locality.

2. Materials and Methods

The experiment was carried out on nitosol in representative farmers' fields in the Yilmana-Densa Adet area of northwestern Ethiopia in the main cropping seasons from 2002 to 2004. Adet is located at $11^0$17'N and $37^0$43'E, with an altitude of 2240 m above sea level (a.s.l.) The dominant soil type is nitosol, exhibiting clay, sand and silt contents of approximately 70, 10 and 20% respectively. Based on climatic data recorded at the Adet site over the past 8 years (1997-2004), mean monthly maximum and minimum temperatures were 26.0 and 9.6^0C respectively. The mean maximum temperature ranged from 22.4^0C in August to 29.4^0C in March while the mean minimum temperature ranged from 5.5^0C in January to 12.2^0C in August. The rainfall pattern of the area is essentially unimodal. The rainy period extends from May to October with a peak during July. Total annual precipitation is 1161 mm with 1067 mm falling during the May–October growing season.

The experiment was conducted in a total of four sites (1 site in 2002, 2 sites in 2003 and 1 site in 2004). It was designed in a factorial split plot using tillage as a main plot and weeding as a sub-plot with three replications. The tillage consisted of four frequencies (seven plows,

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five plows, three plows and one plow + roundup) and weeding consisted of four levels (no weeding, weeding once at tillering stage, weeding once at stem elongation and weeding twice at the tillering and stem elongation stages of the crop). The variety DZ-01-196 was used at seed rate of 30 kg ha^{-1}. The gross and net plot size were 6m x 3m (18 m^2) and 5m x 2m (10 m^2), respectively. The first plowing, for all plots except the untilled plot, was done immediately after the harvest of the precursor crop. The herbicide, roundup, was sprayed once at a rate of 3 l/ha on the untilled plot at about 10 days before the planting of tef. The first weeding, at the tillering stage of the crop, was done about one month after planting and the second weeding at stem elongation was done about one month after the first weeding. Weed count is taken twice; firstly for untilled plots at the time of the roundup spray and, secondly, for all plots at the tillering stage of the crop using a quadrant size of 50 cm X 50 cm at two randomly-selected spots in each plot. Plant height of five randomly-selected plants in each plot was measured and the average plant height was calculated. The straw yield was calculated by subtracting the grain yield from the total crop dry biomass of the net plot. The data collected was subjected to analysis of variance using MSTATC Statistical software. The mean grain yield data was adjusted 10% lower and subjected to partial budget and sensitivity analysis (CIMMYT, 1988). The labor data for tillage and weeding and the herbicide cost were considered as variable costs for economic analysis. An average market price of tef grain during the experimental periods 2003 and 2004 of the three months (Dec. to Feb.) was used.

Total costs that varied for each treatment were calculated and treatments were ranked in order of ascending total variable cost (TVC). Dominance analysis was used to eliminate those treatments costing more but producing a lower net benefit than the next lowest cost treatment. The marginal rate of return (MRR) was calculated for each non-dominated treatment. Sensitivity analysis was made through the assumption that variable costs and tef grain prices increased and decreased, respectively by 20 % (Table 1).

Table 1. The mean cost of inputs and price of tef grain during the experimental years in Adet area.

Cost/Price of input/output	Current situation	Sensitivity analysis
Cost of weeding (Birr/man days)	5.00	6.00
Cost of plowing (Birr/ha)	80.00	96.00
Cost of herbicide (Birr/l).	60.00	72.00
Price of tef grain (Birr/kg)	2.29	2.09

3. Results and Discussion

Generally, low weed infestation was recorded during the experimental periods. Weeds emerged late and weed infestation at the time of herbicide spraying of the untilled plot was not as expected. However, the herbicide (roundup) totally destroyed the emerging weeds on that particular plot. Sixteen weed species were recorded on the untilled plot with a total number ranging from 926 to 1962/m^2, depending on the experimental sites. *Cyperus esculentus, Commelina subulata and Setaria pumila* were the major weeds on the untilled plots at the time of pre-sowing. The late emergence of weeds was due to inadequate precipitation in April and May of the experimental years compared to the previous years (Figure 1). Generally, the average annual precipitation during the experimental years was 1001.2 mm which is less than the previous 5 years' average annual precipitation of 1257.28 mm. The low annual precipitation during the experimental years contributed to low weed infestation during the crop growing season. Twenty one weed species were recorded at the tillering stage of the crop with total weed population ranging from 685 for seven plows treatment to 802/m^2 for one plow plus roundup treatment (Table 2). This suggests that frequent tillage decreased the weed population during the crop growing season through enhancing weed emergence at the time of pre-sowing and thereby reducing the weed seed bank in the soil. This is in line with the findings of Yeshanew *et al.* (1996). The increase in weed species from 16 at pre-sowing on the untilled plot to 21 at the tillering stage of the crop is due to the fact that tillage led to a higher number of weed species emerging than the no-tillage system.

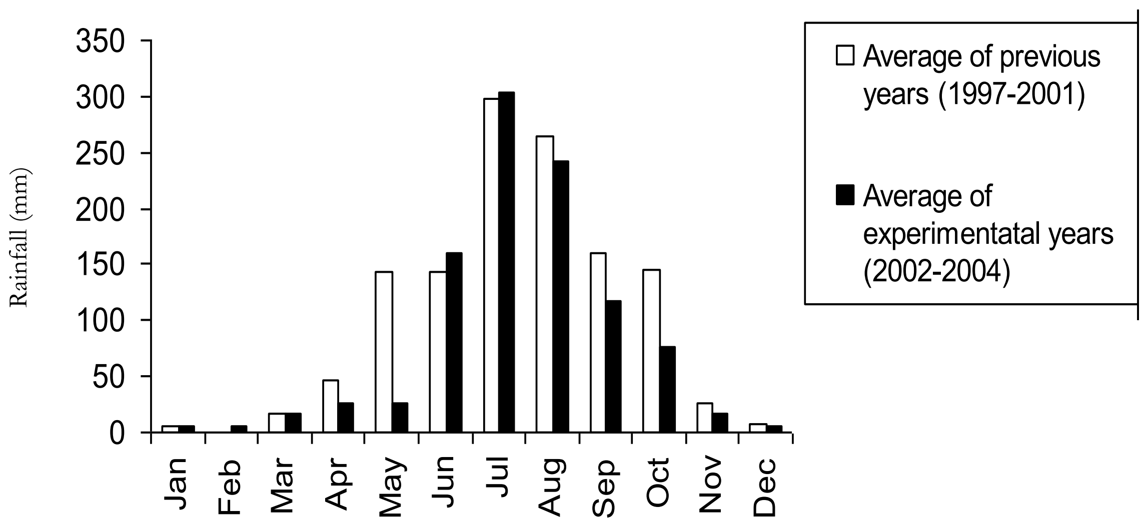

Figure 1. Monthly mean rainfall of the experimental years in relation to the previous years at Adet Agricultural Research Center

Table 2. Counting of some major weed species (number/m^2) at the tillering stage of tef on the nitosol of Yilmana-Densa, northwestern Ethiopia.

Weed species	Plowing frequency				
	P_7	P_5	P_3	P_1 + R	Mean
Corrigiola capensis	164	191	186	252	198
Polygonum nepalence	198	181	171	222	193
Commelina sabulata	69	68	66	79	71
Cyperus esculentus	58	68	84	31	60
Setaria pumila	50	56	65	31	51
Erucastrum arabicum	21	33	29	32	29
Guizotia scabra	23	16	15	22	19
Other minor weeds	102	119	104	133	115
Total	685	732	720	802	

P_7 = Seven plows, P_5 = Five plows, P_3 = Three plows, P_1 = One plow, R = *roundup*

Plant height and straw yield showed non significant responses to plowing frequency in almost all sites except site 3 for plant height and site 1 for straw yield (Table3). Grain yield response to plowing frequency was significant in site 1 and site 4. All crop parameters showed significant responses to weeding and weeding by plowing frequency interaction in all the sites. The coefficient of variability of sub-plot and main plot varied between sites.

The combined analysis of plant height, grain and straw yield over sites (Table 4) indicated non-significant differences for sites by plowing frequency for all crop parameters. On the other hand, site-by-weeding interactions revealed significant differences in all of the crop parameters, showing variations in weed infestations among the sites. Grain and straw yield showed significant responses to plowing, weeding and their interactions whereas plant height showed significant responses only to weeding.

Table 3. Analysis of variance for individual sites on plant height, grain and straw yield of tef on nitosols in Yilmana-Densa, northwestern Ethiopia.

Source	Site 1			Site 2			Site 3			Site 4		
	Plant height (cm)	Grain yield (kg/ha)	Straw yield (kg/ha)	Plant height (cm)	Grain yield (kg/ha)	Straw yield (kg/ha)	Plant height (cm)	Grain yield (kg/ha)	Straw yield (kg/ha)	Plant height (cm)	Grain yield (kg/ha)	Straw yield (kg/ha)
Plowing (P)	NS	*	*	NS	NS	NS	*	NS	NS	NS	*	NS
Weeding (W)	*	**	*	**	**	**	**	**	**	**	**	**
PxW	**	**	**	**	**	**	**	**	**	*	**	**
CV% (main plot)	7.87	14.76	19.15	6.30	18.84	22.63	5.49	28.94	19.49	4.02	16.42	26.87
CV% (sub plot)	3.59	5.47	11.00	4.92	11.18	16.13	4.39	17.07	11.81	5.34	11.23	11.46

**, ** Significant at 5 and 1% level of Probability, respectively*
NS = Non-significant

Table 4. Combined analysis over sites on plant height, grain and straw yield of tef on nitosols in Yilmana-Densa, northwestern Ethiopia.

Source of variation	Plant height (cm)	Grain yield (kg/ha)	Straw yield (kg/ha)
Plowing (P)	NS	**	**
PxS	NS	NS	NS
Weeding (W)	*	**	**
WxS	**	**	**
PxW	NS	**	*

**, ** Significant at 5 and 1% level of probability, respectively*
NS = Non-significant
S = Site

The highest plant height was recorded in the plot of highest plowing frequency combined with un-weeded treatment (Table 5). This may be due to the fast vertical growth of the crop enabling it to successfully compete with weeds for light.

The highest and lowest grain yield of tef was obtained on the plots of highest and lowest plowing frequency respectively (Table 5). There was a linear increase in grain yield as plowing frequency increased which may be due to the increased competitive capacity of the crop with decreased weed population. Previous research results in different tef-growing areas of the country also indicated increased tef grain yield as plowing frequency increased (Fufa *et al*, 2001).A grain yield increase of 23 % was recorded in the seven times plow over the one plow + roundup spray. In the case of weeding, the highest grain yield was obtained in plots with hand weeding twice at tillering and stem elongation and the lowest was in un-weeded plots. Yield increase by 39 % was recorded in plots weeded twice over un-weeded. Generally the highest grain yield (1771 kg/ha) was obtained when seven times plow was combined with hand weeding twice at tillering and stem elongation. A yield increase of 96 % was achieved over the lowest yield treatment (one plow + roundup + un-weeded).

Similarly, straw yield linearly increased as plowing frequency increased (Table 5). A sraw yield increase of 19 % was recorded in the seven times plow over the one plow + roundup spray. Unlike grain yield, the highest straw yield (4723 kg/ha) was obtained when seven times plow was combined with un-weeded treatment. The highest straw yield in the un-weeded treatment compared to weeded treatments may be due to the inseparable mixtures of some weed plants with the total crop biomass at the time of harvesting.

An economic analysis on grain yield for the single factor effect is presented in Table 6. Seven times plow gave the highest net benefit (NB) compared to the other plowing frequencies. However, the marginal rate of return (MRR) for seven times plow was below the acceptable level. Weeding once at tillering gave the highest NB compared to the other weeding levels. Weeding at tillering had an acceptable level of MRR, both according to the current situation and sensitivity analysis. However, the economic analysis on grain yield for the interaction effect (Table 7) showed better NB and MRR than the single factor effect. The highest NB was obtained when five times plow was combined with hand weeding at the tillering stage but the MRR was below the acceptable level. Since frequent plowing aggravates soil erosion (Reddy, 2000), low plow frequency with the highest MRR is advisable. Three times plow combined with hand weeding at tillering exhibited the highest MRR (343 %) and NB (birr 2470 ha^{-1}). The sensitivity analysis even in the worst economic situation is in line with the results of the current situation (Table 7). Previous research results did not show the necessity of plowing more than three times (Fufa *et al*, 2001).

4. Conclusion

Three times oxen plow combined with hand weeding at tillering was found to be the best choice to be recommended to small-scale farmers for tef production and also to promote sustainable crop production with fewer unfavorable effects on the environment. The plowing frequency should be performed in such a way that the first plow takes place immediately after the precursor crop has been harvested, the second plow takes place in June about a week before planting and the third plow takes place at the time of planting.

In seasons of high annual precipitation, a second weeding at stem elongation may be necessary depending on the intensity of weed infestation. Further research on tillage frequency in reference to vertisols and precursor crops is to be carried out in Yielmana Densa area.

Table 5. Plant height, grain yield and straw yield of tef as affected by tillage frequency and weeding on nitosols in Yilmana Densa, northwestern Ethiopia.

Plowing frequency	Plant height (cm)					Grain yield (kg/ha)					Straw yield (kg/ha)				
	W_0	W_t	W_S	$W_t + W_S$	Mean	W_0	W_t	W_S	$W_t + W_S$	Mean	W_0	W_t	W_S	$W_t + W_S$	Mean
P_7	98.2	96.8	90.0	95.6	95.1	1394	1609	1475	1771	1562	4723	4583	3658	4279	4311
P_5	95.8	96.2	84.1	92.2	92.1	1226	1589	1269	1575	1415	4074	4445	2997	3850	3841
P_3	96.4	94.3	87.9	93.2	92.9	1120	1441	1257	1557	1344	3880	4026	3110	3776	3698
P_1 + roundup	97.1	96.5	89.2	93.5	94.1	904	1439	1216	1528	1272	3513	4336	2917	3706	3618
Mean	96.8	95.9	87.8	93.6		1161	1519	1304	1608		4047	4348	3171	3903	
		P	W	PxW			P	W	PxW			P	W	PxW	
CV%		6.14	4.59	4.59			18.89	10.40	10.40			21.85	12.70	12.70	
$LSD_{5\%}$		NS	2.4	NS			111	59	118			356	199	398	

P_7 = Seven plows, P_5 = Five plows, P_3 = Three plows, P_1 = One plow, R = *roundup*
W_0 = Unweeded, W_t = Weeding at tillering, W_S = Weeding at stem elongation

Table 6. Economic analyses of plowing frequency and weeding on tef grain yield on nitosols in Yilmana Densa, northwestern Ethiopia.

	Current cost and price situation				Current cost and price situation			Variable costs and price of tef grain, increased and decreased, respectively by 20%		
Plowing frequency	TVC (Birr/ha)	Net Benefit (Birr/ha)	MRR (%)	Weeding	TVC (Brr/ha)	Net Benefit (Birr/ha)	MRR (%)	TVC (Birr/ha)	Net Benefit (Birr/ha)	MRR (%)
P_3	240	2530		W_0	0	2393		0	2184	
P_1 + roundup	260	2362 D	-	W_t	260	2871	184	312	2545	116
P_5	400	2516 D	-	W_s	415	2273 D	-	498	1955 D	-
P_7	560	2659	40	W_tW_s	490	2825 D	-	588	2437 D	-

D = dominated treatment, NB = net benefit, TVC = total variable costs, MRR = marginal rate of return
P_7 = Seven plow, P_5 = Five plow, P_3 = Three plow, P_1 = One plow, R = *roundup*
W_0 = Unweeded, W_t = Weeding at tillering, W_S = Weeding at stem elongation

Table 7. Economic analysis of plowing frequency and weeding interaction on tef grain yield on nitosols in Yilmana-Densa area, northwestern Ethiopia.

	Current situation			Scenario (if variable costs and price of tef grain, increased and decreased, respectively by 20%)		
Plowing frequency by Weeding interactions	TVC (Birr/ha)	Net Benefit (Birr/ha)	MRR (%)	TVC (Birr/ha)	Net Benefit (Birr/ha)	MRR (%)
P_3W_0	240	2068		288	1819	
P_1 R W_0	260	1603 D		312	1388 D	
P_5W_0	400	2127	37	480	1826	4
P_3W_t	500	2470	343	600	2111	237
P_1RW_t	520	2446 D		624	2083 D	
P_7W_0	560	2313 D		672	1950 D	
P_3W_s	655	1936 D		786	1578 D	
P_5W_t	660	2615	91	792	2197	45
P_1RW_s	675	1831 D		810	1477 D	
$P_3W_tW_s$	730	2479 D		876	2053 D	
$P_1RW_tW_s$	750	2399 D		900	1974 D	
P_5W_s	815.0	1800 D		978	1409 D	
P_7W_t	820.0	2496 D		984	2043 D	
$P_5W_tW_s$	890.0	2354 D		1068	1893 D	
P_7W_s	975.0	2065 D		1170	1604 D	
$P_7W_tW_s$	1050.0	2600 D		1260	2071 D	

D = dominated treatment, NB = net benefit, TVC = total variable costs, MRR = marginal rate of return
P_7 = Seven plows, P_5 = Five plows, P_3 = Three plows, P_1 = One plow, R = *roundup*
W_0 = Unweeded, W_t = Weeding at tillering, W_S = Weeding at stem elongation

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Management of Termite (*Microtermes adschaggae*) on Hot Pepper Using Powdered Leaves and Seeds of Some Plant Species at Bako, Western Ethiopia

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Abstract: A study was conducted to evaluate the field efficacy of eleven pesticidal plants against termites on hot pepper at Bako, western Ethiopia during the 2001, 2003 and 2004 cropping seasons. The powdered leaves and seeds of the pesticidal plant species were applied at the rate of 50 g per 12.6 m^2 plot size. In all years, plants with the least termite damage were recorded from plots treated with *Maesa lanceolata*, *Azadirachta indica* and the insecticide diazinon 60% EC (2.5 lit ha^{-1}). The highest stand count and yield were also obtained from plots treated with the same plant species and diazinon. Treatment with *Shinus molle* and *Ficus vasta* appeared to have the lowest effect on termite damage protection. Consequently, there was low plant population at harvest. The use of *M. lanceolata* and *A. indica* should be promoted as part of an integrated management system of termites on hot pepper, particularly by poor farmers.

Keywords: *Azadirachta indica*; *Maesa lanceolata*; Pepper; Termite

1. Introduction

Termites have been regarded as serious insect pests that attack a wide range of agricultural crops, forest trees and buildings in western Ethiopia. Most of the prevailing termite species are *Macroterms subhyalinus* (Rambur) and *Microtermes adschaggae* (Sjosted). They are subterranean in nature and only a few species are mound forming and are difficult to locate and destroy. Termite attacks caused up to 62% and 36% reduction in yields of hot pepper and maize respectively in the region (Abdurrahaman, 1983; Abraham, 1990; Devendra *et al*., 1998). This devastating insect pest also causes soil degradation by reducing vegetation and leaving the soil surface barren and exposed to erosion (Abraham, 1990; Devendra *et al.,* 1998). As a result, farmers are forced to abandon their farmlands and migrate to other places (Abraham and Adane, 1995). In addition, the consequences of termite infestation reduced farm productivity, increased land degradation and vulnerability of resource poor farmers (Altieri, 1984; Devendra *et al*., 1998).

Use of cultural control methods such as mound destruction, removal of the queen, flooding, use of hot ash, are not effective against termites. As a result, termite control methods depend heavily on synthetic chemicals, especially organochlorines such as aldrin (Abdurahaman, 1990). Many plant species have been reported to posses insecticidal and repellent properties against termites; however, only *Azadirachta indica* and *Ipomea fistulosa* products have been field-tested. According to Listinger *et al.* (1978), incorporating such plants and their derivatives into the annual cropping system may provide an ecologically-sound method of termite control. Hence, the present study reports on the field efficacy of some plant products against subterranean termites.

2. Materials and Methods

2.1. Description of the Study Site

The experiment was conducted at the Bako Agricultural Research Center (BARC), western Ethiopia. The center lies between 9° 6' N latitude and 37°09' E longitude, 1650 meters above sea level. The mean annual rainfall is 1217 mm and its pattern is unimodal. The rainy period is from April to October. It has a warm humid climate with mean minimum, mean maximum and annual mean temperatures of 13°C, 28°C and 18°C respectively (Table 1). Sixty percent of the soil is reddish brown Nitosols with a pH range of 5.0 -5.31.

Table 1. Total rainfall, temperature, relative humidity at Bako, western Ethiopia during the 2001 and 2003 cropping seasons.

Year	Total Rainfall (mm)	Temperature ^{0}C			Relative Humidity (%)
		Min.	Max.	Mean	
2001	1452	12.0	27.0	19.5	75.6
2003	1041	13.8	29.0	21.4	58.6

2.2. Trial Design and Management

The experiment was conducted for two years, i.e. during the 2001, 2003 and 2004 cropping seasons. Eleven different species of plants (Table 2) were evaluated, together with the insecticide diazinon 60% EC and untreated checks to determine their efficacy against the termite *Microtermes adschaggae* (Sjosted). The experiment was laid out in randomized complete block design (RCBD) with three replications in 2001 and 2003. The plot size was 4.2 m long and 3 m wide, with the intra row spacing of 0.3 m and inters spacing of 0.70 m. There were eight rows per plot. In 2004, a verification trial with the two most promising plant species, *M. lanceolata* and *A. indica* was conducted on 85m^2 plot size per treatment without replication. Plots treated with diazinon 60% EC and untreated checks were included. DAP and Urea were

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applied at the rates of 207 kg/ha and 137 kg/ha respectively. Hand weeding was done three times.

Table 2. List of pesticidal plants evaluated against termite on hot pepper in 2001 and 2003 cropping seasons at Bako, Western Ethiopia.

Scientific name	Plant part used
Maesa lanceolata	Leaf powder
Chenopodium sp.	Leaf powder
Azadirachta indica	Seed powder
Croton macrostachyus	Leaf powder
Tagetes minuta	Leaf powder
Datura stramonium	Leaf powder
Vernonia amygadalina	Leaf powder
Phytolacca dodecandra	Leaf powder
Nicotiana tobaccum	Leaf powder
Shiness molle	Leaf powder
Ficus vasta	Leaf powder

2.3. Treatment Application

The leaves of the selected plant species were collected, dried and ground into fine powders. The powders of the plant species were applied at the rate of 50 gm /plot as a basal or root application at the transplanting and pod setting growth stages. Likewise, the recommended rate of diazinon 60% EC (2.5 lit /ha) was applied at the transplanting and pod setting growth stages. Untreated check plots were neither treated with the insecticide nor with leaves and seed powders of plants species.

2.4. Data Collection and Analysis

Two weeks after the first treatment application and every two weeks thereafter until physiological maturity, ten plants were randomly sampled per plot to assess for termite-damage. The mean of termite-damaged plants was expressed as a percentage of the total samples. To avoid double counting, tags were placed on sampled plants. Stand count was taken at harvest. The six middle rows were harvested at physiological maturity. Dry pod yield per plot was converted to kg ha^{-1}. The percentage of termite-damaged plants and stand counts at harvest were square-root transformed to stabilize the variances. One-way analysis of variance was used. The data were analyzed using MSTAT and the Least Significant Difference (LSD) was used for mean separation at *P< 0.05*. Yield advantage in Table 5, was calculated by comparing the untreated check plots with the treated plots.

3. Results and Discussion

In all the years, lower termite-damaged plants were recorded from plots treated with *M. lanceolata*, *A. indica* and diazinon 60% EC than from the remaining treatments (Tables 3 and 4). The highest stand count and yield were also obtained from plots treated with the same plant species and diazinon 60% EC. This was further verified in the large area in 2004 (Table 5). Treatment with *S. mole* and *F. vasta* appeared to have the least effect on termite damage protection. Consequently, there was low plant population at harvest. Aschalew *et al.* (2005), reported that C. *macrostachyus* and *T. minuta* have repellent properties against termites while *D. stramonium*, *F. vasta, A. indica* leaves and *Chenopodium* sp. had shown insecticidal effects. On the other hand, Gold *et al.* (1991) and Epilla *et al.* (1988) reported that these plants possess insecticidal, repellent, or antifeedant properties. Several species of plants have been reported as being toxic or repellent to termites. However, only *A. indica* and *I. fistulosa* products have been field-tested. Fekede and Kedir (2004) reported that *M. lanceolata* also had fungicidal properties comparable to the fungicide, thiram, used against sorghum head smut. The fact that these botanicals reduced the damage level of termites might be attributed to their antifeedant, repellant, insecticidal effects or a combination of them.

