Evaluation of Statistical Models for Analysis of Insect, Disease and Weed Abundance and Incidence Data

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Abstract: Analysis of variance (ANOVA) has been a fundamental method used for analysis of abundance and incidence data. However, abundance and incidence data often violate the assumptions of ANOVA. Researchers often ignore ANOVA assumptions, transform the data using arbitrarily chosen functions and then fail to evaluate whether or not the transformation actually corrected the problem. The statistical power of the tests used is also seldom reported. Therefore, the objectives of this paper are to demonstrate (1) implications of using arbitrarily chosen transformations and ANOVA to the validity of statistical inference on pest abundance and incidence and (2) the application of LMMs and GLMs for efficient analysis of such data. Abundance data were analyzed assuming normal, Poisson and negative binomial error distributions. Incidence data were analyzed assuming normal and binomial error distributions. Among the data transformation functions, logarithmic transformation gave better description of abundance data compared with square root. Working logits were better than angular or square root transformation of incidence data. The study has also demonstrated that the choice of transformation can influence the statistical significance and power of test. Transformation of either abundance or incidence data did not necessarily ensure normality or variance homogeneity. According to the Akaike information criterion (AIC), a GLM assuming negative binomial error distribution was better for description of most abundance datasets compared with a GLM assuming Poisson error distribution or LMM. LMM based on working logits also gave a better description of the data than a GLM assuming binomial distribution. It is concluded that LMMs and GLMs simultaneously consider the effect of treatments and heterogeneity of variance and hence are more appropriate for analysis of abundance and incidence data than ordinary ANOVA.

Key words: Mixed Models; Generalized Linear Models; Statistical Power

1. Introduction

Abundance refers to the number of individuals per unit area. It is a fundamental ecological parameter and a critical consideration when making management and conservation decisions. In most work in entomology, pathology and weed sciences, counts are used as proxies of abundance. In the case of counts a substantial proportion of the values are zero, and the remainder have a skewed distribution (Fletcher *et al*., 2005; Martin *et al*., 2005; Warton, 2005). The term incidence refers either to the number of plants (or plant units) that is visibly diseased or affected by an insect (out of a given total number) (Madden and Hughes, 1995). Pathologists and entomologists often collect incidence data because in many instances, notably with plant diseases caused by viruses, it is impractical to assess diseases on the basis of pathogen abundance (McRoberts *et al*., 1996). Similarly, with small arthropods such as mites, thrips, aphids, psyllids and leafhoppers, presence or absence is often easier to establish than estimating abundance by counting individuals. Recently, a positive relationship between incidence and abundance of a species has been demonstrated (Gaston *et al*., 2000). Based on such relationships, Sileshi *et al.* (2006a) have demonstrated that insect abundance can be estimated from incidence or *vice versa*.

By their nature, abundance and incidence are not normally distributed (Madden and Hughes, 1995; Garrett *et al*., 2004). Abundance is quantified by discrete variables, and can be described well by the Poisson or negative binomial distributions. The Poisson distribution is described by one parameter, θ, or the mean. In the Poisson distribution the variance is equal to the mean (Johnson and Kotz, 1969). The negative binomial distribution (NBD) is more convenient model for analyzing insect and weed counts or pathogen density with over-dispersion (Anscombe, 1949; McRoberts *et al*., 1996; Sileshi *et al*., 2006a; b). The NBD is related to several distributions. According to Johnson and Kotz (1969) the NBD is a mixture of Poisson distributions such that the expected values of the Poisson distribution vary according to a gamma (Type III) distribution. This supports one of the four derivations of the NBD (Anscombe, 1950). It has been shown that the limiting distribution of the NBD, as the dispersion parameter (k) approaches zero, is the Poisson. When k is an integer, the NBD becomes the Pascal distribution, and the geometric distribution corresponds to k=1. The log series distribution occurs when zeros are missing and as $k \rightarrow \infty$ (Saha and Paul, 2005).

Incidence is a binary variable because each observed individual plant is either visibly affected or not, or damage symptoms are present or absent (Madden,

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2002). Hence, it is characterized by a binomial or beta-binomial distribution (Madden and Hughes, 1995; Collette, 2002). Despite the many advantages of using the binomial distribution (Collette, 2002), this distribution only occasionally describes actual disease incidence data. Diseased individuals typically are clustered in nature, resulting in greater heterogeneity of disease incidence than would be expected for a random pattern (Madden, 2002). More typically, the variance is larger and the observed frequency of diseased individuals is more skewed than that predicted by the binomial distribution (Hughes and Madden, 1995). The variance is a function of the mean in both incidence (Hughes and Madden, 1995) and abundance (Taylor, 1961) data.

Statistical inference based on abundance and incidence using conventional statistical methods such as analysis of variance (ANOVA) poses several challenges. There is a wide range of situations where the assumptions of normality and homogeneity of variance are not met for insect or weed abundance data (Sileshi and Mafongoya, 2002; 2003; Sileshi *et al*., 2002; 2006b). ANOVA models focus on null hypothesis testing based on mean tendencies in the data. These tests typically assume that the errors (after fitting the model) are independent and identically distributed as normal random variables with constant variance. These techniques were developed, and to some extent derive their validity, from the randomization underlying designed experiments (Fisher, 1935). However, a large proportion of entomological and pathological research consists of observational studies in which the goal is to explain a pattern relative to a series of explanatory variables.

The standard methodology in ANOVA has been to use a transformation of the response variable that results in a variable that is approximated by a normal distribution. In a sense, this is forcing the data to fit a model that was developed for analysis of continuous variables, rather than using an appropriate statistical model for the data at hand (Hughes and Madden, 1995; Garrett *et al*., 2004; Madden *et al*., 2002). Furthermore, variance-stabilizing transformations may not, in fact, fully stabilize variances in count (McArdle and Anderson, 2004) or incidence data when some of the means are close to 0 or 100% (Madden, 2002). It is well known that departures from the assumption of homogeneity can result in inflated error rates (Cochran, 1947). Tests of significance, standard errors, and contrasts of the means can be affected if ANOVA is used for discrete and binary data.

In ANOVA, coefficients are computed using ordinary least square (OLS) methodology which minimizes the sum of squared distances of data points to the parameter estimate. An alternative to OLS is provided by the Restricted Maximum Likelihood (REML) and maximum likelihood (ML) estimation methods (Littell, 2002). REML is used in linear mixed models (LMM), while ML can be used in both LMM and generalized linear models (GLMs) (Collett, 2002). The LMM is an extension of ANOVA, and it still assumes normality (Littell, 2002). However, it extends the ANOVA model by allowing for both correlation and heterogeneous variances. Wolfinger (1993) and Piepho *et al.* (2003) provide detailed information on LMMs. Better still are GLMs, which are more appropriate for analyzing discrete and binary data (McCullagh and Nelder, 1989; Collett, 2002; Madden, 2002; Hughes and Madden, 1995; Garrett *et al*., 2004; Turechek and Madden, 2002). In GLMs, the response is assumed to possess a probability distribution of the exponential form such as the Poisson, NBD and binomial. In GLM coefficients are computed using ML, which maximize the odds that a dependent variable equals a given value. Here, a function of the expected value of Y is modelled as a linear function of the variables of interest (Collett, 2002). This function can be written as $g(\mu)$, where μ is the expectation of $Y[\mu=E(Y)$, and is known as the link function. This is quite different from the regular normal distribution-based approach of transforming Y to produce $g(Y)$ and then fitting a model to $g(Y)$. The reader is referred to McCullagh and Nelder (1989) for detailed information on GLMs, and to Hartley and Rao (1967) and Harville (1977) for information on REML and ML.

Despite the recent developments on LMM and GLM methodology (Garrett *et al*., 2004; Madden, 2002; Madden *et al*., 2002) and wider availability of computer software, they have been little used by entomologists, pathologists and weed scientists. Researchers still use arbitrarily chosen data transformations and apply OLS ANOV. Very few actually are aware of the power of these tests (Thomas and Krebs, 1997). The statistical power of a significance test is the long-term probability (given the population effect size, alpha, and sample size) of rejecting a false null hypothesis. While power analysis is a vital tool for study planning, it has been largely ignored in entomology, pathology and weed research. The objectives of this paper are to demonstrate (1) implications of using arbitrarily chosen transformations and ANOVA to the validity of statistical inference on pest abundance and incidence and (2) the application of LMMs and GLMs for efficient analysis of such data.