Table 3. Effect of treatment with leaves and seed powder from different plant species on termite damage, stand count at harvest and dry pod yield of hot pepper at Bako, Western Ethiopia in 2001 cropping season.

Treatments	Percent damaged plants	Mean stand count at harvest	Dry pod yield kg/ha
Maesa lanceolata	2.8 ± 1.2*f	56.0 ± 1.5a	670 ± 39a
Chenopodium spp.	10. 6 ± 0.9cde	47.0 ± 0.6cde	400 ± 37b
Azadirachta indica	5.0 ± 1.2ef	54.0 ± 1.5ab	650 ± 19a
Croton macrostachys	8.3 ± 0.6def	41.7 ± 3.3ef	420 ± 66b
Tagetes minuta	8.3 ± 0.6def	39.3 ± 3.7f	330 ± 27bc
Datura stramonium	10.6 ± 0.9cde	50.3 ± 1.2bcd	350 ± 99bc
Vernonia amygadalina	9.4 ± 1.8cde	39.7 ± 2.2f	360 ± 50bc
Phytolacca dodecandra	8.9 ± 1.7de	43.7 ± 0.7ef	280 ± 17bc
Nicotiana tobacum	15.0 ± 1.7bc	29.0 ± 0.6g	310 ± 81bc
Shinus molle	12.8 ± 1.6bcd	29.7 ± 0.9g	370 ± 61b
Ficus vasta	16.7 ± 1.5b	28.0 ± 3.5g	310 ± 45bc
Diazinon 60% EC	5.6 ± 1.2ef	52.0 ± 1.0abc	580 ± 17a
Untreated check	23.9 ± 0.9a	31.6 ± 3.8g	230 ± 25c
LSD (0.05)	5.6	5.4	1.5
Mean	10.5	40.5	4.00

** Means with the same letter in a column are not significantly different at P<0.05.*

Table 4. Effect of different pesticidal plants treatment against termite damage, stand count at harvest and dry pod yield (kg/ha) of hot pepper at Bako, Western Ethiopia in 2003 cropping season.

Treatments	Percent damaged plants	Stand count at harvest	Dry pod yield kg/ha
Maesa lanceolata	12.2 ± 1.3g	52.0 ± 1.5a	250 ± 22ab
Chenopodium spp.	40.0 ± 2.6bc	36.0 ± 2.6bcd	170 ± 44bcd
Azadirachta indica	13.9 ± 0.8fg	51.3 ± 0.6a	290 ± 26a
Croton macrostachys	26.7 ± 1.5de	39.3 ± 2.2bc	190 ± 38bcd
Tagetes minuta	25.5 ± 1.7de	36.0 ± 2.1bcd	170 ± 30cde
Datura stramonium	23.3 ± 1.0def	39.7 ± 0.3b	90 ± 16e
Vernonia amygadalina	25.6 ± 3.7de	41.0 ± 0.6b	190 ± 20bcd
Phytolacca dodecandra	38.3 ± 1.1bc	33.3 ± 2.9cd	190 ± 14bcd
Nicotiana tobaccum	31.7 ± 2.9cd	36.7 ± 3.2bcd	140 ± 21de
Shinus molle	46.7 ± 0.6b	32.0 ± 1.2d	160 ± 21cde
Ficus vasta	57.2 ± 0.5a	25.3 ± 1.1e	160 ± 21cde
Diazinon 60% EC	16.7 ± 1.5efg	49.0 ± 1.5a	230 ± 31abc
Untreated check	45.0 ± 1.3b	33.0 ± 1.2d	190 ± 5bcd
LSD (0.05)	10.1	6.3	70
Mean	30.5	39.2	180

** Means with the same letter in a column are not significantly different at P<0.05.*

The highest yield of pepper was obtained from treatment with *M. lanceolata, A. indica and* diazinon 60% EC (Tables 3 & 4). The other treatments, however, did not differ in yields from the untreated check except the treatment with *C. macrostachyus* and *S. mole* in 2001. In the 2004 verification trial, yield advantages of 109 to 150% over the untreated check were recorded in plots treated with *M. lanceolata* and *A. indica* respectively (Table 5). Brown (1962) reported that incorporating such plants and /or their derivatives into the annual cropping system may provide ecologically-sound methods of termite control. Similar findings were reported by Gold *et al*. (1991), Logan *et al.* (1999), and Schroth *et al.* (1992), where *A. indica* and *I. fistulosa* mulches were found to reduce termite activity for seven weeks and this should be given due consideration in termite control strategies.

Several plant species have been reported as being toxic or repellent to termites. However, only *A. indica* and *I. fistulosa* products have been field-tested (Gold *et al*., 1971). On the other hand, Gold *et al.* (1991) reported that *A. indica* and *I. fistulosa* mulches reduced termite activity for seven weeks after treatment. In conclusion, the use of *M. lanceolata* and *A. indica* should be promoted as part of an integrated management system of termites on pepper, particularly by (resource) poor farmers.

Table 5. Verification trial on the effects of *Azadirachta indica* and *Maesa lanceolata* on the percentage of damage, stand count at harvest and dry pod yield (kg/ha) of hot pepper at Bako, Western Ethiopia during the 2004 cropping season.

Treatments	Percent damaged plants	Stand count at harvest	Yield kg/ha
Azadirachta indica	16.38	335	1382
Maesa lanceolata	14.64	344	1654
Diazinon 60% EC	14.39	345	1595
Untreated check	39.45	241	662

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Variability in Phytochemicals, A-Galactosides, Sucrose Composition and *in Vitro* Protein Digestibility of Common Bean (*Phaseolus vulgaris* L.) Varieties

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Abstract: The variability in the phytochemicals, α-galactosides, the sucrose composition and the *in-vitro* protein digestibility of common bean varieties released from research centres were investigated. Concentrations for α-galactosides (raffinose and stachyose) and phytochemicals (lectins, saponins, phytic acid, protease inhibitors and tannins) varied significantly ($P < 0.05$) amongst the common bean varieties. Mean values for raffinose, stachyose, total α-galactosides, sucrose, trypsin inhibitors, tannins, phytic acid, saponin and lectins were 3.14 mg g^{-1}, 14.86 mg g^{-1}, 17.99 mg g^{-1}, 24.22 mg g^{-1}, 20.68 TUIx10^3 g^{-1}, 17.44 mg catechin equivalent g^{-1}, 20.54 mg g^{-1}, 1.01 g 100 g^{-1} and 4.75 g kg^{-1} PHA based on dry weight basis respectively. *In vitro* protein digestibility varied significantly ($P < 0.05$) among the bean varieties and had a positive significant correlation with sucrose content and negative correlations with trypsin inhibitors, tannins, lectins, α-galactosides and saponins. The correlation matrix indicated that variability in α-galactosides, the protein digestibility, the phytochemical composition and the sucrose contents of beans existed. In addition, a protective role against diseases was correlated with the amount of phytochemicals quantified in the bean samples. Amongst the studied bean varieties, Roba has the potential to be used as a raw material in the food-processing industry owing to its higher *in vitro* protein digestibility, lower phytochemicals composition and other beneficial nutritional parameters.

Keywords: *Phaseolus vulgaris;* Protein Digestibility; A-Galactosides; Phytochemicals; Sucrose

1. Introduction

Common beans (*Phaseolus vulgaris* L) are considered to be one of the major sources of dietary proteins. They are most widely cultivated and consumed in Latin America, India and Africa as a whole seed (Salunkhe and Kadam, 1989). In Ethiopia, common beans are used as the least expensive protein source for (resource) poor people who cannot afford to buy expensive meat. Furthermore, beans are produced primarily by small-scale farmers and function as a cash-generating crop in the central rift valley of Ethiopia (Dawit and Demelash, 2003).

Protein quality in leguminous seeds does not, however, reach the same level as in animal products. This is due to various factors, among the most well-known are their unbalanced amino acid composition, the low true digestibility of protein and the presence of phytochemicals in the seeds (Bressani and Elias 1980; Norton *et al*., 1985). Common beans synthesize several undesirable chemical substances termed phytochemicals that are known to exert deleterious effects when ingested by humans or animals. The endogenous phytochemicals present in common beans are produced by the plant to protect itself against environmental stress. In general, phytochemicals are compounds that impair health by destroying nutrients/vitamins or by reducing the uptake of such essential elements by different mechanisms. They give an astringent taste, odour and flavour and which can cause adverse physiological responses or diminish the bioavailability of certain nutrients and hinder utilization of common beans for human nutrition and animal feed (Salunkhe, 1982). Phytochemicals inhibit protein and carbohydrate digestibility; interfere with mineral bioavailability, induce pathological changes in intestine and liver tissue thus affecting metabolism, inhibit a number of enzymes and bind nutrients making them unavailable (Bressani and Sosa 1990; Bressani 1993).

The main phytochemicals found in *Phaseolus vulgaris* are enzyme inhibitors, tannins, lectins (phytohaemagglutinins), phytic acid (phytate), flatulence-causing α-galactosides and saponins (Liener, 1989). Flatulence-causing α-galactosides are oligosaccharides of the raffinose-series family which include raffinose, stachyose and verbascose. α-galactosides contribute to flatulence production in humans and mono-gastric animals due to a lack of the necessary α-galactosidase enzyme which helps to break down raffinose-series oligosaccharides during the consumption of dry beans. Hence, they are considered as unwanted components as a consequence of the accumulation of gas in the intestinal tract is discomfort, abdominal rumblings, cramps, pain and diarrhea after bean ingestion. The α-galactosides are also associated with a low food intake in animal experiments (Frias *et al*., 2000). Phytic acid has long been recognized as a phytochemicals which affects the bioavailability of minerals (Ca^{2+}, Mg^{2+}) and trace elements such as Zn^{2+}, Fe^{2+}, Cu^{2+} and Mn^{2+} (Reddy *et al*., 1982). Tannins are a group of polyphenols which form insoluble complexes with protein and inhibit several enzymes (Bressani, 1993). Trypsin inhibitors (enzyme inhibitors) are capable of binding to the trypsin enzyme, thus inhibiting its activity, interfering with the digestion of proteins and resulting in an increased pancreatic secretion and hypertrophy of the pancreas (Birk, 1989). Saponins are bitter tasting, foam producing glycosides and detected by their hemolytic activity and surface-active properties (Duhan *et al.,* 2001). Lectins, the sugar-binding proteins that agglutinate animal red blood cells, are the main toxic components in *Phaseolus vulgaris* (Liener, 1983). A number of investigators have demonstrated that the poor digestibility and

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biological utilization of beans is directly related to the phytochemicals content of beans (Pusztai *et al*., 1975; Rao and Belavady 1978; Maga, 1982; Singh and Krikorian 1982; Johnson *et al*., 1986; Laurena *et al*., 1994; Shimelis, 2005).

Most of the research on Ethiopian common beans has been related to varietal selection where the criteria for selection have always been adaptation, resistance to disease, rate of maturation, yields, seed size, color and specific agronomic traits, but never nutritive quality. Information on the composition of phytochemicals and protein digestibility of improved common beans released from research centers has not been available at national level in the Ethiopian context (EARO, 2002). This information would, therefore, be of great interest to Ethiopia because the knowledge provided would help to orient the work of breeders involved in varietal selection, give baseline information for exporters and processors on the levels of unwanted components and protein digestibility which, in turn, would help to develop suitable, simple and inexpensive processing techniques for the reduction or removal of those factors. Furthermore, it could boost the utilization of common bean varieties as value-added products at small-scale industry level in the developing countries by local food processors.

The present study aims to evaluate the variability in concentration of phytochemicals, α-galactosides, sucrose and find out the levels of protein digestibility of common bean varieties grown in Ethiopia. The study also compares the obtained results to those observed in beans grown in other areas of the world which can be influenced by genotype, environmental and varietals interaction. The outcome of this study could contribute to the intensive utilization of *Phaseolus vulgaris* in the form of processed commercial products at industry level through large-scale cultivation of selected varieties in developing countries, exclusively in the East and Great Lakes regions of Africa where common beans are utilized to a great extent.

2. Materials and Methods

2.1. Common Bean Varieties

The common beans used in this study were grown at Nazareth Agricultural Research Centre of Ethiopia under similar field conditions and normal agronomic practices required for bean crops. The eight varieties of *Phaseolus vulgaris* used for the study were Awash 1 (G-4445) and Mexican 142 (G-11239) (Export types), Beshbesh (XAN76 x BAT85), Gobirasha (ICA-15541), Gofta (G-2816), Redwolita (local collection), Roba 1 (A-176) and Tabor (A-788) (Food types) which were released from Haramaya, Awassa, Jimma and Nazareth Research Centres. The test samples were clean, uniform in size with natural colour, good appearance, and free from abnormal odors, broken seeds, dust and other foreign materials including living or dead insects. The bean samples were finely ground in analytical mill (Cole-Parmer, Cole-Parmer Instrument Company, Model 4301-02, U.S.A) and sieved through a 0.5 mm mesh screen. Samples were stored at 4°C prior to analyses. All chemicals and reagents used were either analytical or reagent grade.

2.2. A-Galactosides and Other Sugars Analyses by HPLC

The α-galactosides and other sugars were extracted from the bean samples using the AOAC official method (AOAC, 2000). The analyses of sugars were carried out using high-performance liquid chromatography (HPLC) according to Doyon *et al*., (1991). The liquid chromatograph used for this study was "Agilent 1100 series" with analytical column (APS-2 HYPERSIL, 5μm, 250 x 4.6 mm, L x I.D, Thermo Electron Corporation, England) equipped with differential refractive index (RI) detector (Model, G1362A, Agilent technologies, Germany). Individual sugar standards were allowed to dry for 12hrs at 60 ^{0}C under vacuum. Subsequently, standard solutions of raffinose-series oligosaccharides (raffinose, stachyose, verbascose; procured from Sigma Chemical, St. Louis, MO, USA) and other sugars (glucose, sucrose, fructose and maltose; purchased from Sigma Chemical, St. Louis, MO, USA) were prepared at a concentration of 1mg ml^{-1} (stachyose, raffinose, verbascose) and 5mg ml^{-1}(other sugars) each and used for calibrating a selected plot.

The prepared extracts (unknown samples) were eluted with CH_3CN/ H_2O 73:27 (v/v) as a mobile phase at a pump rate of 1ml min $^{-1}$ in to the HPLC column and were quantified by comparison with the standard sugars. The results obtained from HPLC analysis were expressed in mg g^{-1}.

2.3. Determination of Trypsin Inhibitor Activity

Trypsin inhibitor activity (TIA) in common bean flour was measured according to Smith *et al*., (1980).

2.4. Measurements of Lectins, Saponins, Phytic Acid and Tannins

A competitive indirect ELISA assay for quantification of *Phaseolus vulgaris* lectins was conducted following the procedure of Burbano *et al*., (1999). The saponin contents of bean samples were determined using the method described as Hiai *et al*., (1976). Phytic acid content was evaluated using the method of Haug and Lantzsch (1983). Tannins were also determined following the method described by Makkar *et al.,* (1998).

2.5. Zinc, Total Ash Composition and Colour Measurement

Zinc analysis was carried out using the method reported on Issac and Johnson (1975) atomic absorption spectrophotometer **(**Hitachi, Model Z-8230, Japan). Total ash composition of the seed flour was performed according to official methods (AOAC, 2000). Common beans were monitored for their colour by using colour flex spectrocolorimeter (Model no. 45/0, Hunter Lab Reston, VA, USA, 2002). The parameters recorded were **L**, **a** and **b** co-ordinates of the CIE scale.

2.6. *In Vitro* Protein Digestibility Analysis

Proteins from common beans were isolated for digestibility analysis, using the method of Satterlee *et al.*, (1975). In *vitro* protein digestibility analysis of common bean samples was carried out with a mixture of three enzymes: trypsin (porcine pancreatic trypsin type IX, with 15,500 BAEE units per mg protein), α-chymotrypsin (bovine pancreatic chymotrypsin, type II, 76 units per mg protein) and peptidase (porcine intestinal mucosa, grade III, 102 units per gm solid). All these enzymes were procured from Sigma Chemical Co., St Louis, MO, USA. The multi-enzyme solution was freshly prepared before each series of tests, and its activity was determined using casein (bovine milk, purchased from Sigma Chemical Co., St Louis, MO, USA) of known *in vivo* apparent digestibility with the method described by Hsu *et al.*, (1977).

3. Experimental Design and Statistical Analyses

The experiment was laid out using complete randomized design (CRD). Data were scrutinized using analysis of variance (ANOVA), followed by least significant difference (LSD) for multiple comparisons among treatment means at 5% level of significance. Statistical analyses were performed using SPSS/12 software for windows. All values were presented as means of triplicates ± standard deviation.

4. Results and Discussion

4.1. A-Galactosides and Sucrose

The α-galactosides and sucrose contents of eight common bean varieties studied are presented in Table 1. Stachyose was the major α-galactoside contained in all the samples analyzed, which also contained significant quantities of raffinose. Nevertheless, verbascose, fructose, glucose and maltose were not detected in HPLC analyses of all common bean samples. The sucrose content of common beans ranged from 17.27 mg g^{-1} (in Beshbesh) to 28.58 mg g^{-1} (in Mexican). Raffinose concentrations ranged from 2.35 mg g^{-1} (in Awash) to 4.34 mg g^{-1} (in Gobirasha) and stachyose concentrations from 12.38 mg g^{-1} (in Roba) to 18.41mg g^{-1} (in Beshbesh). Comparable concentrations of raffinose family oligosaccharides and sucrose have been reported for common beans grown in Canada (Sosulski *et al.*, 1982) and in Burundi (Barampama and Simard, 1993). However, some investigators, Agbo (1982); Sathe *et al.*, (1983); Reddy *et al.*, (1984); Salunkhe and Kadam (1989); Burbano *et al.*, (1990) who assayed common bean varieties grown in the USA for flatus factor, have observed raffinose (2-10 mg g^{-1}) and stachyose (2.0-56.2 mg g^{-1}) concentrations higher than those obtained for common bean varieties grown in Ethiopia and used in this study. Similarly, for common bean varieties grown in different Spanish areas, flatus factors were reported as 0.9-5.6 mg g^{-1} raffinose, 18.3-29.3 mg g^{-1} stachyose, 0.4-2.7 mg g^{-1} verbascose and 12.8-28.9 mg g^{-1} sucrose (Burbano *et al.*, 1990; Muzquiz, 1999). However, cultivars of *Phaseolus vulgaris* grown in Brazil (Trugo *et al.*, 1990) have observed raffinose (0.5-1.4 mg g^{-1}), stachyose (3.2-4.7 mg g^{-1}) and sucrose (3.0-3.7 mg g^{-1}). These values are lower compared to the beans analyzed in the present study. Jood *et al.*, (1985) also reported that the raffinose and sucrose content of Rajmah (red bean) from India (Hissar) were 0.89 % and 1.58 % respectively. From the comparisons, it can be concluded that the concentration of these oligosaccharides varies depending on the location of growth and the variety used.

Table 1. The α-Galactosides, sucrose and total oligosaccharide compositions of eight common bean varieties (mean ± SD, n=3).

Varieties	Raffinose (mg g^{-1})	Stachyose (mg g^{-1})	α-Galactosides (mg g^{-1})	Sucrose (mg g^{-1})	Total Oligosaccharides (mg g^{-1})^X
Roba	3.36 ± 0.07^b	12.38 ± 0.01^e	15.74 ± 0.04^e	26.84 ± 0.01^b	42.58 ± 0.03^c
Gobirasha	4.43 ± 0.05^a	14.16 ± 0.04^c	18.59 ± 0.05^c	23.44 ± 0.02^e	42.03 ± 0.04^c
Beshbesh	2.89 ± 0.01^c	18.41 ± 0.07^a	21.30 ± 0.04^a	17.27 ± 0.01^g	38.57 ± 0.03^d
Gofta	4.34 ± 0.00^a	14.19 ± 0.01^c	18.53 ± 0.01^c	24.05 ± 0.03^d	42.58 ± 0.02^c
Awash	2.35 ± 0.03^d	16.67 ± 0.06^b	19.02 ± 0.05^b	25.24 ± 0.01^c	44.26 ± 0.03^b
Mexican	2.82± 0.03^c	16.31 ± 0.02^b	19.13 ± 0.03^b	28.58 ± 0.07^a	47.71 ± 0.05^a
Redwolaita	2.48 ± 0.08^d	13.03 ± 0.01^d	15.51± 0.05^d	28.18 ± 0.01^a	43.69 ± 0.03^b
Tabor	2.40 ± 0.00^d	13.69 ± 0.05^d	16.09 ± 0.03^d	20.16 ± 0.08^f	36.25 ± 0.06^e

$^{a\text{-}g}$ *Means with different superscript letters within a column indicate statistically significant differences (P < 0.05).*
^{X}*Total oligosaccharides (mg g^{-1}) = a-galactosides (mg g^{-1}) + sucrose (mg g^{-1})*

4.2. Trypsin Inhibitor Activity

There was a significant difference ($P < 0.05$) in trypsin inhibitor activities between varieties (Table 2). Gobirasha and Beshbesh varieties had higher mean values 27.25 and 29.27 TUI mg^{-1} respectively, while Roba had the lowest (4.59) TUI mg^{-1}. The variations in the activity of trypsin inhibitors ranged from 4.59 to 29.27 TUI mg^{-1} on dry matter basis of *Phaseolus vulgaris*. These are in agreement with the findings of Sosulski *et al.*, (1982) and Barampama and Simard (1993) for common bean varieties grown in different countries. Higher concentrations have been reported for trypsin inhibitors of different varieties and species of legumes (Thorn *et al.*, 1983; Khokhar and Chauhan, 1986; Kantha *et al.*, 1986). A significant ($P < 0.01$) negative correlation between trypsin inhibitor and protein digestibility is in agreement with the findings of Hernández-Infante *et al.* (1979) and Furuichi *et al.*, (1988). The negative relation which exists between the trypsin inhibitor and protein digestibility may be implicated in the reduction of nutritive protein quality in common beans.

4.3. Tannins

Tannins concentration ranged from 5.38 (in Roba) to 28.79 mg catechin equivalent g^{-1} (in Beshbesh) and there were significant ($P < 0.05$) differences among the varieties tested. The results revealed that a negative correlation was observed between tannins and the *in-vitro* protein digestibility of common beans (Table 3). Similarly, a highly significant ($P < 0.01$) negative correlation between tannins concentration and protein digestibility has also been reported by Sosulski *et al.* (1982) and Aw and Swanson (1985). Tannins concentration levels 0.3-29.3 mg catechin equivalent g^{-1} were reported by Sathe *et al.* (1983); Aw and Swanson (1985). Deshpande and Cheryan (1983); Reddy *et al.* (1985) have observed lower tannins concentrations (0.34 to 26.50 mg catechin equivalent g^{-1}) for common bean varieties grown in the USA. Barampama and Simard (1993) have also reported on common beans grown in Burundi with a wider range of tannins concentration (0.11 to 28.78 mg g^{-1}). Thus, tannins might contribute to the reduction of nutritional quality of protein in common beans confirmed by the results of this study.

4.3.1. Relation between Tannins and Colour Co-ordinates

Colour measurement was done to correlate the tannins content of bean varieties with their colour value. **L** (whiteness) values obtained for the samples studied ranged from 28.82 to 73.94 among the different common bean varieties (Table 4). The export-type beans such as Mexican and Awash had the highest **L** value 73.94 and 69.34 respectively, and the Redwolaita variety had the lowest **L** value. The colour scale value of **a** (red) ranged from 1.69 to 14.39 in different common bean varieties. The highest **a** value was obtained (14.39) in Redwolaita and lowest (1.69) in Mexican varieties. The highest **b** (yellow) value of 25.39 was obtained in Roba and the lowest of 5.71 in Redwolaita.

There were differences in the surface colour of the eight varieties of beans. The tannins concentration seemed to be influenced by the colour of the common bean seeds. Coloured bean seeds (Table 4), Beshbesh and Gobirasha varieties indeed presented higher tannins concentrations than the other bean seeds studied (Table 2). This observation is in agreement with the findings given by Sotelo and Hernández (1980) for tannins in common bean varieties grown in the USA. Mexican and Awash are exporting type varieties from Ethiopia due to their high white colour quality and reasonable protein digestibility. Roba and Redwolaita are the most popular varieties in farming society in Ethiopia, especially in the central rift valley and southern areas, due to their colour preference, acceptability and food-making qualities. Though white and light creamy beans would be preferred from a protein digestibility point of view, it may not be the only basis for the purchase of such products from and in Ethiopia.

4.4. Phytic Acid

The phytic acid composition of common bean varieties studied is presented in Table 2. The level of phytic acid varied among the eight varieties of common bean from 16.81 to 24.07 mg g^{-1}. The highest phytic acid content is found in Awash and the lowest in Mexican. The ANOVA indicated that phytic acid mean difference was significant at 0.05 levels. Deshpande and Cheryan (1983) have reported that, for common bean varieties grown in the USA there is a concentration of phytic acid ranging from 18.1-27.5 mg g^{-1}. Barampama and Simard (1993) reported that phytic acid varied from 12.37 to 23.60 mg g^{-1}. However, Muzquiz *et al.*, (1999) reported a low value of phytate (3.10-5.01 mg g^{-1}) for common bean varieties grown in different areas of Spain. Phytate reduces the bioavailability of minerals and the solubility, functionality and digestibility of protein and carbohydrate in common beans (Reddy *et al.*, 1982). Therefore, special attention must be given to eliminating or reducing the levels of phytic acid during the preparation of weaning food formulations to assure its high protein quality and mineral bioavailability.

4.4.1. Effect of Phytic Acid on Zn

The results of this study show that bean varieties had a range of zinc content varying from 15.39 mg kg^{-1} to 28.03 mg kg^{-1} (Table 5). The significant ($P < 0.01$) positive correlation for total ash and phytic acid; and negative correlation with ash and zinc is presented in Table 3. The results of this study confirm that phytic acid and zinc have a significant negative correlation. The amount of phytic acid, the type and amount of protein and the total Zn content have a major impact on the amount of Zn absorbed from foods (Lopez *et al.*, 2002). Phytic acid strongly binds Zn in the gastrointestinal tract and reduces its availability for absorption and re-absorption (Flanagan 1984).

Zinc concentrations in the eight varieties varied from 15.39 mg kg^{-1} to 28.22 mg kg^{-1} (Table 5). These values are comparable to concentrations reported by Meiners *et al.* (1976), Rockland *et al.* (1979) and Augustin *et al.* (1981). Zinc is an essential trace micronutrient involved in the immune function, in the activation of many enzymes, normal healthy growth and reproduction Umeta *et al.* (2000). Therefore, zinco-protein supplementation of formulated bean-based foods can reduce protein-energy malnutrition (PEM) disease which is common in countries like Ethiopia.

Table 2. Phytochemical composition and *in vitro* protein digestibility of the bean varieties (mean ± SD, n=3).

Varieties	Phytic acid (mg g^{-1})	Saponins (10^{-2}g g^{-1})	Trypsin inhibitors (TUI[1] mg^{-1})	Lectins (g kg^{-1} PHA)[2]	Tannins (mg g^{-1})	*In vitro* protein digestibility (%)
Roba	23.51 ± 0.12[b]	0.96 ± 0.02[d]	4.59 ± 0.02[h]	1.92 ± 0.01[e]	5.38 ± 0.01[g]	80.66 ± 0.03[a]
Gobirasha	22.94 ± 0.09[c]	0.75 ± 0.04[e]	27.25 ± 0.07[b]	6.43 ± 0.07[c]	23.55 ± 0.01[b]	68.87 ± 0.07[g]
Beshbesh	17.34 ± 0.10[g]	1.32 ± 0.08[a]	29.27 ± 0.09[a]	9.98 ± 0.02[a]	28.79 ± 0.14[a]	65.64 ± 0.04[h]
Gofta	20.09 ± 0.07[e]	1.05 ± 0.03[c]	24.09 ± 0.06[c]	7.77 ± 0.04[b]	19.69 ± 0.01[c]	69.36 ± 0.01[f]
Awash	24.07 ± 0.09[a]	1.18 ± 0.01[b]	20.89 ± 0.05[e]	4.52 ± 0.03[d]	17.56 ± 0.08[d]	71.15 ± 0.02[e]
Mexican	16.81 ± 0.02[h]	1.16 ± 0.00[b]	21.44 ± 0.08[d]	4.49 ± 0.06[d]	17.69 ± 0.06[d]	72.33 ± 0.05[d]
Redwolaita	18.27 ± 0.05[f]	0.72 ± 0.03[e]	17.97 ± 0.04[g]	1.02 ± 0.09[f]	11.15 ± 0.01[f]	77.44 ± 0.01[b]
Tabor	21.27 ± 0.01[d]	0.94 ± 0.04[d]	19.94 ± 0.01[f]	1.90 ± 0.08[e]	15.68 ± 0.09[e]	73.57 ± 0.02[c]

All values are means of three replicate analyses and expressed in dry weight basis

[1]*Trypsin units inhibited;* [2]*Lectin as PHA (Pvulgaris lectin)*

[a-h]*Means with different superscript letters within a column indicate statistically significant differences (P < 0.05)*

Table 3. Correlation coefficients among the bean varieties presented in matrix form.

	Protein digestibility	Trypsin inhibitors	Tannins	Phytic acid	Sucrose	α- Galactosides	Raffinose	Stachyose	Lectins	Saponins	Ash	Zinc
Protein digestibility	1											
Trypsin inhibitors	-0.94**	1										
Tannins	-0.98**	0.95**	1									
Phytic acid	-	-	-	1								
Sucrose	0.64*	-0.68**	-0.67**	-	1							
α- Galactosides	-0.89**	0.95**	-	-	-0.46*	1						
Raffinose	-	-	-	-	-	-	1					
Stachyose	-0.76**	0.81**	0.76**	-	-0.44*	0.92**	-	1				
Lectins	-0.89**	0.75**	0.88**	-	-0.76**	-	-	0.86**	1			
Saponins	-0.49*	0.76**	0.44*	-	-0.74**	-	-	-	0.57*	1		
Ash	-	-	-	0.97**	-	-	-	-	-	-	1	
Zinc	-	-	-	-0.49*	-	-	-	-	-	-	0.41*	1

***Highly significant (0.01< P < 0.001) and *Significant (0.01 < P < 0.05)*

4.5. Saponins and Lectins Concentrations

Concentrations of saponins and lectins of released varieties of common beans studied are presented in Table 2. For all varieties, significant differences ($P < 0.05$) existed in the saponins and lectin contents. Concentrations varied from 0.72 (in Redwolaita) to 1.32 g 100 g^{-1} (in Beshbesh), from 1.02 (in Redwolaita) to 9.98 g kg^{-1} (in Beshbesh) for saponins and lectins respectively. Concentrations of saponins were reported to be lower (0.44 to 2.05 g kg^{-1}) for common beans grown in Spain (Burbano *et al.*, 1990) compared to this study. According to the results obtained, the lectins content of common bean varieties were significantly ($P < 0.05$) different. The content of lectin ranged from 1.02 g kg^{-1} (Redwolaita) to 9.98 g kg^{-1} (Beshbesh). These values are in agreement with the report of Burbano *et al.*, (1990) for common beans varieties grown in Spain, and Barampama and Simard (1993) for common beans grown in Burundi. Concentrations of saponins varied from 0.72 to 1.32 g 100g^{-1}. The Redwolaita variety had the lowest concentrations of saponins while Beshbesh had the highest concentration of saponins and lectins. Protein digestibility was affected by the composition of saponnins and lectins of common beans. It was pointed out earlier that digestibility was negatively influenced by lectins and saponins. This study indicated that saponins and lectins had significant positive correlations (Table 3).

4.5.1. Role of Saponins and Lectins Concentrations Towards Disease Resistance

The results of this study reveal that, among the varieties studied, large quantities of phytochemical composition especially lectins and saponins were obtained in the Beshbesh variety. Many roles have been attributed to lectins, and it has been suggested that they play a protective role against insect, fungal and pathogenic bacterial attacks in the field and under storage conditions ((Janzen *et al.*, 1976; Mirelman *et al.*, 1975; Sequeira, 1978, Shimelis, 2005). Gatehouse *et al.*, (1984) reported that lectins purified from *Phaseolus vulgaris* seeds were shown to be toxic to the development larvae of the bruchid beetle *Callosobruchus maculates,* a major storage pest of many legumes. Thus, the presence of lectins is of considerable importance in preventing *C. maculates* from attacking the seeds. Beshbesh was released by the crop protection program of Nazareth Agricultural Research Centre for its resistance to disease (EARO, 2001). Beshbesh is highly resistant to bean stem maggots (BSM) (*Ophiomyia spencerella*) which represent a principal insect pest of beans in southern Ethiopia and other East African countries like Uganda, Kenya, Tanzania and Zimbabwe (EARO, 2001).

Analogous suggestions were further corroborated by the reports of Gatehouse and Boulter (1983) and Gatehouse *et al.*,(1992), which confirmed that resistance to pests can lead to an increment in phytochemicals composition in the seed of common beans. A report by Oluwatosin (1999) also supports that increase in resistance to pests demonstrated in an enlargement in phytochemical concentration for cowpea varieties. Consequently, the presence of a high concentration of phytochemicals (lectins and saponins) in the Beshbesh variety verifies a correlation with its resistance to disease. On the other hand, Redwolaita has lower concentrations of lectins (1.02 g kg^{-1} PHA), saponins (0.72 g 100 g^{-1}) and immense quantities of sucrose concentration (28.18 mg g^{-1}). Accordingly, this shows that Redwolaita might be susceptible to many field and storage pest diseases.

Table 4. Colour analysis of common bean seeds.

Varieties	Seed Color[1]		
	L	a	b
Roba	58.54 ± 0.10^{d}	6.49 ± 0.08^{e}	$25.39 \pm 0.13^{a*}$
Gobirasha	30.30 ± 0.19^{g}	12.57 ± 0.11^{b}	5.87 ± 0.24^{f}
Beshbesh	61.67 ± 0.25^{c}	7.51 ± 0.12^{d}	17.77 ± 0.20^{c}
Gofta	55.73 ± 0.39^{e}	8.19 ± 0.11^{c}	22.50 ± 0.19^{b}
Awash	69.34 ± 0.55^{b}	2.18 ± 0.06f	13.31 ± 0.19^{d}
Mexican	$73.94 \pm 0.20^{a*}$	1.69 ± 0.06g	11.08 ± 0.35^{e}
Redwolaita	28.82 ± 0.64^{f}	$14.39 \pm 0.09^{a*}$	5.71 ± 0.62^{f}
Tabor	57.48 ± 0.29^{d}	8.65 ± 0.15^{c}	18.41 ± 0.28^{c}

[1]L (lightness), a (chroma) and b (hue)

[a-g] Means with different superscript letters within a column indicate statistically significant differences ($P < 0.05$)*

All values are means of triplicates ± standard deviation

Table 5. Zinc composition and ash contents of common bean varieties expressed according to dry weight basis.

Varieties	Zn (mg kg^{-1})	Ash (10^{-2}g g^{-1})
Roba	15.99 ± 0.07^{e}	3.93 ± 0.01^{b}
Gobirasha	23.91 ± 0.16^{c}	3.84 ± 0.02^{b}
Beshbesh	28.03 ± 0.22^{a}	3.12 ± 0.01^{e}
Gofta	27.60 ± 0.13^{b}	3.36 ± 0.00^{d}
Awash	17.21 ± 0.23^{d}	4.26 ± 0.16^{a}
Mexican	17.91 ± 0.16^{d}	2.86 ± 0.04^{f}
Redwolaita	28.22 ± 0.00^{a}	3.27 ± 0.09^{d}
Tabor	15.39 ± 0.01^{e}	3.59 ± 0.03^{c}

All values are means of three replicates ± standard deviation
$^{a-f}$ *Means with different superscript letters within a column indicate statistically significant differences (P < 0.05)*

4.6. *In-vitro* Protein Digestibility

In vitro-protein digestibility of eight common bean varieties studied is presented in Table 2. An analysis of protein digestibility in the present study revealed a significant difference among the eight bean varieties at the 0.05 level. Significant ($P < 0.01$) negative correlation between phytochemicals (lectins, tannins and trypsin inhibitors) and α-galactosides along with *in-vitro* protein digestibility was investigated. Additionally, significant ($P < 0.05$) negative correlation between saponins and protein digestibility were examined. Protein digestibility had a significant ($P < 0.05$) positive correlation with the sucrose content of common beans (Table 3). The range of *in-vitro* protein digestibility of common beans varied from 65.64% (in Beshbesh) to 80.66% (in Roba). The protein digestibility values obtained are comparable to those reported (66.9 - 70.9%) by Deshpande *et al.*, (1984) for common bean varieties grown in the USA; Barampama and Simard (1993) for common bean varieties grown in Burundi; Vadivel and Janardhanan (2000) for velvet bean varieties grown in South India. Pusztai *et al.*, (1979) and Sathe *et al.*, (1984). Lower values for protein digestibility (36.3-56.0%) have been also reported by Salunkhe and Kadam (1989) for different common bean varieties. The protein digestibility of common bean varieties studied by different investigators concluded that it is influenced by genotype environmental factors and varietals interaction.

Factors influencing the nutritional quality of common bean proteins include the amino acid pattern and degree of digestibility, as well as the quantity and quality of the other food proteins consumed along with the common bean proteins (Bressani and Elias 1980). The higher protein digestibility of Roba (80.66%) and the lowest TUI mg^{-1} concentrations among the varieties studied supports the popularity and acceptability of this variety by the consumers among the dozen released varieties of common bean from research centres in Ethiopia (Shimelis and Rakshit, 2005). Beshbesh had the highest TIA and the lowest protein digestibility and thus makes it less acceptable to the consumers in the central rift valley of Ethiopia. It is interesting to note that there is a market for the varieties with a higher trypsin inhibitor in a research-focussed role in cancer treatment. This has been the case in Ethiopia where the variety Beshbesh with its higher trypsin inhibitor can be imported by many buyers for this purpose. However, from a nutritional point of view a lower trypsin inhibitor level which increases protein digestibility is desirable.

The release of more varieties with higher digestibility and protein content, which require less cooking time and have other physico-chemical properties, is vital as a means of contributing to the reduction of malnutrition-related problems in the country as a whole. The design and development of bean-based food products from the varieties that contain higher protein quality can be carried out to increase new types of value-added products that are affordable for most of the consumers/farmers.

5. Conclusions

The variability in the concentrations of α-galactosides, phytochemicals, sucrose and *in-vitro* protein digestibility of eight common bean varieties is evident. Genetic variability was the predominant factor in the observed variability. In the study, correlation was observed among *in-vitro* protein digestibility, phytochemicals, α-galactosides, sucrose, zinc and ash compositions for the common bean varieties analyzed. An increase in phytochemicals composition, especially in saponins and lectins concentrations, can lead to an increase in disease resistance. Hence, analyses of phytochemicals and the sucrose composition of common beans can be used as a identifying factor of the pest resistance of the cultivars.

This study could help breeders to select common bean varieties with reduced levels of phytochemiclas for human consumption through large-scale cultivation. Roba was found to be the best variety in terms of higher *in-vitr*o protein digestibility, lower level of flatulence-causing factors, tannins, lectins, saponins and trypsin inhibitors. Thus, the Roba bean variety could be used as a raw material for the manufacturing of bean-based value added products at industry level through large scale cultivation which in turn could help the bean farmers of Ethiopia to increase earning in the market. Bean varieties such as Gofta, Goberasha and Tabor could also be used as a raw material in the food/feed processing industries after the reduction of unwanted components through the use of appropriate processing technology. Similarly, in developing countries like Africa which utilize common beans to an immense extent, the release of potential varieties which have low phytochemical composition from research centres must be encouraged to support the nutritional requirements through the design and development of bean-based value added food products processed in agro-processing industries. Further investigations on product design and development, end-users preference and product diversification is required. Finally, attention must also be paid to the selection of genotypes (new cultivars) that meet consumer criteria in terms of dense nutrient content, preferred colour, required grain size, higher digestibility with fewer flatulence factors and low phytochemicals composition.

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Effect of Plant Density on Morphological Characteristics, Yield and Chemical Composition of Napier Grass (*Pennisetum purpureum* (L.) Schumach)

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Abstract: An experiment to assess the effect of plant density on morphological characteristics, dry matter production and chemical composition of Napier grass (*Pennisetum purpureum* (L.) Schumach) was conducted in 2004 and 2005 at Haramaya University, eastern Ethiopia. There were a total of nine treatments with 1.5, 1 and 0.5m spacing between rows and 0.75, 0.5 and 0.25m spacing between plants, which consisted of 8,888.9, 13,333.3, 26,667.7, 13,333.3, 20,000, 40,000, 26,667.7, 40,000, and 80,000 plants per ha, arranged in a randomized complete block design with three replications. The plot size was 3m width x 6m length and the spacings between replications and plots were 1.5m and 1m respectively. There was no significant (P > 0.05) effect in morphological characteristics of Napier grass due to plant density during the establishment year. However, the number of tillers, total leaves, internode number, internode length, basal circumference and leaf length per plant were significantly (P < 0.05) affected by plant density in the second year. There was a significant (P < 0.05) difference in dry matter (DM) yield due to plant density. A considerable variation in DM yield between the two years and number of harvests in each year was observed during the study and the DM yield in 2005 was much greater than the 2004 crop season. Higher DM yields were obtained from 80,000 (7.80 t/ha) and 40, 000 (39.9 t/ha) plant density in 2004 and 2005 respectively. There was no significant (P > 0.05) effect on the chemical composition of Napier grass due to plant density. However, the crude protein (CP) content of all the treatments was above 15%, which is the optimum required for animal growth or production. The fibre fractions were also below the threshold level (600 g/kg DM) at which DM intake of cattle is affected. Based on DM yield production and CP content, the production of Napier grass using 40, 000 plants per hectare is recommended to livestock producers in eastern Ethiopia agro-ecologies of the country.

Keywords: Chemical Composition; Dry Matter Yield; Morphological Characteristics; Napier Grass; Plant Density

1. Introduction

The development of the livestock sub sector in Ethiopia is hindered by many constraints of which unavailability of both high quantity and quality feed is the major factor (Azage *et al.,* 1995). More than 90% of livestock feed is crop residues and natural pasture in Ethiopia (Alemayehu, 2004), both of which are low in quantity and quality for sustaining animal production (Seyoum *et al.,* 1998), resulting in slow growth rates, poor fertility and high rates of mortality (Osuji *et al.,* 1993). The shortage of feed can be solved through the introduction and utilization of adaptable and high-yielding cultivated forage crops with better nutritional values than the existing feed resources in the country (Seyoum *et al.,* 1998; Tessema and Halima, 1998).

Amongst the improved forage crops introduced in Ethiopia, Napier grass (*Pennisetum purpureum* (L.) Schumach) could play an important role in providing a significant amount of quality forage, both for the smallholder farmer as well as intensive livestock production systems with appropriate management practices (Alemayehu, 1997; Seyoum *et al.,* 1998; Tessema and Halima, 1998; Alemayehu, 2002; 2004). Because of the importance of Napier grass in small-scale livestock farming enterprises, it is one of the most widely-used fodder crops among the livestock producers in Kenya (Annido and Potter, 1994; Kariuki *et al.,* 1998), Pakistan (Butt *et al.,* 1993), USA (Robert *et al.,* 1995), Malaysia, Tanzania (Kidunda *et al.,* 1990). It also performs well in the low, mid and highland areas of Ethiopia (Alemayehu, 1997; Seyoum *et al.,* 1998; Tessema and Halima, 1998). It is superior to many other tropical grasses in terms of dry season growth and forage quality (Bayer, 1990) and can support a large number of animal units (Sollenberger *et al.,* 1990) through the cut-and-carry system (Alemayehu, 1997; Kariuki *et al.,* 1998).

Napier grass has been introduced in soil conservation areas, around homesteads, road-sides and livestock exclusion areas by smallholder farmers due to land shortages in Ethiopia. With appropriate management practices, Napier grass can provide a continual supply of green forage throughout the year and best suits intensive small-scale farming systems (Orodho, 1990; Alemayehu, 1997). The present study was therefore designed to assess the effect of different plant densities on the morphological characteristics, dry matter production and chemical composition of Napier grass in semi-arid areas of eastern Ethiopia where information is lacking.

2. Material and Methods

2.1. Location, Treatment and Experimental Design

The napier grass plant density experiment was conducted on alluvial-vertisols (Tamire, 1982) at Haramaya University Research Centre (9º 26' N, 42º 03' E; 2240 m a s l). The 0-40cm layer of the soil before fertiliser application had a pH of 6.34, total N of 0.16, available phosphorus level of 0.66 ppm, organic matter level of 2.28% and organic level carbon of 1.33%. The twenty years mean annual rainfall for the area is 625 mm and the average annual air temperature is 20.15ºC. The monthly rainfall, number of rainy days, and the minimum and maximum air temperatures during the study are presented in Table 1.

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Table 1. Monthly total rainfall (mm), number of rainy days, and minimum and maximum air temperature during 2004-2005 at Haramaya, Ethiopia.

Months	Rainfall (mm)		Temperature (^{0}c)			
			Mean maximum		Mean minimum	
	2004	2005	2004	2005	2004	2005
January	38.2	0.5	24.15	21.43	9.3	9.65
February	0	2	23.95	24.26	5.85	6.25
March	25.4	39.9	25.65	24.45	8.85	8.76
April	163.5	119.5	23.9	25.7	14.2	13.5
May	39.5	198.3	26.45	23.7	11.7	12.5
June	25.5	19.2	24.75	25	14.1	14.4
July	71.32	68.1	24	23	13.3	13.2
August	116.4	126.2	24.5	24	13.6	13.5
September	126.7	156.4	24	23	12.1	12.5
October	43.8	17	25.04	23.1	6.45	11.2
November	38.6	33.6	24.7	23.7	5.5	7.9
December	4.5	0	21.43	22.4	4.0	6.1

The study was conducted in a randomised complete block design with three replications on a plot size of 3m (width) by 6 m (length). The spacings between replications and plots were 1.5m and 1 m, respectively. The treatments consisted of plant spacing of: 26,666.7 (1.5m row x 0.25m), 40,000 (1.0m row x 0.25m), 80, 000 (0.5m row x 0.25m), 13,333.3 (1.5m row x 0.5m), 20,000 (1.0m row x 0.5m), 40,000 (0.5m row x 0.5m), 8,888.9 (1.5m row x 0.75m), 13,333.3 (1.0m row x 0.75m) and 26,667.7 (0.5m row x 0.75m) plants per hectare. The treatment structure of the experiment is presented in Table 2.

Table 2. Row and plant spacing structures of the treatments during the experimental periods.

Row spacing (m)	Plant spacing (m)	Area/plant (m^2)	Number of plants/ha
1.5	0.25	1.5m x 0.25m = 0.375	26,666.7
1	0.25	1.0m x 0.25m = 0.25	40,000
0.5	0.25	0.5m x 0.25m = 0.125	80,000
1.5	0.5	1.5m x 0.5m = 0.75	13,333.3
1	0.5	1.0m x 0.5m = 0.50	20,000
0.5	0.5	0.5m x 0.5m = 0.25	40,000
1.5	0.75	1.5m x 0.75m = 1.125	8,888.9
1	0.75	1.0m x 0.75m = 0.75	13,333.3
0.5	0.75	0.5m x 0.75m = 0.375	26,667.7

2.2. Establishment and Management of Napier Grass

High-yielding and adaptable Napier grass accession (ILRI No. 16791) was vegetatively propagated using uniform root splits on well-prepared soil under rainfed conditions in the last week of July 2004 when the soil was moist. Diammonium phosphate was applied at planting at 100 kg ha^{-1} for establishment and urea at 50 kg ha^{-1} was applied after establishment as recommended (IAR, 1988). In the second year, the same amount of urea was applied at the start of the main rainfall after uniform cutting of all the plots at the same time.