2. Materials and Methods

2.1. Source of Data

The data reanalysed in this study included abundance of witch weeds (*Striga asiatica*), grass and broad leafed weeds in maize, and two insect species, namely the leucaena psyllid (*Heteropsylla cubana*) and *Exosoma* sp. The data on witch weed (*Striga asiatica*) comes from Sileshi *et al.* (2006b) but is restricted to only one of the experiments described in that paper. The experiment was established in December 1991 and consisted of maize grown in a mixed intercropped system with the tree legumes *Caliandra callothyrsus*, *Flemingia macrophylla*, *Gliricidia sepium*, *Leucaena leucocephala, Senna siamea, Sesbania sesban*. Details of the treatments, plot layout, randomization and management of this experiment have been described in Sileshi *et al.* (2005; 2006b). The abundance of witch weed was monitored in 1995, 1996 and 1997 cropping season, and the effect of treatment and year of sampling was analyzed. The abundance of arable weeds was assessed in a legume fallow experiment established in the year 2000 at Msekera sites. The treatments in this experiment consisted of maize planted in pure-species fallows of *Gliricidia sepium*, *Acacia anguistissima*, *Leucaena collinsi*, *Calliandra calothyrsus*, *Senna siamea* and maize monoculture with and without fertilizer. Assessment was made by counting the number of grass weeds (all weeds of the family Graminae) and broad leafed weeds (all non-grass weeds) in an area measuring 1 m by 1 m, and the effect of treatments on abundance of grass and broad leaved weeds was analysed.

Populations of the leucaena psyllid, *Heteropsylla cubana* (Homoptera: Psyllidae), a pest of the tropical agroforestry tree *Leucaena leucocephalla* were monitored in April-May 2005 in four experiments established in 1991, 1992, 1997 and 1999 at Msekera. These experiments have been described in detail in Sileshi *et al*. (2005). In all the trials, trees were cut to a height of 30 cm above ground after three years of growth and allowed to re-sprout in the subsequent years where the shoots were cut back to fertilize maize crops. A cluster of 10 adjacent stumps were selected in every replicate of each experiment, and the numbers of psyllids on a randomly selected shoot per stump were recorded. The effect of site of establishment on the abundance of psyllids was analyzed using the different statistical models.

The datasets on abundance of *Exosoma* came from studies reported elsewhere by the author (Sileshi and Mafongoya, 2002; and 2006b). Abundance data were collected from various agroforestry treatments involving *Sesbania sesban* at Msekera, eastern Zambia in 2002. In each treatment the numbers of *Exosoma* on 10 randomly selected plants were recorded and effect of treatment on abundance analysed.

The incidence data used in this study included foliar diseases (a complex of fungal diseases) of the indigenous fruit Uapaca (*Uapaca kirkiana*), and termite damage in maize reported by the author elsewhere (Sileshi *et al*., 2005). The study on Uapaca foliar diseases involved a randomized and replicated experiment consisting of a factorial combination of three potting mixtures (unsterilized forest soil, sterilized forest soil and forest soil + saw dust), soil applied fertilizer (with and without compound D), and a foliar applied fertilizer (with and without). Data on foliar disease incidence were collected in July and October 2002. The incidence of the insects and diseases was determined by observing the disease status of single whole plants used as the sampling unit. Incidence constituted the proportion of plants in a row showing foliar disease symptoms.

Termite damage was assessed in 2002 and 2003 in two experiments established in 1991 and 1992 at Msekera. The treatments consisted of maize grown after of *Caliandra callothyrsus*, *Flemingia macrophylla*, *Gliricidia sepium*, *Leucaena leucocephala, Senna siamea* and monoculture maize grown with and without the recommended rate of fertilizer. Details of the treatments, plot layout, randomization and management of this experiment have been described in Sileshi *et al*. (2005). In both experiments, damage was assessed by recording the number of lodged plants per plot in 2002 and 2003, and the effect of fallow length, year of sampling and treatment on termite incidence was analyzed.

2.2. Statistical Analyses of the Data

For analysis of abundance data, the normal, Poisson and negative binomial distribution models were used. The normal distribution model applies ordinary least square (OLS) ANOVA on transformed insect counts. The probabilistic model using OLS assumes that the underlying errors of the transformed data are all uncorrelated with homogeneous variance, and hence follow an approximate log-normal distribution (McArdle and Anderson, 2004; Warton, 2005). In this study, count data were transformed using natural logarithms and square root functions because of the popularity of these transformations. However, various other types of transformation are available for count data (Taylor, 1961; McArdle and Anderson, 2004). Incidence data were transformed using the angular (arcsine), square root functions and the working logit (Cox, 1970) given by

$$Z = \ln\left(\frac{R + ½}{n - R + ½}\right)$$

where Z is the working logit, *R* is the number responding (e.g., infested plants) and *n* is the number observed. The working logit was tested because this transformation has the advantage of being able to take 0 and 100% response data into account.