2.3. Data Collection and Analytical Procedures

Vigour was rated visually on the scale of 1 = poor to 5 = excellent. Three plants in each treatment were randomly selected to record number of tiller per plant (NTPP), basal circumference per plant (BCPP), total number of leaves per plant (TLPP), internode number per plant (INPP), leaf length per plant (LLPP) and leaf: stem ratio (LSR). Two tillers from each randomly-taken plant were used to determine the number of leaves per tiller (NLPT) (Butt *et al.,* 1993; Tessema, 2000; Tessema *et al.,* 2003). Napier grass was harvested about 10-15 cm above the ground from all the treatments, excluding border rows, and all harvested samples from each plot were thoroughly mixed and 250 g was taken for dry matter (DM) yield determination by drying at 65^{o}C for 72 h (constant weight). Harvests were made 2 and 3 times in 2004 and 2005 respectively when the plant height reached 1 m. Representative whole plants from each treatment were oven-dried, ground to pass through a 1 mm sieve and stored in airtight containers for different chemical analyses. Ash was determined by igniting at 550 ^{o}C overnight, total DM by drying at 105 ^{o}C and N by auto-analyser (Chemlab, 1984). Crude protein (CP) was calculated as N x 6.25. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were determined according to Goering and Van Soest (1970). Hemicellulose and cellulose were calculated as NDF - ADF and ADF – ADL respectively. All the chemical analyses were done in duplicate (at the Haramaya University Animal Nutrition Laboratory.) to increase precision.

2.4. Statistical Analysis

Analysis of variance was carried out using the SAS (1998) General Linear Models' procedure and applied to randomized complete block design and mean separation was tested by least significant difference (LSD).

3. Results and Discussion

3.1. Morphological Characteristics

There was no significant (P > 0.05) effect in morphological characteristics of Napier grass due to plant density during the establishment year (Table 3). However, NTPP, TLPP, INPP, ILPP, BCPP and LLPP were significantly (P < 0.05) affected by different plant density in the second year (Table 4).

Table 3. Morphological characteristics of Napier grass as influenced by different plant populations during the establishment year.

Plant population	Morphological characteristics							
	Vigor	NTPP	NLPT	TLPP	INPP	BCPP	ILPP	LSR
26,666.7	5.00	22.27	11.00	244.64	6.00	70.67	7.67	1.24
40,000	5.00	25.53	11.73	264.76	5.67	65.00	6.33	0.98
80,000	5.00	20.67	12.33	252.77	6.00	64.33	8.23	1.07
13,333.3	4.00	18.93	11.33	216.03	4.67	58.67	6.17	1.08
20,000	4.67	24.20	10.80	257.04	4.33	48.33	5.60	1.08
40,000	5.00	20.80	11.53	239.21	4.67	51.67	5.40	1.41
8,888.9	4.33	24.13	10.00	236.21	4.67	61.00	4.97	0.93
13,333.3	3.33	18.80	11.27	206.21	4.67	54.67	7.03	1.30
26,667.7	5.00	20.40	11.27	229.33	5.00	64.00	7.80	1.11
Mean	4.59	21.75	11.25	238.50	5.07	59.82	6.58	1.13
s.e.	0.35	2.31	0.72	33.83	0.64	7.13	1.65	0.20
P level	*	NS	NS	NS	NS	NS	NS	NS

** = P ≤ 0.05; NS = Non-significant; NTPP = number of tillers per plant; BCPP = basal circumference per plant (cm); TLPP = total number of leaves per plant; INPP = internode number per plant; LSR = leaf: stem ratio; NLPT= number of leaves per tiller*

Table 4. Morphological characteristics of Napier grass as influenced by different plant populations during the second year of establishment.

Plant population	Morphological characteristics							
	NTPP	NLPT	TLPP	INPT	INPP	ILPT	BCPP	LL	LSR
26,666.7	62.3	15.3	955.5	10.3	637.0	14.3	198.7	116.7	1.02
40,000	35.0	15.0	525.0	9.7	372.0	15.7	153.3	120.7	0.94
80,000	36.0	14.7	528.1	10.3	381.3	17.3	167.7	127.0	1.00
13,333.3	38.3	13.3	510.9	8.0	297.7	17.3	160.7	121.0	0.95
20,000	29.7	14.0	415.5	10.0	297.0	15.7	125.3	125.7	1.09
40,000	22.7	14.0	317.4	8.3	176.3	16.0	126.7	126.7	1.12
8,888.9	59.3	15.0	890.0	10.0	596.7	19.0	191.3	121.7	0.95
13,333.3	32.0	14.0	448.0	9.0	289.3	16.0	141.7	121.3	0.90
26,667.7	24.3	14.0	340.6	8.3	200.3	17.7	125.0	128.3	1.01
Mean	37.74	14.47	547.9	9.33	360.9	16.6	154.6	123.2	1.00
s.e.	6.97	1.02	114.0	1.36	102.1	0.98	17.7	2.51	0.06
P level	**	NS	**	NS	*	*	*	*	NS

*** = P ≤ 0.01 * = P ≤ 0.05; NS = Non-significant; NTPP = number of tillers per plant; BCPP = Basal circumference per plant (cm); TLPP = total leaves per plant; INPP = internode number per plant; LLPP = leaf length per plant; LSR = leaf: stem ratio; NLPT= number of leaves per tiller*

The highest NTPP (62.3), INPT (10.3), TLPP (955.5) and BCPP (198.6 cm) were obtained from 26,666.7 plants per hectare. High morphological characteristic values of Napier grass were observed from medium and lower plant density compared to higher plant density per hectare during the study. This might be due to the fact that plants with wider spacing produced many fine-stemmed tillers and showed with vigorous growth and development and leafy structures because of reduced competition for space, moisture and nutrients during the growing period as reported by Wilson *et al.* (1989).

The general trend of LSR increased as the spacing between plants and rows increased in Bana grass (Berihun, 2005). Napier grass planted at 50 cm × 50 cm spacing produced 1.49 leaf to stem ratio (Taye, 2004) compared to plant spacing of 100 cm ×50 cm with 1.91 LSR (Tessema, 2000; Tessema *et al.,* 2003). Narrow spacing resulted in a higher number and longer internodes than wider spacing (Singh and Singh, 1971) and the tillering capacity increased with their relative increase in plant spacing. The maximum tillers in Mott Napier grass were recorded in spacing of 120 cm × 120 cm followed by 105 cm x 105 cm against the minimum tillers count in a spacing of 45 cm × 45 cm (Yasin *et al.,* 2003). Khan and Manghatt (1965) on pearl millet (*Pennisetum typhoides*) reported that the number of tillers increased consistently with an increase in plant spacing. Leaves' expansions from narrow spacing were smaller in length compared to those from wider spacing (Begna *et al.,* 2000).

3.2. Dry Matter Production

There was a significant (P < 0.05) difference in DM yield among the different plant densities in Napier grass (Table 5). Higher total DM yields were obtained from 80,000 (7.80 t/ha) and 40, 000 (39.9 t/ha) in 2004 and 2005 crop seasons respectively. There was also a considerable variation in DM yield between the two years and number of harvests in each year (Tables 5, 6).

Table 5. Dry matter production of Napier grass as influenced by different plant populations.

Plant population	Dry matter yield (t/ha)											
	2004/05 harvest					2005/06 harvests						Mean
	1st	2nd	Total	LDM	SDM	1st	2nd	3rd	Total	LDM	SDM	
26,666.7	4.1	2.0	6.1	3.4	2.8	20.2	17.9	0.8	38.9	19.8	19.1	22.5
40,000	4.27	1.7	5.9	2.9	3.0	22.0	15.8	0.9	38.7	19.0	19.7	22.3
80,000	5.9	1.9	7.8	4.0	3.5	17.6	14.5	1.0	33.16	16.4	16.7	20.4
13,333.3	3.2	1.3	4.6	2.4	2.2	14.9	15.6	0.6	31.0	15.3	15.7	17.8
20,000	3.1	1.3	4.4	2.2	2.2	17.3	16.9	0.9	34.9	18.4	16.5	19.7
40,000	4.2	1.9	6.1	3.5	2.6	24.0	15.1	0.9	39.9	21.1	18.8	23.0
8,888.9	3.0	1.7	4.5	2.1	2.7	12.6	22.9	0.7	36.2	18.2	16.1	20.5
13,333.3	2.3	1.6	3.9	2.1	1.9	20.5	18.8	0.8	40.0	19.2	20.8	22.0
26,667.7	3.6	1.6	5.2	2.7	2.3	18.2	18.6	0.9	37.7	18.7	19.0	21.5
Mean	3.8	1.7	5.4	2.8	2.6	18.6	17.4	0.9	36.7	18.5	18.36	21.2
s.e.	0.67	0.23	0.82	0.43	0.50	1.54	2.56	0.104	2.86	1.53	1.33	1.98
P level	*	NS	*	*	NS	**	*	NS	*	**	**	NS

*** = P ≤ 0.01; * = P ≤ 0.05; NS = Non-significant; 1st = First harvest; 2nd = second harvest; Total = Total dry matter yield (the sum of all harvests in each season); LDM = Leaf dry matter yield; SDM = Stem dry matter yield;*

Table 6. The combined analysis of variance (ANOVA) for Napier grass plant density experiments over the years (2004-2005).

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F calculated	Probability
Replication	2	419.208	209.602	8.8740	0.0008
Year	1	13215.926	13215.926	559.5214	0.0000
Treatment	8	129.686	16.211	0.6863	
Treatment x Year	8	143.214	17.902	0.7579	
Error	34	803.082	23.620		
Total	53	14711.116			

The DM yield in 2005 was much greater than in the 2004 crop season. This might be due to the perennial nature of Napier grass, which produces more tillers and high vegetative growth as the pasture period increases, as reported by Tessema (2005) and Ndikumana (1996) from tests on different Napier grass accessions in the north western parts of Ethiopia and many African countries. In addition, the number of harvests taken in the 2005 crop season was three but only two harvests were taken in 2004 since it was the year of Napier grass establishment. The DM yield of the first harvest was higher than the second or third harvests in each year because of the fact that the first harvest was taken during the rainy season where rainfall was sufficient for growth, while the second and third harvests were taken in the early and late dry seasons respectively which might have resulted in reduced DM yield production.

The present findings are similar to those of Berihun (2005) who reported that there was a significant (P < 0.05) effect on DM yield of Bana grass due to plant density in semiarid areas of north-western Ethiopia. However, the same author reported a non-significant (P > 0.05) effect on the combined DM yield of Napier grass due to plant density. The effect of plant density in Napier grass was enhanced in the year of establishment and in the dry seasons, contrary to the subsequent years and in rainy seasons and, consequently, the overall effect of plant density on long-term average annual yields was negligible (Boonman, 1993). In addition, most trials with plant density varying from 3333 (300 cm x 100 cm) to 20,000 plants (100 cm x 50 cm) gave almost identical herbage yields when totalled over wet and dry seasons for a number of years in Kenya, as indicated by Boonman (1993). Low plant density or wider spacing made an enormous difference to the rate of plant growth and yield performances, clumps expansion and filling for continuous growth within the rows compared to narrow spacing (Boonman, 1993). Dry matter yield increased as plant density increased. However, narrower row spacing may facilitate stand establishment and increase forage production in the early life of the pasture sward. Saeed *et al.,* (1996) on Mott Napier grass reported that close spacing produced higher productivity than wider plant spacing after establishment.

3.3. Chemical Composition

There was no significant (P > 0.05) effect on the chemical composition of Napier grass due to plant density during the study (Table 7). However, Berihun (2005) reported that the combination of row and plant spacing affected the CP, NDF, ADF, ADL, Ca, P and IVDMD values of Bana grass in semiarid areas of north western Ethiopia but a significant effect was not reported on cellulose and hemicellulose contents due to plant density (Berihun, 2005). This might be due to the fact that all the plant materials used in the study were from the same genetic accession and all the treatments were harvested at the same growth stage. Many research reports revealed that plant height at cutting (Tessema, 2000; Tessema *et al.,* 2002a; 2002b; 2003), stage of growth (McDonald *et al.,* 1988; Seyoum *et al.,* 1998; Tessema *et al.,* 2002a; Tessema and Baars 2003; Taye 2004; Berihun, 2005) and varietal difference (Ndikumana, 1996; Seyoum *et al.,* 1998 and Tessema, 2005) are the major factors that affect the chemical composition and digestibility of Napier grass.

Plant density did not show any significant effect on the chemical composition of Napier grass in the study; however, the CP content of all the treatments was above the minimum CP level of 75 g/kg required for adequate rumen function in ruminants (van Soest, 1984). The minimum CP content required for lactation and growth of cattle is 150 g/kg (Norton, 1982), suggesting that all the treatments were above the recommendation (range 158.3-171.8g/kg) and would satisfy the production requirement of ruminants. The threshold level of NDF in tropical grass beyond which DM intake of cattle is affected is 600 g/kg (Meissner *et al.,* 1991), suggesting that all the treatments have a lower value than this (range 533.4-554.5g/kg). In the study, the cellulose (range 256.7–271.7 g/kg) and hemicellulose (range 237.4-253.0 g/kg) contents of the treatments were lower than those of most tropical grasses, 319 and 354 g/kg respectively (Moore and Hatfield, 1994).

Table 7. Chemical composition of Napier grass as influenced by different plant populations.

Plant Population	Chemical compositions (% DM basis)									
	DM	CP	NDF	TA	ADF	ADL	Cellul	Hemi cel	SS	BS
26,666.7	96.63	15.83	54.49	15.04	29.44	3.60	25.86	25.06	2.24	1.88
40,000	96.27	16.12	54.93	14.68	29.64	3.33	26.31	25.30	2.06	1.81
80,000	95.57	15.46	55.45	14.64	31.09	3.91	27.17	24.36	1.66	2.05
13,333.3	96.07	16.62	54.68	15.56	29.54	3.74	25.80	25.14	2.62	1.93
20,000	95.10	17.18	53.98	14.63	29.39	3.57	25.81	24.60	2.47	1.73
40,000	95.90	16.39	54.97	15.23	29.79	4.12	25.67	25.18	2.44	2.09
8,888.9	96.13	16.21	54.56	14.72	26.62	3.06	26.55	24.94	1.99	1.92
13,333.3	96.67	17.06	53.61	14.85	29.87	3.50	26.37	23.74	2.49	1.73
26,667.7	96.13	16.74	53.34	15.07	29.91	3.58	26.33	23.43	2.33	2.20
Mean	96.05	16.40	54.45	14.94	29.81	3.60	26.21	24.64	2.26	1.93
s.e.	0.52	0.54	0.83	0.56	0.59	0.33	0.50	0.62	0.29	0.40
P level	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = P > 0.05; ADF = Acid detergent fiber; BS = Biogenic silica; Cellul = cellulose; CP = Crude protein; DM = dry matter; Hemicel = Hemicellulose; SS = Sand silica; TA = Total ash

4. Conclusions

In conclusion, there was no significant effect on the morphological characteristics of Napier grass due to plant density during the establishment year. However, NTPP, TLPP, INPP, ILPP, BCPP and LLPP were significantly affected by plant density in the second year. There was a significant difference in DM yield among different plant densities in Napier grass over the two seasons' study period. Higher DM yields were obtained from 80,000 and 46, 667 in the 2004 and 2005 crop seasons respectively. There was no significant effect on the chemical composition of Napier grass due to plant density during the study. However, the CP content of all the treatments was above the minimum CP level of 75 g/kg required for adequate rumen function in ruminants and the fibre fractions were below the threshold level at which DM intake of cattle is affected. Based on DM yield production and CP content, the planting of Napier grass using 40, 000 plants per hectare on 0.25m^2 area/plant; i.e. 1m x 0.25m or 0.5m x 0.5m would be advantageous to the smallholder farmers (in the semiarid areas of Ethiopia and in similar agro-ecologies of the country.) instead of large areas per m^2. Moreover, further studies on the economics of plant density are recommended as a means of achieving least-cost Napier grass pasture production in smallholder conditions in the semiarid areas of Ethiopia and other similar areas.

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Farmers' Perceptions on the Productivity of Water in Agriculture: A Case Study at Debre Kidane Watershed, Eastern Tigray, Ethiopia

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Abstract: Awareness of the knowledge of farmers on the productivity of water in agriculture (PWA) is the basis for all irrigation activities. This paper assesses the current knowledge level of farmers towards PWA in the Debre Kidane watershed which is located in eastern Tigray. It also identifies obstacles regarding the spread of knowledge of PWA and indicates the best knowledge-disseminating strategies and tools for raising awareness about PWA. Data for the study was obtained from a formal household questionnaire survey, key informant discussion and direct observations of farmers' fields. In the study area, the concept of PWA is new. All the farmers measure the crop harvested but not the volume of water used to produce it. Almost none of the irrigators know when their crop needs water and when to stop irrigating their crop. However, farmers are keen to discover methods which could help them to produce more crops per drops of water. Consequently, farmers indicated that training is the most suitable knowledge-sharing strategy for creating awareness about PWA, and its absence is the barrier that hinders them from recording PWA. Furthermore, they pointed out that training given through demonstration is their method of preference. Most of the farmers irrigate their farmland by checking the availability of the water in their shallow wells and irrigating their crop until the furrow holds up water. For better utilization of the groundwater resources in the area, the farmers have to be introduced to the concept of PWA.

Keywords: Groundwater; Knowledge; Productivity; Strategy; Tool.

1. Introduction

Producing enough food and generating adequate income in the developing world to feed the poor and reduce the number of those suffering is a great challenge. This challenge is likely to intensify, with a global population that is projected to increase to 7.8 billion in 2025, of which more than 80% of the population increase is expected to occur in developing countries (Kijne *et al.*, 2003). The picture for Ethiopia is more severe and serious as the country's food production per capita is below the average for Sub-Saharan African countries. Despite agriculture being the main sector of the economy, the performance of the sector has been unsatisfactory in Ethiopia since the problem of food security is still very serious (Lemma, 2004). In addition, the lack of adequate rainfall combined with the variability in the onset and duration of rain remains a major threat to agricultural production.

Irrigation development is an important means of achieving food self-sufficiency in many arid and semi arid countries, including Ethiopia, in order to address the main challenge caused by rainfall variability and moisture stress. However, irrigation has only been possible where there are adequately developed water resources. According to Rockström *et al.* (2003), irrigation accounts for about 72% of global and 90% of developing countries' water withdrawals and water availability for irrigation may have to be reduced in many regions in favor of rapidly increasing non-agricultural water use in industry and households, as well as for environmental purposes. They further stated that, with growing irrigation-water demand and increasing competition across water-using sectors, the world now faces a challenge to produce more food with less water. This goal will be realistic only if appropriate strategies are found for saving water and for more efficient water use in agriculture. One important strategy for alleviating this problem is an increase in the productivity of water in agriculture.

Productivity of Water in Agriculture (PWA) varies greatly according to the specific conditions under which the crop is grown. Due to this, researchers define productivity of water in agriculture (PWA) differently, for example:

1. The ratio of benefits obtained to the amount of water that is quantitatively or qualitatively depleted during the parsecs. The benefit may include biomass produced, the economic value of the produced or the value attached to the social benefits (Kijne *et al.,* 2003).
2. The ratio of the amount of water required for an intended purpose divided by the total amount of water diverted (Cai *et al.,* 2003). And,
3. The amount of crop harvested per unit volume of water used (Oweis *et al.*, 2003).

From all these definitions, in general PWA can be defined as the amount of crop produced per unit volume of water.

To increase the productivity of water in agriculture at farm level, improving the knowledge of farmers towards PWA through different means is essential. According to Kasele (2004), the preferred way of transferring information is face-to-face communication. However documents and others communication tools are also vital sources of knowledge acquisition. Knowledge-sharing among the farmers is also a means of improving and transfering the existing knowledge. A study conducted in Tanzania, Mkoji sub-catchment, by Kasele (2004) strengthens this idea that appropriate knowledge-sharing

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tools are needed to enhance the transferring of knowledge within different groups.

In Tigray there are 35 districts with a total population of four million, out of which 75% of the population are food insecure and seriously threatened by drought, which hit the region every 3 to 4 years (Hugo**,** 2003). A major climatic limitation for agricultural production in the region is erratic rainfall, often combined with intermittent dry spells that regularly have an adverse effect on the survival of crops. The study area is one of the food insecure and drought affected areas of the region. In the area, on average households harvest enough food for about 4.79 months of the year. The remaining food gap is supplemented by a combination of activities including: food purchased from the market, earning food from work and food relief. This is mainly due to the erratic and unreliable nature of rainfall. The watershed also has significant problems regarding the distribution of rainfall throughout the rainy season. According to the rainfall data record only, 5 % of the mean annual rainfall takes place in September. However, this month is the ripening period for most of the dominant crops. This is considered to be the main cause for the recurrent crop failure the area is facing. In addition, there is uneven rain distribution throughout the month on average for 5 -10 days between each rainstorm at some critical times. This uneven distribution of rain also has a negative impact on the normal growth of crops.

Currently, in the study area, the farmers are carrying out irrigation to cope with this problem. The source of water for the irrigation is groundwater. In the Debre Kidane watershed, around 361 hand-dug shallow wells were constructed from 2003 to 2005 for the purpose of irrigation as well as domestic and livestock use. The households are nowadays benefiting from the intervention by producing different high-value crops two to three times per year. In the study area, almost all the farmers measure the crop harvested but not the volume of water used to produce it. None of the irrigators knows when his/her crop needs water and when to stop irrigating their crop. They usually wait until the crop starts to wilt or the soil dries and irrigate their crop either until the furrow holds up water or the water in the shallow wells runs out. This exposes the groundwater of the area to high risk and mismanagement. Consequently, the farmers fail to utilize the groundwater resource more efficiently and in a sustainable manner. To avoid this unwise use of water and to properly utilize the groundwater to increase agricultural production, increasing the knowledge of farmers of PWA is crucial. The main objective of this research work was to assess the current knowledge level of the farmers towards PWA, identify the constraints related to it and offer a solution.

The specific objectives of this research are to assess the current knowledge levels of the farmers on productivity of water in agriculture, to identify obstacles regarding the spread of knowledge of PWA, to identify the best knowledge-disseminating strategies and to identify the best tools for raising awareness about PWA.

2. Methods

2.1. Description of the Study Area

The Debre Kidane watershed is located at about 106 km northeast of Mekelle in the Eastern Zone of Tigray National Regional State. Geographically, it is located between 39º 25' to 39º 30' E and 13º 52' to 13º 57' N (Figure 1). It has an aerial coverage of about 45.09 square kilometers, with a mean altitude of 2200 meters above sea level.

The mean annual rainfall of the area is 524.08 mm. Monthly rainfall distribution in the area is concentrated mostly from mid-June to mid-September. The mean annual temperature is 18.1 ºc, and the yearly average maximum and minimum temperatures are 25.1 ºc and 10.8 ºc respectively. The annual range of temperatures is 3.7 ºc.

The watershed comprises of two 'Tabias', which are the smallest administrative units: Debre Birhan and Selam. The total population is 13, 279 with a percentage of 50.3% for females and 49.7 for males. The number of households is 3761 from which about 35% are headed by females and 65% by males.

2.2. Data Sources

The data for the study was collected from both primary and secondary sources. Primary data was obtained from a formal household questionnaire survey, key informant discussions and direct observations of fields. The farmers' questionnaires generally included questions about current levels of knowledge of productivity of water in agriculture, the existence of obstacles to knowledge flow, the best mechanisms for dissemination of knowledge and appropriate knowledge-sharing tools for raising awareness about PWA. Questions to generate data about personal household resources were also included in the questionnaires. Moreover, some general information about the major problems of the farmers regarding the efficient utilization of groundwater for irrigation and the socio-economic conditions in the community were obtained from key informant group discussions at site level. In the focus-group discussions, experts from the extension service, individuals who were believed to be knowledgeable about the past and present history of the watershed, irrigation water users and rain-fed agriculture practicing farmers,, committee members of the irrigation water users' association, executive members of peasant associations and development agents were questioned.