Then tests for normality and homogeneity of variance were conducted. Shapiro-Wilk statistic and the Kolmogorov-Smirnov *D* statistic were used for testing normality. The assumption of equality of variance in the transformed data was tested using Bartlett's and Levene's tests of homogeneity of variance via the GLM procedure of the SAS system (SAS/STAT, 2003). ANOVA was conducted on the transformed data using the GLM procedure of the SAS. The statistical power of the ANOVA was calculated using the GLMPOWER procedure of SAS system.

LMM was fitted to the transformed abundance and incidence data using MIXED procedure of the SAS system. All interaction effects were considered to be random effects in the LMM. The MIXED procedure was used because in most cases the experimental units on which the data were recorded were grouped into clusters (e.g. replications, rows etc.), and it was assumed that data from a common cluster were correlated. The Poisson and negative binomial distributions were used to analyse the abundance data.

A GLM to relate the mean abundance (μ) to the explanatory variables (X_i), the following linear probability model was used:

$$Log(\mu) = a + b_1 X_1 + b_2 X_2 + ... + b_n X_n$$

(Equation 1)

where a is the random intercept, X_1, X_2 … X_n are covariates and b_1, b_2 … b_n are parameters to be estimated for the n^{th} covariate. The *log* is the canonical link for the Poisson and negative binomial distributions.

Incidence data were analyzed using the GLMs by assuming binomial distribution of diseased individuals. A GLM to relate the binomial parameter (p) of incidence to the explanatory variables (X_i) a linear probability model of the following form was used:

$$Logit(p_i) = a + b_1 X_1 + b_2 X_2 + ... + b_n X_n$$

(Equation 2)

where the *logit* function is the canonical link for the binomial distribution. For the incidence of the foliar diseases of Uapaca, X_1 , X_2, X_3 and X_4 stand for potting mixture, foliar fertilizer, soil-applied fertilizer and month of sampling, respectively. When over-dispersion was noted, a dispersion parameter was introduced using the ratio of the deviance to its associated degrees of freedom (McCullagh and Nelder, 1989). Parameters of equations 1 and 2 were estimated by the ML method using the GENMOD procedure of SAS systems. For GLMs, the residual deviance is of central importance for determining goodness-of-fit of a model. Therefore, the residual deviance divided by its degrees of freedom (RD/DF) was used to detect goodness-of-fit to the models. Values of RD/DF greater than 1 indicated over-dispersion while values less than 1 indicated under-dispersion. Evidence of over-dispersion or under-dispersion was used as an indication of inadequate fit of the statistical model to the data. Akaike information criterion (AIC) was used for comparing the statistical models (Burnham and Anderson, 2002) and transformations. The second-order Akaike information criterion (AIC_c) correcting for small sample size (Hurvich and Tsai, 1989) was computed from the log likelihood (LL) estimates as:

$$AIC_c = -2LL + 2K + \frac{2K(K+1)}{n-K-1}$$

(Equation 3)

where K is the number of parameters in the model and n is the sample size. The "smaller AIC_c is better" approach was used for comparisons among models. Among the models under consideration, the one with the smallest AICc has the smallest expected loss of information, and was interpreted as the best.

3. Results

The transformations did not normalize the abundance data except for grass and broad leafed weeds. Transformations also failed to normalize the incidence data. Levene's and Bartlett's tests indicated heterogeneity of variance across years in both raw and the transformed witch weed abundance data. When treatment was considered, Levene's test indicated homogeneous variance in the raw data, while Bartlett's test indicated heterogeneity. Both Levene's and Bartlett's test indicated variance heterogeneity across treatments in the raw as well as the transformed data on grass weed, broad leafed weed and *Exosoma* abundance (Table 1).

Table 1. Probability levels for Levene's and Bartlett's tests of homogeneity of variance in abundance before and after transformation of the data using logarithmic and square root (SQRT) functions

Pest group	Fixed effect	Levene's test			Bartlett's test		
		Before	Logarithmic	SQRT	Before	Logarithmic	SQRT
Witch weeds	Year	0.006	<0.001	<0.001	<0.001	<0.001	<0.001
	Treatment	0.299	0.020	0.107	<0.001	0.044	<0.001
Grass weeds	Treatment	0.004	0.003	0.003	0.006	0.004	0.113
Broad leafed weeds	Treatment	<0.001	0.038	<0.001	<0.001	0.065	<0.001
Leucaena psyllid	Site	0.053	0.681	0.118	0.014	0.672	0.214
Exosoma sp.	Treatment	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

On the other hand, variances of leucaena psyllid abundance were homogeneous across sites after transformation compared with the raw data. Levene's and Bartlett's test indicate heterogeneity of variance in incidence of Uapaca leaf disease across months, potting mixtures and soil applied fertilizers before and after angular and square root transformation. However, foliar fertilizer treatment had homogeneous variance before and after transformation (Table 2). Incidence of termite damage in maize had heterogeneous variance across fallow length and year of sampling while treatment had homogeneous variance before and after angular and square root transformation according to the Levene's test. Bartlett's test indicated variance heterogeneity across treatment in the raw data and angular transformed termite incidence, but homogeneity in the square root transformed data. Transformation using working logits homogenized variance across fallow length and years in termite incidence according to both Levene's and Bartlett's tests (Table 2).

Table 2. Probability levels for Levene's and Bartlett's tests of homogeneity of variance in incidence data before and after transformation using angular (Arcsine), square root (SQRT) and working logits (Logit)

Pest group	Fixed effect	Levene's test				Bartlett's test			
		Before	Arcsine	SQRT	Logit	Before	Arcsine	SQRT	Logit
UFD	Month	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Potting mix	<0.001	<0.001	<0.001	0.008	<0.001	<0.001	<0.001	0.024
	Soil applied	0.033	0.038	0.041	0.034	0.017	0.090	<0.001	0.045
	Foliar fert	0.901	0.687	0.354	0.836	0.889	0.735	0.064	0.843
Termites	Fallow	0.002	0.002	0.003	0.419	<0.001	<0.001	<0.001	0.312
	Year	0.005	0.087	0.037	0.412	<0.001	<0.001	0.012	0.291
	Treatment	0.559	0.478	0.685	0.151	<0.002	0.717	0.499	0.008

Under the normal distribution assumption the fixed effects were not significant before transformation of witch weed, grass weed and *Exosoma* abundance (Table 3).

Table 3. Significance (P values) of effects on abundance of pest groups using different data transformation and distribution assumptions

Pest group	Fixed effect	LMM (Normal distribution)			GLM	
		Before	Logarithm	SQRT	Poisson	NBD
Witch weed	Year	0.144ns	0.021	0.164	<0.001	<0.001
Witch weed	Treatment	0.364ns	0.124ns	0.195	<0.001	<0.001
Grass weeds	Treatment	0.161ns	0.018	0.056	<0.001	<0.001
Broad leafed weeds	Treatment	<0.001	<0.001	<0.001	<0.001	<0.001
Leaucaen psyllid	Site	0.025	0.049	0.025	<0.001	0.070ns
Exosoma sp.	Treatment	0.384	0.320	0.342	<0.001	<0.001

ns= variances not significantly different within fixed effect

Significant effects were indicated after logarithmic transformation of witch weed and grass weed abundance at the 5% level. On the other hand, the Poisson and negative binomial models indicated highly significant (P<0.001) effects for all pest groups except the leucaena psyllid (Table 3). The statistical power of ANOVA for the various fixed effects was sufficiently high (>0.90) for most abundance data except for the raw data on witch weed abundance (Table 5).

If one were to analyze the raw data, one would require twice the number of observations to achieve the desired statistical power of 0.90. However, when data were transformed using the logarithmic function, the desired statistical power was achieved using the same sample size. Under both the normal and binomial distribution assumptions, the incidence of Uapaca foliar disease significantly differed with month, potting mixture and foliar application of fertilizer. The statistical power of test for the effect of month, potting mixture and foliar application of fertilizer were sufficiently high (>0.90) (Table 4).