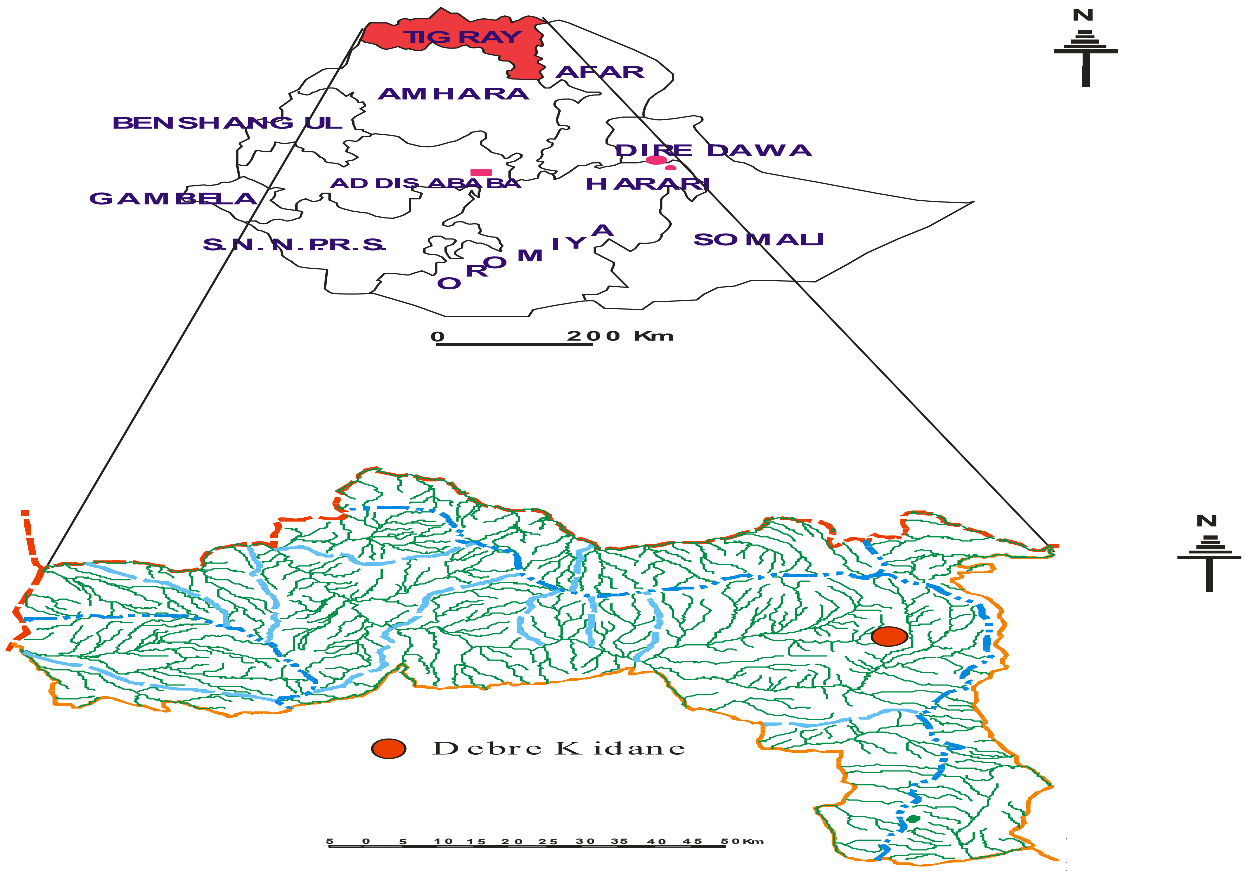

Figure 1. Location map of the study area.

The sample population for the study was drawn from the two 'Tabias' of the study area. By using stratified sampling, the sample populations were drawn both from farmers who practised irrigation and farmers who practised only rain-fed agriculture. The total number of households was obtained from the District Bureau of Agriculture (Table 1). From this number, systematic random sampling was used to select total sample populations. Accordingly, 36 and 72 households were interviewed from a total of 361 irrigation users and 3400 households who did not practise irrigation respectively.

In addition to the primary data, secondary data which is relevant to the research was collected from different sources. The collected data was analyzed using SPSS software.

Table 1. Total number of households and sample size selected from each 'Tabia'.

'Tabias'	TT HHS SW	Sample Size	TT HHS	Sample Size
Debre Birhan	226	23	2200	44
Selam	135	13	1400	28
Total	361	36	3600	72

Source: District Bureau of Agriculture.

NOTE: TT HHS SW: Total households that have shallow wells.

TT HHS: Total households that don't have shallow wells

3. Results and Discussions

3.1 Perspectives of Farmers on PWA

3.1.1 Rain-Fed Agriculture

The main rainy season is from mid-June to September. According to the responses of the farmers, this is their only season for crop production. The major crops grown under rain-fed agriculture are barley, wheat, mixed crops (wheat and barley), teff, finger millet, maize, peas and beans.

Out of the 72 respondents, all of them gave r responses about PWA. Seventy six per cent of the respondents indicated that the concept of PWA is new to them. Twenty four per cent of the respondents indicated that they understand PWA and relate PWA with good yield in a good year and poor yield in a bad year. According to the farmers, a good year is the time when a sufficient amount of rainfall is recorded throughout the growing season and a bad year is characterized by both low and high rainfall that results in moisture stress and water-logging problems respectively.

In general, there is an understanding that water is an important input in agricultural production and farmers relate production from rain-fed agriculture to the frequency, intensity and duration of rainfall that has a direct influence on the yield of crops.

3.1.2 Irrigated Agriculture

The main irrigation season is from November to June. The major crops grown using irrigation are onion, tomato, cabbage, potato and maize. Those farmers who have neither a motor pump nor a treadle pump usually irrigate their farmland at 15-day intervals, whereas those farmers who have either a motor pump or a treadle pump normally irrigate their farmlands at 5 or 10 day intervals.

The timing of different irrigated crops varies according to the types of crops and their growing stages. According to the farmers' responses, vegetables are the ones that take the longest time to irrigate.

Out of the total 36 respondents, all of them gave their responses about their understanding of PWA. Eighty one per cent of the farmers indicated that the concept of PWA is new to them. Nineteen per cent of the farmers claimed to know the meaning of PWA. These farmers who claimed to know the meaning of PWA were farmers who had taken related training when they were in Eritrea. When asked what PWA means, those who claimed to understand its concept gave different definitions. The first definition given by four of the farmers is "the amount of water that is put onto the farm when needed by the plant". A further two farmers said that PWA is "the amount of water that is put onto the plant at each irrigation time" and one of the farmers explained PWA as "the amount of water that is used for irrigation purposes throughout the plant-growing time". Apparently, even those farmers who said they knew the meaning of PWA did not appear to have grasped the concept. None of the farmers in the study area measured the amount of water that they applied during each irrigation period. From the sample population, all of them reported that they put water on their farmland after checking the availability of the water in their shallow wells. Farmers also put water onto the farmland when the plants showed signs of wilting and irrigated their crop until the furrow held water. However, some of the farmers who took training organized by the District Agricultural Bureau and other nongovernmental organizations are aware that the amount of water that should be added to the farmland is different depending on the conditions. As shown in Figure 2, the respondents are well-informed about the fact that crop type, plot size and soil type are the most influential factors for determining the frequency and amount of irrigation water used on the farm plot. Nevertheless, according to the farmers, due to limited availability of groundwater in their shallow wells and, in some cases, labor, they are unable to take such factors into consideration.

3.2 Obstacles to the Spread of the Knowledge of PWA

The concept of PWA is new in the study area. Almost all the farmers measure the crop harvested but not the volume of water used to produce it. Out of the total 36 respondents, all of them gave their responses regarding the obstacles to the spread of knowledge of PWA. All of them indicated that there are obstacles to the spread of knowledge of PWA.

Fifty three per cent of the respondents indicated that absence of training is a barrier regarding the spread of knowledge of PWA. Thirty one per cent and sixteen per cent of the respondents indicated that absence of appropriate training (i.e., training related to water) and absence of adequate training respectively are the barriers regarding the spread of knowledge of PWA. The implication may be that farmers fail to use irrigation water properly due to lack of knowledge about how to use the groundwater properly.

3.3 Knowledge-Sharing Strategies for Creating Awareness on PWA

Sharing knowledge is a social activity that is useful to create awareness about different things. In a complete knowledge-sharing system, meeting the right person or group of people would be of great importance to equip oneself with sound information (Kasele, 2004).

Out of the total 36 respondents, all of them gave their responses regarding strategies for raising awareness about PWA. Seventy two per cent of the respondents indicated that training is the most suitable knowledge-sharing strategy for raising awareness about PWA, whereas eleven per cent respondents indicated that knowledge- sharing with different people is the best way. Seventeen per cent of the respondents indicated that both training and knowledge-sharing with different people are important ways to procure knowledge about PWA.

Although most of the respondents selected training as a more useful and suitable strategy to raise awareness about PWA, most of them had not participated in any training. Out of the total 36 respondents, fifty three per cent of respondents indicated that they had not attended any type of training. The remaining forty seven per cent of respondents indicated that they had taken training. Out of the respondents who claimed to have taken training, thirty one per cent said that the training conducted by the District Agricultural Bureau and other nongovernmental organizations was not related to water use, but focused on how to construct shallow wells and use different pumps. Only sixteen per cent of the respondents who attended the training said it was related to water productivity. During the interview, it was discovered that these farmers took the related training when they were in Eritrea where they lived before. It was also reported earlier that these farmers do not have sound knowledge about PWA and fail to apply the little "knowledge" they have due to several factors, such as shortage of water, labor force, etc.

During the interviews, the respondents who claimed the training was related to PWA said that trainers used theoretical methods rather than practical ones. Consequently, they could not understand the intended output of the training. Focus group discussion sessions were also held to identify suitable knowledge-sharing strategies to raise awareness about PWA. From the results, training was preferred by the group.

3.4 Knowledge-Sharing Tools

Out of the total 36 respondents, all of them gave their responses on suitable tools or teaching methods during training to create awareness about PWA. Eighty three per cent of the respondents indicated that they prefer training given through demonstration. Their reason for choosing demonstration as their number one choice is its potential to allow them to learn by observing and doing. The remaining seventeen per cent of respondents favor field visits as the most suitable teaching method for training to raise awareness about PWA. According to them, this will give them the opportunity to share experiences with others who are well-experienced.

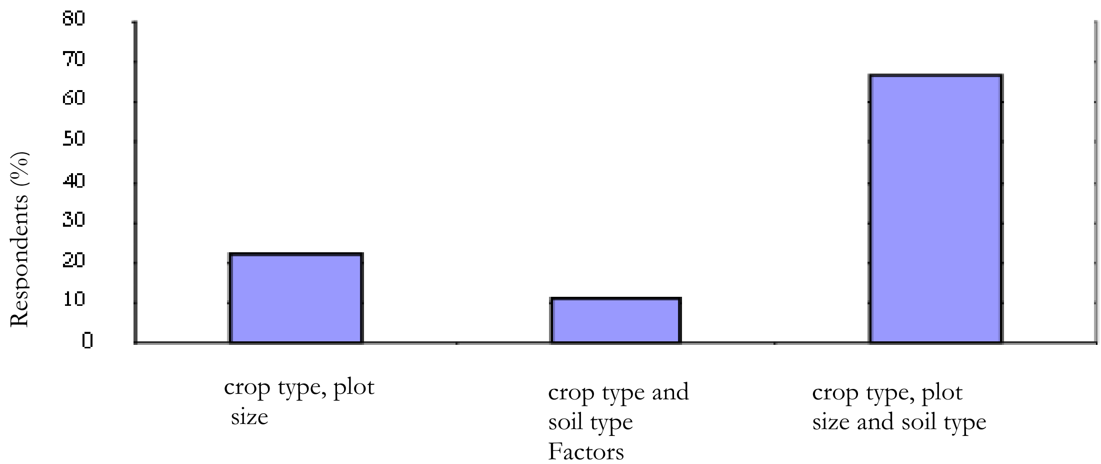

Figure 2. Factors influencing the frequency and amount of irrigation.

7. Conclusion

The introduction of water harvesting and its use for irrigation in the region is a recent phenomenon. So it is not surprising to learn that the majority of farmers practising irrigation are unaware of the concept of productivity of water in agriculture (PWA).

To make irrigation efficient and sustainable, coordinated intervention is required by all stake holders. Training on methods of irrigation and irrigation scheduling with the help of simple charts that can be easily understood by farmers is one of the areas that requires due emphasis. Similarly, when and how much to irrigate crops grown under irrigation, which is the basis for irrigation scheduling, should be calculated by professionals who are working in the field.

8. Acknowledgment

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Determinants of Household Food Security in Drought Prone Areas of Ethiopia

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Abstract: This paper documents the determinants of household-level food security based on the data collected in 2003 from 954 randomly-selected households in major drought-prone areas of Ethiopia; namely from the West and East Haraghe zones of Oromiya and South Gonder zone of Amhara. The food security is assessed using the calorie intake, anthropometrical measures and based on household-declared perceptions about the food security situation. The Probit model for factors affecting the food security level and the Tobit model for factors affecting the incidence of food security were employed. Factors that significantly affected the food security level are agro-ecology, family size, number of crops grown, number of plots owned, access to drinking water, the wealth status of the household and the number of community-based organizations (CBOs) in the village. The incidence of food security was significantly affected by agro-ecology, number and types of crops grown, access to climatic information, proportion of household members with formal education, number of CBOs in the village and the adoption of soil conservation measures. The results confirm the important role of some of the development interventions of both government and non- governmental organizations (NGOs) to promote food security through formal education, soil and water conservation measures and production diversification. In addition, important factors that need to be considered are access to climatic information and strengthening the role of CBOs.

Keywords: Food Security; Calorie Intake; Anthropometric Measures; Ethiopia; Probit; Tobit

1. Introduction

Food security exists when "all people at all times have access to safe nutritious food to maintain a healthy and active life" (FAO, 1996). The main goal of food security is for individuals to be able to obtain adequate food needed at all times, and to be able to utilise the food to meet the body's needs. Food security is multifaceted. In general, there are three pillars underpinning food security; these are food availability, food accessibility, and food utilization. Food security is, therefore, not only a production issue. In addition, Maxwell (1996) suggests including related concepts of access, sufficiency, vulnerability, and sustainability in defining food security

Food availability for the subsistent farm household means ensuring food availability for the household through its own production. However, due to lack of adequate storage facilities and pressing needs, most households are forced to sell excess produce during the harvesting period and sometimes rely on market purchases during the hungry season.

Food access means reducing poverty. Simply making food available is not enough; one must also be able to purchase it, especially the low-income households. D'Silva and Bysouth (1992) defined absolute poverty as lack of access to resources required for obtaining the minimum necessities essential for the maintenance of physical efficiency. This implies that the poor farmers will have little access to food, either produced or purchased. Farm families with limited access to productive resources such as land, inputs and capital required for attaining physical efficiency in food production could be food insecure i.e. resource poverty could lead to low productivity, food insufficiency, and lack of income to purchase the required calories.

Food utilization means ensuring a good nutritional outcome, which is nutrition security. Having sufficient food will not ensure a good nutritional outcome if poor health results in frequent sickness. Building this pillar means investing in complementary resources such as nutrition education, health care, provision of safe water and better sanitation, instituting gender symmetry, and removal of child abuse practices (Doppler, 2002).

Therefore, food security can be defined in terms of food availability, food access and/or food utilization, taking into consideration the factors of farm and farmers' characteristics, access to services (education, market, credit, health, water, extension etc) and other related factors that emanate from the interplay of ecological, social, demographic and economic factors.

The food security situation in Ethiopia has been deteriorating from time to time due to the degradation of natural resources, dependence on rain-fed agriculture, and unbalanced population growth. In 2003, Ethiopia's population was estimated to be approximately 67 million people. In 2001, UNDP estimated that 81.9% of that population lived on under US$1 per day and placed Ethiopia 92nd out of 94 countries on the Human Poverty Index, 169th out of 175 countries on the Human Development Index. The numbers underlying those indices are sobering: Ethiopians' life expectancy is 45.7

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years, HIV/AIDS affects 6.4% of adults, one of every six children dies before age 5 and 52% of children under-five are growth-stunted.

The overall objective of the paper is to assess the level of food security and its determinants among the rural households in the drought-prone areas of Ethiopia. The specific objectives are to:

- document the level of household-level food security using anthropometric measures, level of calorie intake, and based on the farmers' declared level of food security; and
- identify the determinants of the level and incidence (intensity) of household food security

2. Methodology

2.1. The Data set

A classic two-stage cluster sampling design based on Magnani (1997) was used to collect the data used in the three drought-prone and CARE Ethiopia target zone, namely the West Hararghe and East Haraghe areas in Oromiya Region and the South Gonder zone in Amhara region. Primary clusters were localities, selected using PPS (Probability Proportional to Size). Secondary units were households which were selected using random sampling methods. Accordingly, a total sample size of 954 households was selected for primary data collection and the data was collected between May and August 2003. The distribution of the sample size by District (woreda), zone and region is summarized in Table 1.

Table 1. Number of sample households by region, zone and district.

Region	Zone	District	Sample size	%
Oromia	West Hararghe	Chiro	155	16
		Doba	92	10
	East Hararghe	Bedeno	185	19
		Kurfachellee	93	10
Amhara	South Gonder	Laygaint	429	45
Total			954	100

2.2. Approaches for Measuring Food Security

In general, the available literature suggests four approaches for measuring food security (Maxwell, 1996; Aldrerman and Marito, 1994; Shiferaw and Tesfaye, 2004). The first approach is for measuring food consumption (often calorie intake), which normally uses two methods: the "disappearance" method and 24- h recalls of food consumption. The second approach follows anthropometrical measurements, where the level of food security is estimated based on the height for age, weight for age, and/or weight for height Z-scores. The third approach is based on the measurement of coping strategies as a food security index. The fourth approach is based on the household's perception about the level of food security over the year.

In this paper, the food security situation is assessed using the calorie intake and anthropometrical measures and is also based on household-declared perceptions about the food security situation.

2.3. Methods of Data Analysis

The study employs descriptive statistics on the indicators of food security and socioeconomic characteristics of the sampled households. Factors affecting the household-level food security indicators are determined using limited dependent variable models as the dependent variables are categorical or range in value between zero and one.

The first model uses a dependent variable quantified based on the level of calories consumed per head and day. Dietary allowances of nutrients have been recommended by national and international bodies from time to time, based on the available scientific information on human requirements. Dietary standards may vary from country to country and serve as guidelines for planning and procuring food supplies for population subgroups, for interpreting food consumption records of individuals and populations, for establishing standards for food assistance programs, for evaluating the adequacy of food supplies in meeting national nutritional needs, for planning diets, for designing nutrition education programs and for developing new products in the food industry (Mohammad and Mohammad, 1998). Based on the WHO recommendation, an adult-equivalent person should consume at least 2000 k calories of energy per day, even though this varies from country to country and region to region. Maxwell (1996) recommends that households that get about 80% of the recommended level of calorie intake can be considered as food-secured. Thus, those households that are able to get at least 80% of the recommended rate were considered as food secured (value = 1) and those with less than the recommended value were considered as food insecure (value = 0) for this analysis. The functional form appropriate for such a type of analysis is the binary choice model, where the dependent variable takes only two values (zero and one). The most frequently-applied models are *Logit* and *Probit* (Greene, 1997; Aldrich and Nelson, 1984; Amemiya, 1981). This helps to identify the factors affecting the general food security level of households. Both models give comparable results, particularly when the sample size is high. In this report, the probit model is used mainly because it best fitted the data. The probit model is specified as:

$$Z = \beta' X + \varepsilon \quad \varepsilon \sim \mathrm{N}(0,1)$$

$$Y = 1 \text{ if } Z > 0 \text{ and } Y = 0 \text{ if } Z \le 0$$

Where:

β' –vector of parameter to be estimated
Z is observed probability of adoption
Y is estimated probability of adoption
X – vector of independent variables
E – Error term

The second model is based on the households' perceptions of the food security situation and the proportion of months the household considers as food-secured in a year is used as a dependent variable. In this case, the value 1 represents the fact that the household is food-secured throughout the whole year. In such a situation, *Tobit* is the appropriate functional form (Green, 1997), which enables the identification of factors affecting the intensity (incidence) of food security level of the households. This is because the proportion of months that the household is food-secured to the year shows how the food insecurity situation is severe among households. The Tobit model is specified in terms of an index function as follows:

$$Y_i^* = \beta^I X_i + \varepsilon_i \ \varepsilon_i \sim \mathrm{N}[0, \sigma^2]$$

$$Y_i = 0 \text{ if } Y_i^* \leq 0$$

$$Y_i = Y_i^* \text{ if } Y_i^* \geq 0$$

Where Y_i is a limited dependent variable,

Y_i^* is an underlying latent variable that indexes the level of the food security

X_i is independent variable,

β^I is a vector of parameters to be estimated

ε_i is the error term

The two models were arranged independently for Hararghe, Laygaint and for the whole sample in order to see the difference in the importance of the hypothesized determinants across the two locations. Thus, it is important to test whether there is a significant difference in the coefficients of the food security level determinants between the equations for Hararghe and Laygaint. For this purpose, the Chow test was employed. For each case, a test for multi-collinearity among the respective explanatory variables was checked using Variance Inflation Factor (VIF).

3. Results and Discussion

3.1. The Status of Food Security

3.1.1. Anthropometrical Measures

The anthropometrical measures of a child from 6 - 59 months of age in each household were taken during the survey. If there was more than one child in the stated age range, a child was randomly selected in each household. The result of the nutritional status of the child is summarized in terms of weight-height (WHZ), weight-age (WAZ) and height- age (HAZ) z-score in Table 2.

Comparisons can be made using the standard cut-off points for the nutritional and dietary indicators. The widely accepted cut-off point for height for age (HAZ) and weight for age (WAZ) z- score value is - 2.00, where for values of HAZ and WAZ less than -2.00 the household is considered to have growth-stunted and underweight children respectively. For weight-for-height z-score (WHZ) the cut-off point is - 1.00, where for values less than -1 the household is considered to have wasted children (Maxwell, 1996). However, the author Cogill (2001) recommends using -2.00 as a cut-of point for all three anthropometric measures. In this report, Cogill's recommendation was used.

The average values of WHZ, WAZ and HAZ show that the average household in the study area had no wasted, stunted or underweight children as the values are below the cut-off points. When the data is separated according to district, however, the average household in Laygaint has wasted, underweight and stunted children and in Kurfachelle there is also evidence that there are households with underweight and stunted children (Table 3.)

Using a cut-of point in the nutritional measures (a Z-score of -2.00 for height for age, weight for age, and for weight for height), the proportion of households with underweight, stunted and wasted children is presented in Table 3. In the study area 26%, 22% and 7.13% of the households had underweight, stunted and wasted children respectively.

Calorie Intake

The self-declared level of total consumption and production for the different crops was used to estimate the actual level of calorie intake per head in each household. The family size was first converted into adult equivalent[1] in order to estimate the calorie intake per head in a comparable manner. The conversion factor used to convert the different types of crops into calorie was based on Asrat and Lakech (1994) and Burton (1989).

In general, categorizing households based on the level of per capita calorie intake depends on the age and sex of the household members, which requires the conversion of different household members into comparable indicators. Accordingly, adult-equivalent figures were used to calculate the calorie intake per head in each household. The standard calorie requirement for an adult equivalent (2000 kcalorie/day/head) was compared to the actual calorie intake. Some authors recommend considering households who get at least 80% of the recommended calorie intake as food secure. Maxwell (1999) suggests considering a household that provides less than 80% of the calorie requirement for its total number of adult equivalents as food-insecure. Accordingly, the same figure has been adapted to categorize households into food secure and insecure.

[1]The factor used to convert household members into adult equivalent is 0.4 for 0-24 months old, 0.48 for 25-48 months, 0.56 for 49-59 months, 0.56 for 5-6 years old, 0.64 for 7-8 years, 0.76 for 9-10 years, 0.8 for 11-12 years, 1 for 13-14 years, 1.2 for males 15-18 years, 1 for females 15-18 years, 1 for males 19-59 years, 0.88 for females 19-59 years, 0.88 for males older than 60 years, and 0.72 for females older than 60 years old.

Table 2. Nutritional status of children (6 - 59 months old) by district.