Table 4. Significance (P values) of effects on and incidence of pest groups using different data transformation and distribution assumptions

Pest group	Fixed effect	LMM (Normal distribution)				GLM (Binomial distribution)
		Before	Arcsine	SQRT	Logit	
UFD	Month	<0.001	<0.001	<0.001	<0.001	<0.001
	Potting mix	<0.001	<0.001	<0.001	<0.001	<0.001
	Soil applied	<0.001	<0.001	<0.001	<0.001	0.007
	Foliar fertilizer	0.083	0.068	0.231	0.162	0.258
Termites	Fallow length	0.003	0.007	<0.001	<0.001	<0.001
	Year	0.002	0.004	<0.001	<0.001	<0.001
	Treatment	0.799	0.892	0.467	0.504	0.582

Table 5. Statistical power of test for ANOVA before and after logarithmic and square root (SQRT) transformation of abundance of pest groups and additional samples required to achieve the desired statistical power

Pest group	Fixed effect	Sample size	Transformation Before	Logarithmic	SQRT
Witch weed	Year	96 plots	0.77 (192)	>0.90 (0)	0.66 (96)
	Treatment	96 plots	0.66 (192)	>0.90 (0)	0.89 (96)
Grass weeds	Treatment	63 plots	>0.90 (0)	>0.90 (0)	>0.90 (0)
Broad leafed weeds	Treatment	63 plots	>0.90 (0)	>0.90 (0)	>0.90 (0)
Leaucaen psyllid	Site	360 shoots	>0.90 (0)	>0.90 (0)	0.72 (720)
Exosoma sp.	Treatment	270 plants	>0.90 (0)	>0.90 (0)	>0.90 (0)

Figures in parenthesis indicate additional sampling units required to achieve the desired statistical power of 0.90

However, incidence did not differ with soil application of fertilizer. Statistical power analysis showed that the lack of significance was due to the inadequacy of the sample size used. If a meaningful conclusion is to be drawn about the effect of soil application of fertilizer, at least 5-11 times more observations (or 2260-4972 Uapaca plants) would be required (Table 6).

Table 6. Statistical power of test for ANOVA before and after transformation of incidence data using the angular (arcsine), square root (SQRT) functions and working logits and additional samples required to achieve the desired statistical power

Pest group	Fixed effect	Sample size	Transformations Before	Arcsine	SQRT	Logit
UFD	Month	452 plants	>0.90 (0)	>0.90 (0)	>0.90 (0)	>0.90 (0)
	Potting mix	452 plants	>0.90 (0)	>0.90 (0)	>0.90 (0)	>0.90 (0)
	Soil applied	452 plants	0.80 (452)	0.80 (904)	0.81 (452)	0.84 (906)
	Foliar fertilizer	452 plants	0.31 (1808)	0.33 (2260)	0.18 (4520)	0.22 (3624)
Termites	Fallow length	128 plots	>0.90 (0)	0.66 (246)	>0.90 (0)	>0.90 (0)
	Year	128 plots	>0.90 (0)	0.51 (369)	>0.90 (0)	>0.90 (0)
	Treatment	128 plots	0.21 (640)	0.07 (4059)	0.25 (512)	0.24 (612)

Figures in parenthesis indicate additional sampling units required to achieve the desired statistical power of 0.90

Similarly, ANOVA showed lack of treatment effects on the incidence of termite damage in maize. Power analysis indicated that this was due to inadequate sample size. To make a valid conclusion about the effect of treatments 6-8 times more observations than the current sample (or 768-984 plots) would be needed.

The DEV/DF values were greater than unity indicating that the Poisson assumption of random distribution did not hold for all the abundance data. The AIC scores (Table 7)

Table 7. Second-order Akaike Information Criteria (AICc smaller is better) for selection of transformation functions and statistical models appropriate for analysis of abundance and incidence of different pests

Pest group	Linear Mixed Model Before	SQRT	Log	Arcsine	Logit	Generalized Linear Models Poisson	NBD	Binomial
A. Abundance								
Witch weed	1227.4	593.5	212.6	NAPP	NAPP	-59170.6	**-70089.5**	NAPP
Grass weeds	622.2	270.3	6.8	NAPP	NAPP	-58671.9	**-60142.8**	NAPP
Broad leafed weeds	537.7	233.5	20.4	NAPP	NAPP	-11042.7	**-11455.2**	NAPP
Leucaena psyllid	2848.1	1389.2	1046.4	NAPP	NAPP	-19828.0	**-22376.6**	NAPP
Exosoma sp.	623.0	88.3	**-253.2**	NAPP	NAPP	304.2	264.2	NAPP
B. Incidence								
UFD	3922.9	1511.2	NAPP	3819.7	**1176.6**	NAPP	NAPP	1547.8
Termites	1132.9	519.4	NAPP	913.8	**388.1**	NAPP	NAPP	846.7