District		WHZ (Wasted)	WAZ (Underweight)	HAZ (Stunted)
Chiro	Mean	-0.82	-1.79	-1.87
	Std. Deviation	0.97	1.06	1.25
	N	92	92	92
Doba	Mean	-0.83	-1.46	-1.24
	Std. Deviation	0.79	1.02	1.61
	N	38	38	38
Laygaint	Mean	-1.03	-2.06	-2.04
	Std. Deviation	0.83	0.94	1.18
	N	219	219	219
Bedeno	Mean	-0.98	-1.77	-1.59
	Std. Deviation	0.93	1.10	1.46
	N	115	115	115
Kurfachelle	Mean	-1.04	-1.99	-1.89
	Std. Deviation	0.97	1.02	1.33
	N	50	50	50
Total	Mean	-0.97	-1.90	-1.83
	Std. Deviation	0.89	1.02	1.33
	N	514	514	514
F-value		1.17	4.06***	4.33***

*Note: *** shows significant difference among districts at p < 1%*

Table 3. Health status of households (% of households with children underweight, stunted and wasted).

Anthropometric measures		District					Total
		Chiro	Doba	Laygaint	Bedeno	Kurfachell	
Underweight	Yes	26.45	9.78	29.14	24.32	30.11	26.00
	No	32.90	31.52	21.91	37.84	23.66	27.88
	No child	40.65	58.70	48.95	37.84	46.24	46.12
Stunted	Yes	28.39	6.52	24.94	20.54	22.58	22.64
	No	30.97	34.78	26.11	41.62	31.18	31.24
	No child	40.65	58.70	48.95	37.84	46.24	46.12
Wasted	Yes	5.81		7.46	10.81	7.53	7.13
	No	53.55	41.30	43.59	51.35	46.24	46.75
	No child	40.65	58.70	48.95	37.84	46.24	46.12

Source: Survey result

In calculating the amount of calorie intake per adult equivalent in each household, two estimates of consumption were taken into consideration. The first was the self-declared level of consumption by crop type and the second was the total production of crops in each household. The production level is assumed to estimate the level of actual consumption, more effectively as the amount sold is usually substituted by consumption good. The result in Table 4 shows that the average proportion of food-secured households is about 21% of the total households, considering total consumption declared by the households; whereas about 33% of the households were food-secure, considering total production to estimate the calorie intake. Thus, on average, the proportion of food-secure households ranges from 21 to 33% of the total households based on the level of calorie intake. There are statistically-significant differences among districts for both estimates of calorie intake using consumption and production (Table 4).

Taking into consideration the dominance of the agricultural sector in the rural communities in the country in general, and in the study area in particular, it is expected that most of the farmers will produce more than their requirement so that there will be excess production over the household requirement. However, only 33% of households were able to produce enough to fulfill their calorie requirements from their own production. In other words, household-level self-sufficiency is achieved by only 33% of the sampled households. The highest proportion of households that secure their calorie requirements from their own production was observed in Laygaint (38%) and the least in Doba (18%).

Table 4. Proportion of food secure households based on calorie intake.

	Basis for Calorie intake calculation			
	Consumption		Production	
District	Mean (Std)	N	Mean (Std)	N
Chiro	0.17 (0.38)	130	0.24 (0.43)	129
Doba	0.07 (0.26)	83	0.18 (0.39)	84
Laygaint	0.22 (0.41)	382	0.38 (0.49)	390
Bedeno	0.30 (0.46)	176	0.36 (0.48)	175
Kurfachelle	0.18 (0.38)	85	0.27 (0.45)	86
Total	0.21 (0.41)	856	0.33 (0.47)	864
F-value	5.18***		5.22***	

*Note: *** significant at P<1%, N = number of households*

Farmers' Perceptions of Food Security

In this case the self-declared level of food security for each month in a year was considered to identify whether the household was food-secured or not. The perceptions were assessed considering the respondent's lifetime experience for a typical year. The number of months in a year the household declared it was food-secured is used to calculate the proportion of food-secured months to the year, which is used as a proxy for the level of food security. A household with a value of one is then food-secured throughout the whole year.

Table 5. Average proportion of a year with food security by district.

District	Mean	Std. Deviation	N
Chiro	0.28	0.20	155
Doba	0.38	0.21	92
Laygaint	0.51	0.19	429
Bedeno	0.49	0.20	185
Kurfachell	0.44	0.23	93
Total	0.45	0.22	954
F-Value	41.97***		

*Note: *** indicates significance at P <1%*

On average, households in the study area are food-secured for 45% of the time in a year. However, there is significant variation among districts; the lowest period of time in the year can be observed in Chiro (28%) and the highest in Laygaint (51%).

Moreover, the proportion of households with food security to the total sample households was quantified for each month by district to see the distribution of food insecurity level over the year. The trend in Figure 1 shows that a relatively higher proportion of households is food insecure from May to October (68% - 91%) and a lower proportion during November to April (6% - 46%). This is line with the crop production pattern, which is associated again with the rainfall pattern.

The highest proportion of food-unsecured households was observed in August and September in Chiro and Laygaint; in July and August in Doba and Kurfachelle; and in June in Bedeno. Overall in the study area, severe food insecurity can be observed from June to September in a year, based on the proportion of food-insecure households. Out of all the months, August can be seen to be the critical period of food insecurity.

Looking into the trend of the proportion of food insecure households in Bedeno, it shows that the food insecurity problem starts to increase in January and diminishes at the beginning of June, whereas in Laygaint it starts to increase in early February and starts to diminish late in October in the year (Figure 1). This is due to the difference in the cropping patterns because in Bedeno farmers usually grow crops that mature early compared to the crops grown in Laygaint. Thus, in Laygaint there is a need to incorporate into the farming system early-maturing field crops and also horticultural crops like alternative root crops (Yam, Anchote and cassava) that can supply edible parts for a considerably longer period.

Determinants of Food Security

The descriptive statistics of the variables used in the regression analysis of the determinants of food security are presented in Table 6. The dependant variable, dummy variable, is determined based on the level of calorie intake, which is quantified based on the household level of crop production.

The maximum likelihood estimates of the probit[2] models shown in Table 7 indicate that seven factors are found to significantly affect the level of food security in the study area. Among the demographic factors, family size negatively affects the food security status of households. The number of plots and crops grown influenced the level of food security positively. This is due to the fact that crop diversification in a drought prone area is one of the major strategies for minimizing production risk. Similarly, as the number of plots increases, their allocation is expected to be in different places with difference in soil productivity, climate and other production factors. Thus, an increased number of plots can also serve as a means to reduce production risk. In addition to reducing factor productivity, increased fragmentation was also found to reduce production risk.

[2] Probit model is used instead of logit due to its better fit to the data

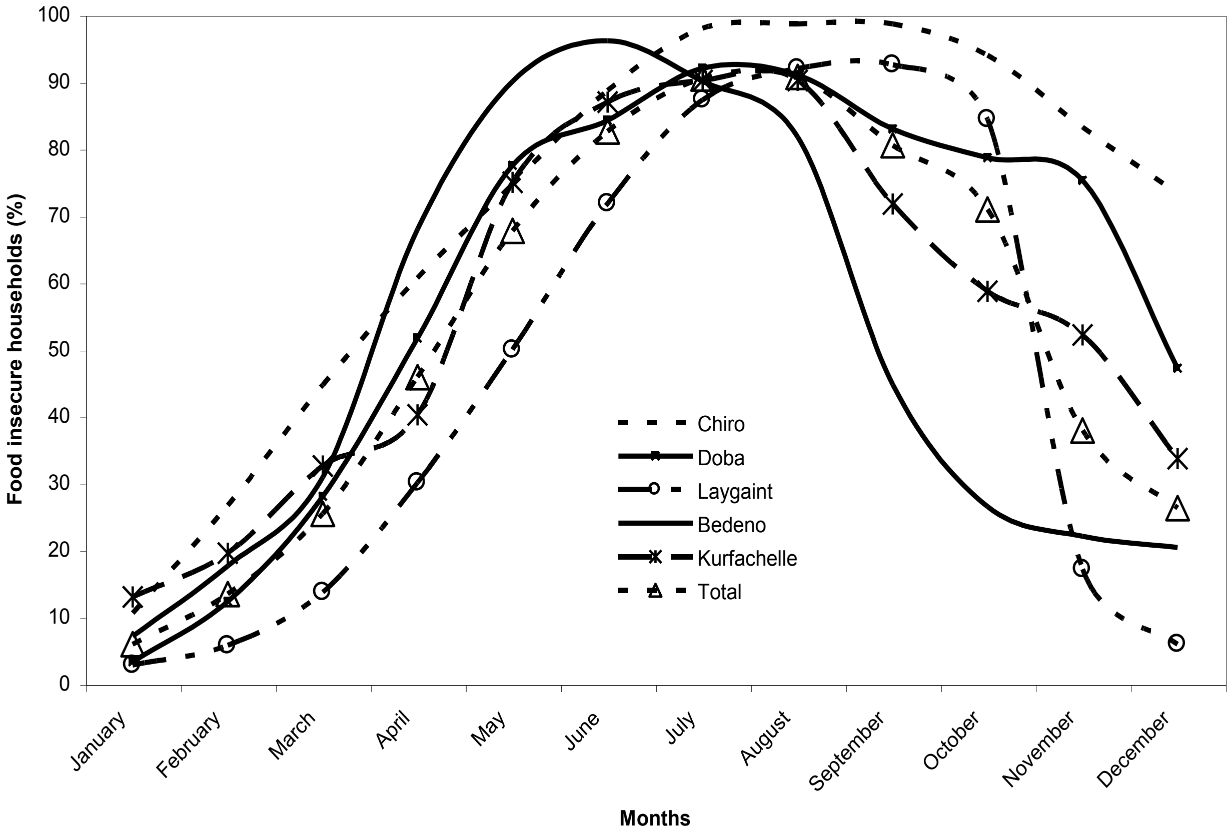

Figure 1. Proportion of food insecure households of the total sample households (%)

Access to drinking water proxied by minutes of walk also negatively affected the food security level, showing that households that are near to water sources are more food-secure than those who need to travel larger distances. Therefore, interventions that can improve access to drinking water are very important for improving the food security situation in the study area. The number of community-based organizations in the village also affected positively the level of food security in the study area (Table7)

The effect of agro-ecology can also be seen as significant where, on average, households in mid highland (woina Dega) areas are less food-secure compared to those in highland (Dega) and lowland (kola) areas.

Due to the expectation that there will be variation in factors affecting the food security level between Laygaint (more of highland with long period intensive cultivation and very poor soil) and Hararghe (Chiro, Doba, Bedeno and Kurfachelle, which are more lowland with shortages of rainfall), a probit model was arranged for both areas independently (Table 7). The result shows that in Laygaint only family size, farm size, the number of cultivated crops and the number of CBOs in the village affected the level of food security. Significant agro-ecological differences were also observed. In Hararghe, on the other hand, agro-ecology, family size, the number of crops grown, access to drinking water, access to information about credit, the wealth status of the household, the proportion of household members with a formal education, and the number of community based organizations in a village were found to be significant. All the factors that significantly affected the food security situation show the expected signs except the proportion of household members with formal education in Hararghe. This could be due to the fact that according to the current mentality which prevails socially, a person with a formal education does not intend to work on a farm but the opportunities of finding work off-farm are very limited, causing households with more members with a formal education to be less food secured. This needs intervention to change the prevailing mentality that rural people have a limited formal education level and encourage youngsters to work hard.

In general, family size, number of crops grown by the household, number of CBOs and Woina Dega agro ecology are found to be consistently significant factors affecting the food security situation. As family size increases, the level of household food security diminishes. Increased number of crops grown is very important because it reduces the risks that may arise due to weather conditions and thus, farmers with more crops are relatively food secure. Similarly, CBOs help in different ways to enable farmers to be food-secured and so there could be advantages to being assisted by some organizations. Since CBOs are engaged in assisting communities, their existence will increase the probability of households being food secured. In terms of agro ecology, compared to the highland farmers, those in the mid-highland areas are less food secured. In Laygaint, those in the lowlands are also food insecure. This is the case as there is more reliable rainfall in the highlands and measures should be considered in the lowlands to improve the level of food security.

Determinants of the Intensity (Incidence[3]) of Food Security

The *tobit* model on the intensity of food security (Table 8), proxied by the proportion of the number of months in the year a household is food secured, was found to be significantly affected by the type of crops grown (Sorghum and teff), access to information, especially to climatic information, the educational level of household members, CBOs, and the adoption of soil conservation technologies.

Due to the expected socioeconomic and biophysical differences between Laygaint and the other districts, independent *Tobit* models were arranged for Laygaint and Hararghe (Chiro, Doba, Bedeno and Kurfachelle togather). The results show that the factors that determine the intensity of food security varied between the two locations. In the case of Laygaint, the significant variables that determined the intensity are sorghum production, the number of household members with a formal education, the number of CBOs in the village and the adoption of soil conservation measures. Whereas, for Hararghe, the significant variables were the number of crops grown, the number of CBOs, the agro ecology, and the adoption of soil conservation measures.

Crop Type Produced: On overage, households growing sorghum had a lower incidence of food security level, whereas those who grow teff had a higher level. The most probable reason is the fact that sorghum has a low level of storability compared to teff, which can be kept for a longer period of time without any damage from storage pests. Moreover, sorghum is mainly produced in the lowland and mid-highland areas, where food insecurity is more severe.

Access to Climatic Information: usually farmers in drought-prone areas are responsive to changes in climatic conditions through what is commonly called "response farming", where farmers change their cropping patterns based on the climatic conditions they anticipate and observe, reducing the production risk of total crop failure. Farmers who had access to climatic information had better intensity of food security. However, this was not the case in Hararghe as this factor was not significant in the model.

Education: The proportion of households with a formal education was found to positively affect the intensity of food security in the study area. The same was observed in Laygaint. This could be due to the fact that households who have more members with a formal education are expected to have a consumption and resource utilization plan compared to those with less formally-educated household members.

Adoption of Soil Conservation Measures: Adopters of soil conservation measures had improved intensity of food security compared to non-adopters in general. This was observed particularly in Hararghe.

Community Based Organization: CBOs are believed to improve the food security level through their role of supporting group work and improving access to rural services. In both Hararghe and Laygaint the number of CBOs had a positive effect on the intensity/ incidence of food security. This means that households with an increased number of CBOs in the village tend to have a higher intensity food security level. This could be due to the fact that CBOs can serve as a counterpart for government institutions so as to promote good governance, resulting in effective utilization of resources and transfer of information. This implies that promotion of CBOs in rural areas could be an option for improving the food security situation.

Agro-ecology: households in areas with "woina dega" agro-ecology achieved consistently lower intensity/incidence of food security compared to those households in "dega" agro-ecology. Households in areas with "kolla" agro ecology did not show significant differences in the incidence of food security compared to those in "dega" agro-ecology, except in Laygaint where significant differences were observed with lower incidences in "kolla" followed by "woina dega" agro-ecology. This implies that households in areas with "woina dega" agro-ecology need to be paid special attention compared to those in dega agro-ecology.

[3] Food security/incidence is here defined as the proportion of time in a year a household is food secured

Table 6. Description of food security determinants (total sample).

Variable		Expected sign	Rationale	Mean	Std. Dev.
Status of food security (1= food secured, 0 = food insecured)		Dependent variable		0.32	0.47
Agro ecology (Dega as base)	Woina Dega (1= Woina Dega 0= otherwise)	-	For the study *dega* areas are less susceptible to drought and crop failure compared to *woinadega*	0.45	0.50
	Kolla (1=Kolla 0=otherwise)	-	For the study dega areas are less susceptible to drought and crop failure compared to *kolla*	0.13	0.34
Gender (1 = male headed, 0 = female headed household)		±	Gender could have a different effect based on the socioeconomic context	0.86	0.35
Age in years		+	Age is a proxy for experience, which can positively influence food security status	45.34	14.93
Family size		-	As family size increases, household resources per head decreases creating a burden on food security	5.32	2.07
Farm size in hectares		+	The higher the farm size, the better the production level, leading to better food security	0.64	0.51
Number of plots		±	Fragmentation of farms can negatively affect the level of production, but it can also positively affect it through the diversification of production	3.00	1.34
Number of crops grown		±	Specialization of production positively can affect the level of production, but it can also affect it negatively due to increased risk	3.22	1.33
Number of income generating activities		+	Increased options of income sources can positively influence food security	0.63	0.74
Access to drinking water in minutes of walk		-	Poor access to drinking water can negatively affect food security through reduction of labor productivity	20.62	20.97
Access to information about prices (1 = yes, 0 = no)		+	Helps farmers to design better marketing strategies that, in turn, positively influence food security	0.91	0.29
Access to information about climate (1= yes, 0 = no)		+	Access to this information enables farmers to plan their production	0.58	0.49
Access to information about credit (1 = yes, 0 = no		+	This information helps to plan household finances and budget for purchases and sales	0.52	0.50
Value of livestock, consumables and farm tools in *birr*		+	The wealthier a farm household, the better the food security	2214.61	1825.58
Proportion of household members with formal education		+	Education is a source of skills for undertaking economic activity	0.17	0.21
Adoption of crop technology (1= adopter, 0 otherwise)		+	Use of improved technology promotes productivity thereby food security	0.69	0.46
Adoption of soil conservation measures (1= adopter, 0 = otherwise)		+		0.62	0.49
Number of Community based organizations in the village		+	CBOs serve to address social problems	2.65	2.81

Table 7 *Probit* maximum Likelihood Estimates of food security determinants.

Variable	Hararghe		Laygaint		Total sample	
	Coefficient	T-value	Coefficient	T-value	Coefficient	T-value
Constant	-0.1077	-0.25	-1.429***	-2.94	-0.291	-1.06
Woinadaga	-0.4645***	-3.64	-0.216***	-4.48	-0.053***	-2.56
Kolla	-0.2456	-1.22	-1.081***	-3.53	-0.224	-1.53
Gender	0.0081	0.62	0.003	0.59	0.002	0.49
Age in years	-0.0026	-0.54	-0.003	-0.59	-0.001	-0.37
Family size	-0.2549***	-6.17	-0.220***	-5.10	-0.221***	-7.97
Farm size in hectares	-0.0026	-0.54	0.512***	2.44	-0.001	-1.03
Number of plots	0.1041	1.47	-0.037	-0.48	0.076**	1.80
Number of crops grown	0.2520***	4.50	0.383***	4.39	0.200***	4.79
Number of income generating activities	-0.1591	-1.68	-0.032	-0.30	0.001	0.32
Access to drinking water in minutes of walk	-0.0050*	-1.62	-0.010	-1.61	-0.005**	-2.03
Access to information about prices	0.0202	0.07	-0.029	-0.12	-0.045	-0.26
Access to information about climate	-0.0055	-0.03	-0.032	-0.21	0.099	0.93
Access to information about credit	0.3386*	1.94	-0.017	-0.09	0.073	0.63
Wealth	0.0001***	2.76	0.0001	1.51	0.0001***	2.69
Proportion of household members with formal education	-1.2947***	-3.38	0.066	0.18	-0.380	-1.61
Adoption of crop technology	-0.0005	-1.19	-0.0003	-0.41	0.000	-0.73
Number of CBOs	0.6262***	4.87	0.215***	4.49	0.053***	2.60
Adoption of soil conservation measures	0.0006	1.52	0.0003	0.42	0.0004	1.36
Number of observations	474		390		864	
Log likelihood function	-216.56		-212.144		-468.10	
Restricted log likelihood	-279.42		-258.89		-543.49	
Chi-squared	125.72***		93.48***		150.79***	
Degrees of freedom	18		18		18	
Significance level	0.00		0.00		0.00	
Correct prediction (%)	80%		73%		72%	
Chow test		X^2 (2)	=	28.03***		

*Note: the dependent variable was quantified based on total crop production, P significant *** at 1%, ** at 5% and * at 10%. The Chow test shows the significant difference in the coefficients between Hararghe and Laygaint.*

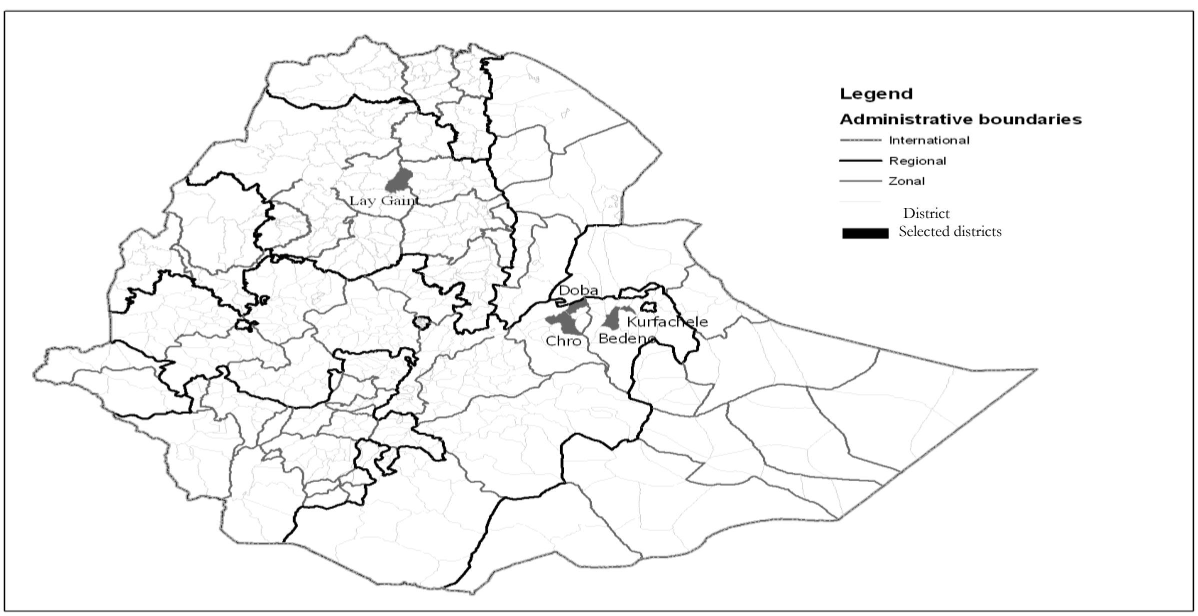

Figure 2. Shaded area shows map of the study area.

Table 8. Factors affecting the intensity of food security (*Tobit* estimates).

Variable	Hararghe		Laygaint		Total sample	
	Coefficient	T-values	Coefficient	T-values	Coefficient	T-values
Constant	0.3883***	7.57	0.2795***	4.91	0.3929***	11.34
Woinadega	-0.0006***	-3.34	-0.0232**	-3.95	-0.0005***	-3.63
Kolla	0.0142	0.57	-0.0648*	-1.72	0.0051	0.25
Gender of the household head	-0.0010	-1.47	-0.0005	-0.82	-0.0008	-1.63
Age of the household head	0.0010	1.54	0.0004	0.58	0.0006	1.43
Number of adult equivalent household members	0.0071	1.55	0.0038	0.81	0.0049	1.47
Number of crops grown	0.0001**	2.19	0.0001	1.28	0.0001**	2.40
Sorghum grower (1 = grower, 0 = otherwise)	-0.0855	-3.83	0.0806*	1.68	-0.0917***	-5.72
Teff growing household (1= grower, 0 =otherwise)	0.0228	0.28	0.0250	0.84	0.0460*	1.68
Access to price information	-0.0079	-0.23	0.0459	1.54	0.0131	0.57
Access to climate information	0.0320	1.34	0.0399**	2.11	0.0292**	1.97
Access to credit information	0.0143	0.59	-0.0278	-1.22	0.0074	0.50
Proportion of household members with formal education	0.0231	0.90	0.1595***	3.67	0.0995***	4.59
Number of CBOs in the village	0.0004***	2.71	0.0229***	3.94	0.0004***	3.03
Adoption of soil conservation measures (1= adopter, 0 = Otherwise)	0.0001***	5.56	0.0000	0.53	0.0001***	5.40
Sigma	0.2121***	30.82	0.1823***	28.59	0.2040***	42.09
Number of observations	525		429		954	
Log likelihood function	27.39		99.57		98.66	
Chow test	$F(2, 711) = 9.67$***					

*Note: P significant *** at 1%, ** at 5% and * at 10%. The Chow test shows the significant difference in the coefficients between Hararghe and Laygaint.*

4. Conclusion

In this paper, the food security situation is assessed using calorie intake, anthropometrical measures and based on household-declared perceptions about the food security situation. Factors affecting these indicators are determined using limited dependent variable models as the dependent variables are categorical or range in value between zero and one. Factors that significantly affect the food security level are agro ecology, family size, number of crops grown, number of plots the household owns, access to drinking water, the wealth status of the household and the number of community-based organizations in the village where the household lives. The intensity/incidence of food security was significantly affected by agro ecology, the number and types of crops grown, access to climatic information, the proportion of household members with a formal education, the number of CBOs in the village and the adoption of soil conservation measures by the household.

In order to improve the food security situation in the study areas, measures should be implemented in the area of household demographics, especially family planning, improving service provision especially climatic information and access to credit, and promotion of crop diversification that will minimize the prevalent production risks.

When considering the proportion of household members with a formal education as a factor influencing food security, it was found that negative effects on the food security level, but has a positive influence with regard to the intensity/incidence of food security. This shows that, even though, households with more formally educated members are food insecure, the time period when they are food insecure in a year is less than those households with fewer formally-educated members. In making such households food secure, efforts should be made to educate youngsters.

As agro ecology is a significant factor, there is a need to target intervention, taking into consideration the agro ecological specifics, especially the adoption of soil conservation measures as they are a significant factor in improving the intensity of food security. Community-based organizations are also an important factor in promoting the intensity of the food security level. Thus, promotion of CBOs should be given due attention.

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The Mathematical Basis of the Calendar Used by the Ethiopian Orthodox Twahedo Church for Fasting Periods and Religious Holidays

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Abstract: The Ethiopian Orthodox Twahedo Church (EOTC) has been the most dominant religion fully supported by the government for many years. EOTC has its own calendar, which is genuinely respected by the people. Nowadays, the Ethiopian people officially celebrate five major religious holidays every year: the New Year called 'Inqutatash', Holy Cross, Christmas, Epiphany and Easter. Easter has no fixed date. The dates of some of the fasting periods and the religious holidays also vary from year to year. In this paper, number theory is applied to the determination of the calendar for the fasting periods and major holidays of the EOTC whose dates vary from year to year.

Keywords: Division Algorithm; 'Nenewe' Fasting Period; New Year 'Inqutatash'; Number Theory; Theory of Congruence

1. Introduction

The Ethiopian Orthodox Twahedo Church (EOTC) has its own calendar which is used to determine the fasting periods and holidays of the church (http://www.ethiopic.com/calendar/ethiopic.htm). The Church has many fasting periods and holidays, the dates of which are determined annually. Some of these dates vary from year to year and they are announced at the ceremony New Year in the Church. Only some of the priests can perform the computation of the variable dates of holidays and fasting periods using the church calendar. Almost all of the followers of the church do not know how to compute the variable dates of the holidays and fasting periods of their religion.

There are two types of fasting periods and holidays, these are:

i) Fasting periods and holidays whose dates vary from year to year. For instance, the 'Nenewe' fasting period and Easter.

ii) Fasting periods and holidays whose dates are fixed. For instance Christmas and the 'Filseta' fasting period.

There is no problem regarding the fasting periods and holidays whose dates are fixed, since the Church followers know them very well.

This paper considers the fasting periods and holidays whose dates vary from year to year. The writer investigates how the dates of these fasting periods and holidays in a given year are arrived at and tries to show how the modern mathematical concept of congruence can be applied to determine of the dates of fasting periods and holidays.

The EOTC has its own calendar. It is the sum of the number 5500 and a year in today's Ethiopian calendar. The EOTC assumes the number 5500 as the era between the creation of Adam and the birth of Jesus Christ (Meseret, 1988). It is referred to as 'Amete Alem'.

The Amete Alem of a year y in E.C. is $5500 + y$.

For instance, the Amete Alem of 1999 in E.C. is 5500 + 1999 = 7499.

Ethiopia uses its own calendar and we call it the Ethiopian Calendar. The Ethiopian Calendar is based on the church's calendar. It is fairly similar to the Ethiopian Orthodox Twahedo Church calendar except that the number 5,500 has to be subtracted from the church's calendar. It has 13 months. The first 12 months have 30 days each. The last month, known as Pagumen, has 5 days and every fourth year, called *leap year*, it has 6 days (Simegne, 2002).

2. Materials and Methods

The author used different books from the Church to analyze and incorporate with the new mathematical concepts in to the Ethiopian calendar. He also carried out interviews with some priests who know how to compute the dates of these holidays and fasting periods to collect information.

2.1. The EOTC Aiwadat (Cycles)

The following constant numbers except the number 4 according to the church are called 'Aiwadat'. The constant numbers 4, 19, 28, 76, and 532 indicate a group of years which is used to compute the fasting periods and the holidays whose dates vary from year to year. They are described briefly (Meseret, 1988; Asrat and Gebrehiwot, 1995) as follows.

1. 7 is referred to as 'Awde Ilet'. It is the length of week cycle in which a day of a week is repeated.
2. 30 is referred to as 'Awde Werha'. It is the length of a month cycle in which a number given to a day of a month is repeated except the 13th month called 'Pagumen' according to the church solar year.
3. 365.25 is referred to as 'Awde Amet'. It is the length of a solar year.
4. 4 is the length of the four year cycle in which the Evangelical name of a year is repeated.
5. 19 is referred to as 'Awde Abktie'. It is the length of a cycle in which the phase of a moon is repeated (Metonic cycle). It is also known as 'Nius Kemer' in the EOT church.

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6. 28 is referred to as 'Awde Tsehay'. It is the length of the cycle in which the concurrence of the day and the evangelical name of a year is repeated. This can be justified mathematically as 28 is the least common multiple of 4 and 7. In the Julian Calendar this cycle is called the Solar Cycle.
7. 76 is referred to as 'Awde Mahtem'. It is the length of the cycle in which the concurrence of Abektie and the evangelical name of a year is repeated. This can be justified mathematically as 76 is the least common multiple of 4 and 19. It is also called 'Maikelawi Kemer' in the church.
8. 532 is referred to as 'Awde Kemer'. This is the length of a cycle in which concurrence of the day, evangelical name and 'Abktie' of a year is repeated. This can be justified mathematically as 532 is the least common multiple of 7, 4 and 19.

2.2. Terminology

There are many Terminological terms used in EOTC, Some of, which are very important in the study, and are defined as follows.

'Nenewe' Fasting Period the 'Nenewe' fasting Period is one of the fasting periods whose dates vary from year to year. It is a three-day fasting period. It is also the key for the other fasting periods and religious holidays whose dates vary from year to year. If you know the first date of the 'Nenewe' fasting period, then the dates for other fasting periods and holidays can be easily calculated from a simple mathematical computation. Therefore, the main problem is determining the first date of the 'Nenewe' fasting period.

In the past, people did not follow formal procedures with regard to respecting fasting periods and holidays.

Pope Dimetros, in about 200-224 A.C, introduced special mathematical formulations and announced axioms for the dates of the first days of the fasting periods and holidays whose dates varied from year to year.

The Ethiopian Orthodox Twahedo Church adopted these axioms and mathematical formulations and has been using them ever since. The church announces these dates for its followers every year at the New Year ceremony 'Inqutatash'.

'Wenber' is assumed as a remainder of an era (Meseret, 1988; Asrat and Gebrehiwot, 1995). It is the basis for the Abektie and Metik, which will be defined later. It has a Mathematical definition which is formulated by Pop Dimetros.

'Abektie' is a remainder of a certain mathematical calculation depending on the 'Wenber' value (Meseret, 1988; Asrat and Gebrehiwot, 1995). It has a constant coefficient which is provided by Pop Dimetros. This constant coefficient is 11.

'Metik' is again a remainder depending on the numerical value of 'Wenber' (Meseret, 1988; Asrat and Gebrehiwot, 1995). Just like Abektie, Metik has a constant coefficient assigned by Pop Dimetros. Its constant coefficient is 19. 'Metik' is used to determine the first dates of fasting periods and holidays whose dates are variable.

The day of 'Metik' itself is, in fact, a holiday and it either in the month of 'Meskerem' (September) or 'Tikimt' (October). Its value is a date of a month.

'Tewusak' is a constant number that is used to fulfill the requirement of the regulation formulated by Pope Dimetros (Meseret, 1988; Asrat and Gebrehiwot, 1995). Weekdays and each holiday whose dates are variable have their own 'Tewusak'.

Table 1. Weekdays 'Tewusak'.

N.O.	Day	Tewusak
1.	Saturday	8
2.	Sunday	7
3.	Monday	6
4.	Tuesday	5
5.	Wednesday	4
6.	Thursday	3
7.	Friday	2

'Mebaja Hamer' is a date number of a day, which is defined as the sum of 'Metik' and the 'Metik' day 'Tewusak' (Meseret, 1988; Asrat and Gebrehiwot, 1995). It either in the month of 'Meskerem' or 'Tikmt' depending on the day of 'Metik'. The value of 'Mebaja Hamer' is the date of the 'Nenewe' first fasting day after four full months or 120 days of its dates.

4. Results and Discussions

4.1. Mathematical Framework

Before coming to the definition given by the Church and theorems we are concerned with, let us examine some points of division algorithms and the theory of congruence.

For any positive integer m the relation $R_m = \{(a,b): a \equiv b \pmod m$, a and b are integers$\}$ is an equivalence relation on Z. The equivalence classes can be given by $\{\bar{0}, \bar{1}, \bar{2}, \ldots, \overline{m-1}\}$, where for $r \in \{0,1,2,\ldots,m-1\}$, $\bar{r} = \{r + mx : x \in Z\}$.

For any integer a, by the division algorithm, $a = mq + r$ with unique integers q, r and $0 \le r < m$. Hence, $a \in \bar{r}$ for some $r \in \{0,1,2,\ldots,m-1\}$.

Definition 1: A subset S of the set of integers is called a complete system of residue modulo m iff for any integer b there exists r∈S such that b ≡ r (mod m) and any two elements of S are incongruent modulo m.

The set $\{0,1,2,\ldots,m-1\}$ is a complete system of residues modulo m and it is the least complete residue class representatives modulo m.

Theorem 1: Suppose $a + c \equiv b \pmod m$ and $c \equiv d \pmod m$. Then $b = d$ iff $a \equiv 0 \pmod m$.

Theorem 2: If $a \equiv b \pmod m$ and $c \equiv d \pmod m$, then $a + c \equiv (b + d) \pmod m$ and $ac \equiv bd \pmod m$ (Uspensky, 1939; Oystein, 1948 and Yismaw, 1995).

4.2. Evangelist's Name of a Year in E.C.

There are four Evangelists, who wrote the Holy Gospel. These are Johannes (John), Mathewos (Mathew), Markos (Mark) and Lukas (Luke). Every year in the Ethiopian Calendar is associated with the name of the Evangelist's (Kidanemariam, 1963). The following statement defines the relationship of Evangelists name and the church calendar 'Amete Alem' to a year with the help of congruence theory.

Definition 2: Let y be a year in the Ethiopian Calendar such that

$5500 + y \equiv R_0 (\text{mod } 4)$, where $0 \le R_0 < 4$ (1)

Then

i) If $R_0 = 0$, then the year is called 'Zemene' John.
ii) If $R_0 = 1$, then the year is called 'Zemene' Mathew.
iii) If $R_0 = 2$, then the year is called 'Zemene' Mark.
iv) If $R_0 = 3$, then the year is called 'Zemene' Luke.

Theorem 3 states the idea of definition 2 with respect to the Ethiopian Calendar only and the proof follows.

Theorem 3: Let y be a year in the E.C.
If $5500 + y \equiv R_0(\text{mod } 4)$, where $0 \le R_0 < 4$ and $y \equiv R'_0 (\text{mod } 4)$, where $0 \le R'_0 < 4$, then
$R_0 = R'_0$. (2)

Proof: It follows from the fact that $5500 \equiv 0 \ (\text{mod } 4)$.
We will use R_0 for the determination of 'Inqutatash'.

4.3. 'Inqutatash'

The first day of the Ethiopian New Year is known as 'Inqutatash'. This is the day on which the dates of the holidays and fasting periods for the coming year are announced. Here we shall provide the mathematical definition of 'Inqutatash' for an arbitrary year in E.C. (Simegne, 2004).

Rabiet: From definition 2 we have $5500 + y \equiv R_0$ (mod 4) where y is a year in E.C. Then by the definition of congruence

$5500 + y - R_0 = 4I_r$, for some integer I_r

$$\Rightarrow I_r = \frac{5500 + y - R_0}{4}$$

The integer I_r is known as 'Rabiet'.

Definition 3: Let y be a year in the Ethiopian Calendar such that

$5500 + y + I_r \equiv R_1(\text{mod } 7)$, where $1 \le R_1 \le 7$ (3)

Then 'Inqutatash' is the R_1^{th} day starting from Tuesday. According to the Church, the day Tuesday is known as 'Tinte kemer' (Kidanemariam, 1963; Asrat, 1991).

The next theorem states definition 3 with respect to the Ethiopian Calendar only and the proof follows.

Theorem 4: Let y be a year in the E.C. If R_0 is as in Definition 2 and

$5y - R_0 \equiv R'_1(\text{mod } 28)$, where $0 \le R'_1 < 28$, (4)

then 1. $R'_1 \equiv 0(\text{mod } 4)$.

2. $R_1 = 1 + \frac{R'_1}{4}$, where R_1 is the non negative integer as given in equation (3).

Proof: 1. Suppose $5y - R_0 \equiv R'_1(\text{mod } 28)$, where y is a year in E.C. and R_0 is as in the Definition 2. Then $28 \mid 5y - R_0 - R'_1$ and then $5y - R_0 - R'_1 = 28I$, for some integer I.

Then $R'_1 = 5y - R_0 - 28I$
$= 4y + y - R_0 - 28I$
$= 4y + 4I' - 28I$, for some integer I'.

Since by theorem1 $y \equiv R_0 \ (\text{mod } 4)$
$= 4(y + I' - 7I)$
$= 4n$, where $n = y + I' - 7I$

Therefore, $R'_1 \equiv 0(\text{mod } 4)$.

Moreover, since $R'_1 \in [0, 28)$ and R'_1 is an integer, the possible values of R'_1 are 0, 4, 8, 12, 16, 20, 24. Thus $\frac{R'_1}{4}$ can only be one of the numbers 0, 1, 2, 3, 4, 5, 6.

2. Suppose $5y - R_0 \equiv R'_1(\text{mod } 28)$, where y is a year in E.C. and R_0 is the number corresponding to Evangelist's name. Then $5y - R_0 - R'_1 = 28I'$, for some integer I'. Then

$\frac{5y - R_0}{28} = I' + \frac{R'_1}{28}$ for some $I' \in Z$, $0 \le R'_1 < 28$ and R'_1 is an integer.

By Definition 2 we know that

i) By (1) we have $R'_1 \equiv 0(\text{mod } 4) \Rightarrow R'_1 = 4k_1$

ii) By Theorem 2 we have $y \equiv R_0(\text{mod } 4). \Rightarrow y - R_0 = 4k_2$

Since $5y - R_0 \equiv R'_1(\text{mod } 28)$
$\Rightarrow 4y + y - R_0 \equiv R'_1(\text{mod } 28)$
$\Rightarrow 4y + 4k_2 \equiv 4k_1 \ (\text{mod } 28)$
$\Rightarrow y + k_2 \equiv k_1 \ (\text{mod } 7)$ (5)
But $6875 \equiv 1(\text{mod } 7)$ (6)

From (5) and (6) we have
$6875 + y + k_2 \equiv (1 + k_1)(\text{mod } 7)$ (7)

Again since $5500 + y + I_r \equiv R_1(\text{mod } 7)$ by definition 3

where $I_r = \frac{5500 + y - R_0}{4}$
$= \frac{5500 + 4k_2}{4}$
$= 1375 + k_2$

It gives $5500 + y + 1375 + k_2 \equiv R_1(\text{mod } 7)$
$6{,}875 + y + k_2 \equiv R_1(\text{mod } 7)$ (8)

From (7) and (8) we have $1 + k_1 = R_1$

Since $k_1 = \frac{R'_1}{4}$ we have $R_1 = 1 + \frac{R'_1}{4}$. This completes the proof.

Let us consider the following example:

To find the day of 'Inqutatash' of the year 2000 in E.C. using the above method, we proceed as follows.

First, let us find the number of the Evangelist's name for the year.

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Suppose $2000 \equiv R'_0 \pmod 4$, where $0 \le R'_0 < 4$. Now we find R_0, $\frac{2000}{4} = 500 + \frac{0}{4}$, then $R_0 = 0$ which is 'Zemene' John.

Inqutatash*: $5y - R_0 \equiv R'_1 \pmod{28}$, where $0 \le R'_1 < 28$*

$\Rightarrow 5(2000) - 0 \equiv R'_1 \pmod{28}$, where $0 \le R'_1 < 28$ Since R_0 is 0.

$\Rightarrow 10000 - R_1 = 28k$ for some $k \in Z$

$$\frac{10,000}{28} = k + \frac{R'_1}{28} = 357 + \frac{4}{28}.$$

Thus $R'_1 = 4$ and $k = 357$

Therefore, $R_1 = 1 + \frac{R'_1}{4} = 1 + \frac{4}{4} = 1+1 = 2$. Therefore 'Inqutatash' of 2000 E. C. is on Wednesday.

4.4. 'Tewusak' of Fasting Periods and Holidays Whose Dates Vary From Year to Year

This is a number which can be defined as the residue of the number of days counted from the starting day of the 'Nenewe' fasting period up to holiday itself or the first date of the fasting period modulo 30. That is, let H be the holiday and k be the number of days from the starting day of the 'Nenewe' fasting period. Suppose $k \equiv R_6 \pmod{30}$. Then the 'Tewusak' of H is R_6.

The 'Nenewe' fasting period has no 'Tewusak'.

4.5. 'Wenber'

The next definition is the computation used by the church with respect to 'Amete Alem' in a year with the help of congruence theory (Asrat, 1991).

Definition 4: Let y be a year in E.C such that

$5500 + y \equiv R_2 \pmod{532}$, where $1 \le R_2 \le 532$ (9)

and then $R_2 \equiv R_3 \pmod{19}$, where $1 \le R_3 \le 19$ (10)

Then 'Wenber' is defined as $R_3 - 1$.

Theorem 5 states definition 4 with respect to the Ethiopian Calendar only and the proof follows.

Theorem 5: Let y be a year in E.C. such that

$y \equiv R'_3 \pmod{19}$, where $1 \le R'_3 \le 19$ (11)

Then

1. $$R_3 = \begin{cases} R'_3 + 9, & \text{if } 1 \le R'_3 \le 10 \\ R'_3 - 10, & \text{if } 11 \le R'_3 \le 19 \end{cases} \quad (12)$$

2. 'Wenber' = $R_3 - 1$ =
$$\begin{cases} R'_3 + 8, & \text{if } 1 \le R'_3 \le 10 \\ R'_3 - 11, & \text{if } 11 \le R'_3 \le 19 \end{cases} \quad (13)$$

Proof: 1. Let y be a year in E.C. Suppose $y \equiv R'_3 \pmod{19}$, where $1 \le R'_3 \le 19$. Then, by the hypothesis of Definition 4, we have

$5500 + y \equiv R_2 \pmod{532}$ where $1 \le R_2 \le 532$ then

$5500 + y - R_2 = 532k$ for some $k \in Z$

$\Rightarrow R_2 = 5500 + y - 532k$ (14)

$R_2 \equiv R_3 \pmod{19}$ where $1 \le R_3 \le 19$ then $R_2 - R_3 = 19n$ for some $n \in Z$

$\Rightarrow R_2 = R_3 + 19n$ (15)

Putting (14) in (15) we have

$5500 + y - 532k = R_3 + 19n$

$\Rightarrow 5500 + y - 532k \equiv R_3 \pmod{19}$

But $532 \equiv 0 \pmod{19}$ then $532k \equiv 0 \pmod{19}$ for some $k \in Z$

Thus $5500 + y \equiv R_3 \pmod{19}$ (16)

Again $5500 \equiv 9 \pmod{19}$ and by the hypothesis of the theorem

$y = R'_3 \pmod{19}$

Thus $5500 + y \equiv (9 + R'_3) \pmod{19}$. (17)

This is by Theorem 2.

If $9 + R'_3 > 19$ which means $R'_3 > 10$, then we can take

$5500 + y \equiv (R'_3 - 10) \pmod{19}$. (18)

Since the integer R_3 is between 1 and 19 inclusively from (16), (17) and (18) we have

$$R_3 = \begin{cases} R'_3 + 9, & \text{if } 1 \le R'_3 \le 10 \\ R'_3 - 10, & \text{if } 11 \le R'_3 \le 19 \end{cases}$$

2. From 1. and Definition 3 it follows that

'Wenber' = $R_3 - 1$ =
$$\begin{cases} R'_3 + 8, & \text{if } 1 \le R'_3 \le 10 \\ R'_3 - 11, & \text{if } 11 \le R'_3 \le 19 \end{cases}$$

The proof is completed.//

Based on the value of 'Wenber' for a year, 'Abektie' and 'Metik' will be defined as follows.

4.5.1. 'Abektie'

Definition 4: If $11w \equiv R_4 \pmod{30}$, (19)

where $R_4 \in Z$, $0 \le R_4 \le 30$ and w = 'Wenber' , then R_4 = 'Abektie'

Note that 'Wenber' has only 19 different values from 1 to 19 inclusive. Since 'Abektie' is a function of 'Wenber', the number of values of 'Abektie' are limited to only 19 different values. These are 0, 1, 3, 4, 6, 7, 9, 11, 12, 14, 15, 17, 18, 20, 22, 23, 25, 26, 28. For one year in the E.C., there is only one 'Abektie' value. The constant coefficient of 'Abektie' is 11.

4.5.2. 'Metik'

It is the basis for the determination of the starting day of the 'Nenewe' fasting period. Like 'Abektie', 'Metik' is a function of 'Wenber' and has only 19 different values. The mathematical definition of 'Metik' is given as follows.

Definition 5: If $19w \equiv R_5 \pmod{30}$ (20)

where w = 'wenber' and $0 < R_5 \le 30$, then R_5 = 'Metik'

If $R_5 = 0$ then we take $R_5 = 30$ and then 'Metik' becomes 30.

The number 19 is the constant coefficient of 'Metik'. Just like 'Abektie', The 19 values of 'Metik' are 2, 4, 5, 7, 8, 9, 10, 12, 13, 15, 16, 18, 19, 21, 23, 24, 26, 27, 29, 30. For one year in the E.C., there is only one **'**Metik' value.

Note: Suppose R_5 is in as in equation (20). As we mentioned above, 'Metik' is assumed to be a holiday in the church and its day is dated by R_5 either in the month of 'Meskerem' or 'Tikemt' in the E.C. If $R_5 > 14$, then the day of 'Metik' is held on the R^{th}_5 of 'Meskerm'. If $R_5 < 14$, then the day of 'Metik' is held on R^{th}_5 of 'Tikimt'.

Theorem 6: Let 'Abektie' = R_4 and 'Metik' = R_5, then

$$R_4 + R_5 = 30 \quad (21)$$

Proof: Let w be 'Wenber'. By the definition

$19w \equiv R_4 (\text{mod } 30)$

$11w \equiv R_5 (\text{mod } 30)$

Then by the Theorem 3 we have

$(11 + 19)w \equiv (R_4 + R_5) \ (\text{mod } 30)$

$\Rightarrow \ 30w \equiv (R_4 + R_5) \ (\text{mod } 30)$ But $30w \equiv 0 \ (\text{mod } 30)$

$\Rightarrow R_4 + R_5 \equiv 0 (\text{mod } 30) \Rightarrow R_4 + R_5$ is a multiple of 30.

Since $0 < R_4 \leq 30$ and $0 \leq R_5 < 30$ we have $0 < R_4 + R_5 < 60$. Since 30 is the only integer which is a multiple of 30 between 0 and 60 exclusively, then we can conclude that $R_4 + R_5 = 30$.

The proof is complete.

4.6. 'Mebaja Hamer'

This is also another term which depends on the value of 'Metik' .

Definition 6: 'Mebaja Hamer' is defined as the sum of 'Metik' and the 'Tewusak' of the day. That means.

'Mebaja Hamer' = 'Metik' + 'Tewusak' of the day.

The day of 'Mebaja Hamer' is administered on:

i) The date of its value in the month of 'Meskerem' in E.C., if $14 < R_5 \leq 30$

ii) The date of its value in the month of 'Tikimt' in E.C., if $R_5 < 14$

4.7. 'Nenewe' Fasting Period

As we mentioned before, 'Nenewe' fasting is a three-day fasting period. It always starts on Monday and ends on Thursday of the same week. It is a function of 'Mebaja Hamer'. We know that the value 'Mebaja Hamer' is the date of a day either in the month of 'Meskerem' or 'Tikmt'.

The starting day of the 'Nenewe' fasting period in a year is the day of a month exactly four full months (120 days) after the day of 'Mebaja Hamer' in the year in the E.C. That means the date of the starting day of the 'Nenewe' fasting period is exactly the value of 'Mebaja Hamer' but 'Nenewe' takes place after four months of 'Mebaja Hamer'.

Note: If 'Mebaja Hamer' is in 'Meskerem', the 'Nenewe' fasting period will be in Tir and begin on the day dated at the 'Mebaja Hamer' value. If 'Mebaja Hamer' is in 'Tikimt', then it will be in 'Yekatit' and begin on the day dated at the 'Mebaja Hamer' value (Kidanemariam, 1963; Asrat, 1991).

Theorem 7: The 'Nenewe' fasting period cannot be administered before 'Tir' 17 and after 'Yekatit' 21.

Proof: The proof is simple.

4.8. Other Fasting Periods and Holidays Whose Dates Vary From Year to Year

Once the 'Nenewe' fasting period for a given year is determined, the other fasting periods and holidays can easily be obtained with the help of their 'Tewusak' as defined before.

Table 2. describes the 'Tewusak' R_6 of fasting periods and holidays whose dates vary from year to year.

4.9. Procedures

The procedures of computing the days of the fasting periods and holidays of any year in E. C. whose dates vary from year to year, are given as follows.

i) Find the number R_0 that corresponds to the Evangelical name of the year.

ii) Find the day of 'Inqutatash' (Ethiopian New Year)

iii) Find the first date of the 'Nenewe' fasting period. To obtain this we need to calculate the values of 'Wenber', 'Metik' and 'Mebaja Hamer'

iv) Find all the other fasting periods and holidays with the help of their 'Tewusaks'.

Let us see some particular cases:

1. To find all the fasting days and Holidays in 1996in the E.C. whose dates vary from year to year, using the above method we proceed as follows.

i) Evangelical Name: Since $y \equiv R'_0 \ (\text{mod } 4)$, where $0 \leq R'_0 < 4$, y is a year, then we have $1996 \equiv R'_0 \ (\text{mod } 4)$ where $0 \leq R'_0 < 4$. That is $1996 - R'_0 = 4k$ for some integer k.

$\Rightarrow 1996 \div 4 = 499 + \frac{0}{4}$, This implies that $R_o = R_0' = 0$.

Therefore, the Evangelical name for 1996 E.C. is 'Zemene' John.

ii) 'Inqutatash': $5y - R_0 \equiv R'_1 (\text{mod } 28)$, where $0 \leq R'_1 < 28$

$5x1996 - R_0 \equiv R'_1 (\text{mod } 28)$

$\Rightarrow$ Since $R_0 = 0$ then we have $9980 - R_1 = 28k$ for some integer k

$$\Rightarrow \frac{9980}{28} = 356 + \frac{12}{28}$$

$$\Rightarrow R'_1 = 12.$$

Thus $R_1 = \frac{R_1'}{4} + 1 = \frac{12}{4} + 1 = 4$

Therefore, four days after Tuesday is Friday. Thus 'Inqutatash' was held on Friday.

iii) The 'Nenewe' Fasting Period :

'Wenber': $y \equiv R_3' \ (\text{mod } 19)$, where $1 \leq R'_3 \leq 19 \Rightarrow 1996 \equiv R_3'(\text{mod } 19)$ $\Rightarrow \frac{1996}{19} = 105 + \frac{1}{19} \Rightarrow R_3' = 1$ and it is between 1 and 10.

Then $R_3 = R_3' + 9 = 1 + 9 = 10$ Therefore, 'Wenber' is $10 - 1 = 9$

'Metik':_$19w \equiv R_5(\text{mod } 30) \Rightarrow 19x9 \equiv R_5(\text{mod } 30)$

$\Rightarrow \frac{171}{30} = 5 + \frac{21}{30} \Rightarrow 171 \equiv 21(\text{mod } 30)$. Therefore, 'Metik' = $R_5 = 21$.

Interpretation: Since 21 > 14, the holiday of 'Metik' will be held on 21st of 'Meskerem' and the day is Thursday.

'Mebaja Hamer': The 'Tewusak' of Thursday is 3. Thus 'Mebaja Hamer' is 21+ 3 = 24

The 'Nenewe' Fasting period began on 'Tir' 24, 1996 after four full months of 'Meskerem' 24.

iv) Now all the other fasting and holidays whose dates vary from year to year can be computed easily with the help of their 'Tewusak'.

Table 2. Other fasting periods and holidays.

No	1st day of fasting / day of holiday	No of days from first day of 'Nenewe' fasting period	R_6
1.	Main fasting period (8 weeks fasting)	14	14
2.	'Debrezeit' (half of the main fasting period)	41	11
3.	'Hosaina' (Historical events of Jesus palm Sunday)	62	2
4.	Thursday praise	66	6
5.	'Siklet' (crucifixion)	67	7
6.	Easter	69	9
7.	The 2nd Easter (day of Thomas)	76	16
8.	'Rikbe kahinat' (day of Priests)	93	3
9.	'Irget' (Ascension)	108	18
10.	'Paraklitos'	118	28
11.	Preachers fasting period (Apostles' fasting) This is up to 'Hamle' 6	119	29
12.	Friday Wednesday fasting begins	121	1

2. To find the first day of 'Nenewe' fasting period 1999 E.C. we proceed as follows.

i) Evangelical Name: Since $y \equiv R'_0$ (mod 4), where $0 \leq R'_0 < 4$ y is a year, then we have $1999 \equiv R'_0$ (mod 4) where $0 \leq R'_0 < 4$. That is $1999 - R'_0 = 4k$ for some integer k.

$\Rightarrow R_o = R_0' = 3$. Therefore, the Evangelical name for 1996 E.C. is 'Zemene' Luk.

ii) 'Inqutatash': $5y - R_0 \equiv R'_1(\text{mod } 28)$, where $0 \leq R'_1 < 28$ $\Rightarrow 5x1999 - R_0 \equiv R'_1(\text{mod } 28)$ $\Rightarrow$ Since $R_0 = 3$ then we have

$9995 - 3 \equiv R'_1(\text{mod } 28) \Rightarrow 9992 - R_1 = 28k$ for some integer k

$\Rightarrow R'_1 = 24$ Thus $R_1 = \frac{R_1'}{4} + 1 = \frac{24}{4} + 1 = 7$. Therefore, we count 7 days from Tuesday. Then the day is Monday. That is, 'Inqutatash' will be held on Monday.

iii) 'Nenewe' Fasting Period :

'Wenber': $y \equiv R_3'$ (mod 19), where $1 \leq R'_3 \leq 19 \Rightarrow 1999 \equiv R_3'(\text{mod } 19) \Rightarrow R_3' = 4$ *and it is between* 1 *and* 10.

Then $R_3 = R'_3 + 9 = 4 + 9 = 13$ Therefore, 'Wenber' is $13 - 1 = 12$

'Metik':_$19w \equiv R_5(\text{mod } 30) \Rightarrow 19x12 \equiv R_5(\text{mod } 30)$

$\Rightarrow 228 \equiv R_5(\text{mod } 30) \Rightarrow 228 \equiv 18(\text{mod } 30)$. Therefore, 'Metik' = $R_5 = 18$.

Interpretation: Since 18 > 14 the holiday of 'Metik' will be held on 18th of 'Meskerem' and the day is Thursday.

'Mebaja Hamer': The 'Tewusak' of Thursday is 3. Thus 'Mebaja Hamer' is 8+ 3 = 21

The 'Nenewe' fasting period will begin on 'Tir' 21, 1999 after four full months of 'Meskerem' 21.

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I. Registration of 'Arjo-1' and 'Bariso' Field Pea (*Pisum sativum* L) Varieties

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Abstract: Arjo-1 and Bariso are common names for the field pea (*Pisum sativum* L) varieties with the pedigree names of EH90025-1 and EH90011-1-2 respectively. They were developed and released by Bako Agricultural Research Center for western Ethiopia. Arjo-1 and Bariso were evaluated for six years (1999-2004) at Arjo, Gedo and Shambu stations and had better mean grain yield than the standard check, Tegegnech. Arjo-1 and Bariso were resistant to ascochyta blight and powdery mildew. The result of multi-location trials showed that Arjo-1 and Bariso had above-average grain yield performance across tested locations and years. Yield stability was studied for Arjo-1 and Bariso and they were stable in grain yield performance.

1. Agronomic and Morphological Characteristics

In the development of Bariso and Ajo -1, early maturity was considered as an important trait for the reason that locals are very late and seriously attacked by diseases occurring later. The seed of Arjo-1 is more uniform and larger than that of Barsio and the seed of Bariso is whiter in color than that of Arjo-1. A summary of agronomic and morphological characteristics is presented in Appendix I.

2. Yield Performance

Arjo-1 and Bariso were developed through hybridization followed by pedigree and bulk selections by Holetta Agricultural Research Center and variety trials by Bako Agricultural Research Center in Ethiopia. Arjo-1 (EH90025-1) is a cross between two parents, Mohanderfer and PS-210794, whereas Bariso (EH90011-1-2) is a cross between EXDZ and PS-210794. The varieties were evaluated with a standard check, Tegegnech and local checks in multi-locations yield trials from 1999 to 2004 at Arjo, Gedo and Shambu. They gave a seed yield ranging from 2.0 to 3.9 tons ha^{-1} at research stations and 2.0 and 2.5 tons ha^{-1} on farmers' fields. Arjo-1 and Bariso have outperformed the standard check, Tegegnech by 24% and 28% at stations in seed yield respectively. On farm mean grain yield, Arjo-1 and Bariso was 2.0 ton/ha compared to 1.6 ton/ha for the standard check, Tegegnech.

3. Stability Performance

Yield stability parameters for nineteen field pea varieties for two years at three locations were calculated based on the method of Eberhart and Russel (1966). The result of the study revealed that Arjo-1 and Bariso had a unity regression coefficient associated with high mean grain yield, implying that they had good general adaptability. Similarly the standard check, Tegenech, was stable but the local check was not stable.

4. Disease reaction

Arjo-1 and Bariso exhibited moderate resistance to the predominant diseases such as aschochyta blight (*Ascochyta pisi*) and powdery mildew (*Erysiphe polygoni)* (Table 1).

5. Conclusion

The field pea varieties, Arjo-1 and Bariso, had above-average grain yield performance in all environments out-yielding the standard check, Tegenech and local check. They have a white seed color with better yield stability than the local check. These varieties are moderately resistant to aschochyta blight and powdery mildew and they have, therefore, been released for production in the highlands of Arjo, Gedo and Shambu, and similar agro ecology in western Ethiopia.

6. Reference

Eberhart, S.A. and Russel, W.A. 1966. Stability parameters for comparing varieties. *Crop Science* 6:36-40.

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Table 1. Summary of mean grain yield and related aspects of Arjo-1, Bariso and checks across years and locations.

Varieties	DF	DM	PH (cm)	# of PPP	# of SPP	100 swt	Ascoch	P. mildew	Yield (ton/ha
EH90025-1	64	112	142	9	34	22	4	4	2.5
EH90011-1-2	66	112	120	9	37	20	4	4	2.6
Tegegnech	61	110	133	10	42	19	5	5	2.0
Local check	68	123	145	9	40	14	6	5	1.9

DF=days to flowering; DM=days to maturity; PH=plant height; # of PPP=number of pods per plant; # of SPP= number of seeds per plant; 100swt=hundred seeds weight; Ascoch=Ascochyta; P.mildew=powder mildew; YID=seed yield

Appendix I. Agronomical and morphological characteristics of Arjo-1 and Bariso.

Characteristics	Arjo-1 (EH90025-1)	Bariso (EH90011-1-2)
1. Adaptation area:		
1.1. Altitude (masl)	2000-2600	2000-2600
1.2. Rainfall (mm)	1000-1300	1000-1300
2. Fertilizer rate:		
2.1. DAP (kg/ha)	100	100
3. Planting date	Mid to late June	Mid to late June
4. Seed rate (kg /ha):	150 - 200	150 - 200
5. Days to flower	60 - 70	58 - 70
6. Days to maturity	110 - 120	109 - 118
7. Plant height (cm)	120 - 140	118 - 130
8. Number of pods per plant	6 - 17	6 - 20
10. Pod character	full (not constricted)	full (not constricted)
11.Seed shape and character	Round and smooth	Round and smooth
12. Seed coat color	White	White
13. Cotyledon color	Light orange	Light orange
14. 100 seed weight (g)	22	20
15. Yield (ton/ha):		
17.1. Research field	2.53	2.61
17.2. Farmer field	2.00	2.01
16. Year of release	2005	2005

II. Registration of 'Angar ' Haricot Bean (*Phaseolus vulgaris* L.) Variety

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Abstract: Angar is a common name for the haricot bean (*Phaseolus vulgaris* L.) variety with the pedigree name EMP-376. It was developed and released by Bako Agricultural Research Center for western Ethiopia**.** This variety was evaluated for four years at Bako, Gute and Boshe and it was found to be the best productive variety. Angar is moderately resistant to common bacterial blight, angular leaf spot, web blight and resistant to anthracnose and floury leaf spot. Results of multi-location trials showed that Angar was superior in grain yield performance across years and locations. Angar was studied for yield stability and it had above-average stability.

1. Agronomic and Morphological Characteristics

Angar has deep green leaves with white flowers and flowers from 41 to 52 days and matures from 85 to 96 days after emergence. The standard check, Red Wolaita, matures earlier than Angar by 6 days. Angar has a plant height ranging from 50 to 72 cm, the number of pods per plant ranges from 13 to 25 and the number of seeds per pod from 4 to 7. Anger has a better pod load and percentage of ground coverage than Red Wolaita. It has a kidney-shaped seed with dull lustre. Angar is a dark red seeded bean whereas Red Wolaita is a red seeded bean with shiny luster. Angar has a seed size ranging from 25 to 30 g per 100 seeds, with 20 to 26 g per 100 seeds for Red Wolaita. Angar is a variety that is suitable for irrigation, rain-fed agriculture and early sowing. It can be intercropped with maize, sorghum and pepper. A summary of the agronomic and morphological characteristics is given in Appendix I.

2. Yield Performance

At the early breeding stages, Angar was evaluated at Bako from 1997 to 1999 for seed yield and other yield-related traits and showed better performance than the standard check, Red Wolaita. In multi-location yield trials at Bako, Boshe and Gute from 2000 to 2003, Angar gave a mean seed yield of 2.3 tons ha^{-1} (Table 1) compared to 1.2 tons ha^{-1} for the standard check, Red Wolaita. On farmers' field trials from 2004 to 2005, Angar gave a mean seed yield of 2.6 tons ha^{-1} compared to 1.9 tons ha^{-1} for Red Woalita.

3. Stability performance

Yield stability in sixteen bush bean varieties was studied for two years across three locations, based on the method of Eberhart and Russel (1966). The regression coefficient of Angar was less than unity, indicating that it has above-average stability and is better adapted to unfavorable growing conditions.

4. Disease reaction

Angar is moderately resistant to common bacterial blight (*Xanthomonas campastris*), angular leaf spot (*Isariopsis sriseola*) and web blight (*Rhizoctonia solani*). It is resistant to anthracnose (*Colletotrichum lindemuthianum*) and floury leaf spot (Table 1).

5. Quality analysis

The results of laboratory tests (Table 2) indicated that Angar has 2% non-soakers and 21 minutes cooking time whereas Red Wolaita obtained 11% non-soakers and 28 minutes cooking time, confirming the superiority of Angar over Red Wolaita with regard to factors that affect food quality (Negash *et al.*, 2005).

6. Conclusion

The bush bean variety, Angar, was the best yielder variety. It has above average stability in grain yield performance and adapts better to unfavorable growing conditions. It has a high pod load with moderate resistance to significant diseases. This variety was released for production in low- to mid-altitude areas of western Ethiopia and areas with similar Agro ecology. It was named after a big river that crosses the Dhidhessa valley. It is a potential river for irrigation.

7. References

Eberhart, S.A. and Russel, W.A. 1966. Stability parameters for comparing varieties. *Crop Science* 6:36-40.

Negash, G., Chemeda, D. and Abeya, T. 2005. On-farm evaluation of four candidate varieties of common bean in western Oromiya, Ethiopia. *In:* Opportunities and Challenges for Transforming Agriculture in Africa, 7th African crop science society conference, 5-9 Dec. 2005, Entebbe, Uganda

Table 1. Summary of pooled mean of yield and other data on Angar and the check across locations and years.

Varieties	DF	DM	PH (cm)	Seed size(gm)	# of PPP	# of SPP	Pod height	YID (ton/ha)	CBB	ALS	FLS	Anth	WB
Anger	48	93	63	25-30	21	43	10	23.34	4	4	3	2	4
Red Wolita	43	88		20-26	20	35	9	12.10	6	3	5	6	5

DF=days to flower; DM=days to maturity; PH=plant height; # of PPP=number of pods per plant; # of SPP= number of seeds per plant; YID=seed yield; CBB=common bacterial blight; ALS=angular leaf spot; FLS=floury leaf spot, Anth=anthracnose; WB=web blight

Table 2. Summary of laboratory analysis made by Holetta Agricultural Research Center, Food Science Division, Ethiopia.

Variety name	Weight of 100 seed (gm)	# of non-soakers	Cooking time (minute)
Angar	25.8	2	21
Check standard (Red Wolita)	23.8	11	28

Appendix I. Agronomical and morphological characteristics of Angar (EMP-376).

1. Adaptation area:	
1.1. Altitude (masl)	1300-2000
1.2. Rainfall (mm)	1000-1300
2. Fertilizer rate:	
2.1. DAP (kg/ha)	100
3. Planting date	Mid -Late June
4. Seed rate:	100 kg/ha
4.1. Spacing (inter x intra row)	40 cm x 10 cm
5. Days to flower	41-52
6. Days to maturity	85-96
8. Plant height (cm)	63
9. Number of pods per plant	21
10. Number of seeds per Pod	6
11. Pod height (cm)	12
12. Seed shape	Kidney
13. Seed color	Dark red
14. Seed coat lustre	Dull
15. 100 seed weight (g)	28
16. Crop pest reaction	tolerant to major diseases
17. Yield (ton/ha):	
17.1. Research field	2.0 - 3.2
17.2. Farmer field	2.0 - 2.8
18. Year of release	2005

III. Registration of 'Tibe' Climbing Bean (*Phaseolus vulgaris* L.) Variety

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Abstract: Tibe is a common name for the climbing bean (*Phaseolus vulgaris* L.) variety with the pedigree name 812-BRC-28. It was developed and released by Bako Agricultural Research Center for western Ethiopia. This variety was evaluated at Bako, Boshe, Gute and Loko, at stations and on farms and it was superior in grain yield performance over the local check. The results of yield stability study showed that Tibe was the most productive variety with maximum stability. It is suitable for intercropping with maize, sorghum, and for sole cropping. It is moderately resistant to bacterial blight, angular leaf spot, floury leaf spot, anthracnose, and web blight. In addition, it is superior in grain yield performance.

1. Agronomic and Morphological Characteristics

Early maturity was considered as one of the most important criteria for selecting Tibe for the reason that almost all local climbers are late. The low leaf loads with uniformly distributed pods through out the plant profile makes Tibe suitable for intercropping with maize. The locals were more aggressive for intercropping with maize due to their higher vegetative growth habits. Tibe has good resistance to shattering. Tibe flowers from 50 to 58 days and matures from 95 to 103 days after emergence. It has white flowers and red seeds with a shiny luster and white helium. It has a red pod color at maturity and its plant height ranges from 180 to 195 cm, the number of pods per plant ranges from 12 to 84 and the number of seeds per pod ranges from 4 to 7. Tibe has a pod height (the height from the ground to the first pod) which varies from 10 to 20 cm compared to 70 to 110 cm for the local checks. It has kidney shaped seeds with a seed size ranging from 25 and 35 g per 100 seeds. A summary of its agronomic and morphological characteristics is given in the appendix.

2. Yield Performance

Tibe was bred by pure line selection out of accessions introduced from Rwanda. It was evaluated for seed yield at multi-locations from 1999 to 2003 and showed a better performance than the local checks. For mixed culture, wider spacing (75 cm inter and 10 cm intra row spacing) was used, while for sole culture 45 cm inter and 10 cm intra row spacing was recommended. Using the former spacing, Tibe gave a mean seed yield of 2.4 tons ha^{-1} (Table 1) at research stations and 2.5 tons ha^{-1} on farmers' fields, the relative advantage over local checks being 36% and 92% respectively. Using the spacing recommended for sole culture, Tibe gave a mean seed yield of 3.7 tons ha^{-1} at station level.

3. Stability performance

Yield stability in eight climbing bean varieties were studied for two years across four locations, based on the method of Eberhart and Russel (1966). The result of the study showed that Tibe was the best productive variety in grain yield performance and showed maximum stability (Chemeda *et al*, 2005).

4. Disease reaction

Tibe is moderately resistant (Table 1) to foliar diseases such as common bacterial blight (*Xanthomonas campastris*), angular leaf spot (*Phaeoisariopsis griseola*), floury leaf spot (*Mycovellosiella phaseoli*), anthracnose (*Collectotrichum lindemuthianum*) and web blight (*Rhizoctonia solani*).

5. Quality analysis

The laboratory analysis (Table 2) indicated that Tibe required an equal amount of time and was higher as a non-soaker compared to the standard check, Red Wolita.

6. Conclusion

Tibe is a stable variety according to its grain yield performance. It has good agronomic traits that make it suitable for intercrossing with maize and sorghum. It is adaptable to a wide environment. Tibe is resistant to important diseases affecting haricot beans in the areas. This climbing variety was released for production in areas ranging from lowland to mid-altitude in Ethiopia. It was named after a place which is known for its high maize production usually intercropped with the climbing bean. Tibe is the first climbing bean variety released in Ethiopia.

7. References

Chemeda, D., Negash, G., Abeya, T. and Firdissa, E. 2005. Genotype x environment interaction and yield stability of climbing bean (*Phaseolus vulgaris* L.) varieties. *Ethiopian Journal of Agricultural Science* 18(1): 123-127.

Eberhart, S.A. and Russel, W.A. 1966. Stability parameters for comparing varieties. *Crop Science* 6:36-40.

Table 1. Mean values for seed yield (Yid), days to flowering (DF), days to maturity (DM), number of pod per plant (#Po/p), number of seeds per plant (#Se/P) and hundred seed weight (HSW).

Varieties	DF	DM	#Po/P	#Se/P	HSW	Yid (ton/ha)	CBB	ALS	FLS	Anth	WB
Tibe	54	101	16	86	29	23.71	4	3	3	2	2
Local check	62	102	10	55	45	19.13	4	4	3	3	2

CBB=common bacterial blight; ALS=angular leaf spot; FLS=floury leaf spot; Anth=Anthracnose; WB=Web blight

Table 2. Summary of laboratory analysis by Holetta Agricultural Research Center, Food Science Division, Ethiopia.

Variety name	Weight of 100 seed (gm)	# of non-soakers	Cooking time (minute)
Anger	32.2	54	101
Check standard (Red Wolita)	49.3	28	100

Appendix I. Agronomical and morphological characteristics of Tibe (812-BRC-28).

1. Adaptation area:	
1.1. Altitude (m.a.s.l.)	1300-2100
1.2. Rainfall (mm)	1000-1300
2. Fertilizer rate:	-
2.1. DAP (kg/ha)	100
3. Planting date	Early June
4. Seed rate:	-
4.1. Spacing for sole (inter x intra row)	45 cm x 10 cm
5. Days to flower	54
6. Days to maturity	101
7. Pod color	Red
8. Plant height (cm)	175
9. Number of pods per plant	12 - 84
10. Number of seeds per pod	6
11. Pod height (cm)	15
12. Seed shape	Kidney
13. Seed color	Red
14. Seed coat lustre	Shiny with white hila
15. 100 seed weight (g)	29
16. Crop pest reaction	Resistant to major diseases
17. Yield (ton/Ha):	
17.1. Research field	2.37
17.2. Farmer field	2.49
18. Year of release	2004