Bold entries indicate the best transformation or model
NAPP = not applicable

showed that the negative binomial model is better for description of the abundance data than the Poisson or normal distribution models. The only exception was abundance of *Exosoma* sp (Table 7). In the case of *Exosoma* sp, LMM (based on log transformation) was adequate for analysis of the data. Among the data transformation functions, logarithms gave the best description of the data (smallest AICc). According to AIC analysis of Uapaca foliar disease and termite incidence without transformation gives poorer description of the data than transformation. For Uapaca foliar disease and termite incidence, the best transformation was working logits. LMM based on working logits also gave a better description of the data than logistic regression (Table 7).

4. Discussion

The results presented indicate that transformation of either abundance or incidence data do not necessarily ensure normality. This is in agreement with the growing body of literature on the subject matter in ecology (Fletcher *et al*., 2005; McArdle and Anderson, 2004; Martin *et al*., 2005; Warton, 2005). Even if approximate normality is indicated by goodness-of-fit tests on the transformed data, if the data come from some other distribution than the normal then the significance tests may be misleading. For instance, the Chi-square test of normality is a non-specific test, in that the test criterion is directed against no particular type of departure from normality (Snedecor and Cochran, 1989). Examples occur in which the data are noticeably skew, although the goodness-of-fit test does not reject the null hypothesis. For small sample sizes, power of test is also low for detecting larger departures from normality that may be important. It is only with larger sample sizes that increasingly smaller departures from normality can be detected (Snedecor and Cochran, 1989).

The study has also demonstrated that transformation of either abundance or incidence data do not necessarily ensure homogeneity of variances, and that transformation functions differed in their ability to ensure homogeneity. Close scrutiny of the tests of homogeneity of variance revealed that the two tests differed in their sensitivity in detecting variance heterogeneity in abundance and incidence. It is well known that ANOVA is less robust to violations of homogeneity of variance than normality. Homogeneity of variance is essential for the valid application of parametric ANOVA. A transformation used to normalize the data may lead to heterogeneity of variance. This is because one transformation might be best for ensuring homogeneity of variance, while another might be best for ensuring normality. In practice, only one of these two transformations can be used, so all the statistical requirements cannot be met with linear models (Garrett *et al*., 2004). Transforming the data to rectify the problem can result in apparently grossly inflated type I errors, altering the model under test and affect the spatial scale of the hypothesis (McArdle and Anderson, 2004). Adding 1 to the zero counts during logarithmic transformations can also result in strange distributions, which has led some workers to model the zeros separately for count data (McArdle and Anderson, 2004; Martin *et al*., 2005). Among the data transformation functions used in this study, logarithmic transformation gave better description of abundance data compared with square root. Working logits were better than angular or square root transformation of incidence data. The study has demonstrated that the choice of transformation can influence the statistical significance and power of test. However, during statistical analyses, researchers all too often ignore the assumptions, transform the data and then fail to evaluate whether the transformation corrected the problem (McArdle and Anderson, 2004). To test for homogeneity variances, the Bartlett's and Levene's tests are often used. However, as indicated by the results in Table 2 the sensitivity of these tests differ. While Bartlett's test has accurate Type I error rates and optimal power when the underlying distribution of the data is normal, it can be very inaccurate if the distribution is even slightly nonnormal (Box, 1953).

Researchers some times use nonparametric methods as alternatives to parametric tests for analyses of abundance and incidence when the data violate the assumptions of ANOVA (Sileshi and Mafongoya, 2002; 2003). Until recently (Brunner and Puri, 2001; Turecheck, 2004) the use of nonparametric approach had been limited because these tests are less powerful than parametric methods. Secondly, they could only be used in one-way analysis as there had been no satisfactory theoretic foundation for analysing data in factorial designs and repeated measures (Shah and Madden, 2004). Unlike parametric ANOVA and nonparameteric tests, GLMs enable appropriate analyses of skewed frequency or binary data. In addition, with GLMs, the properties of data from discrete distributions such as the Poisson and negative binomial distribution (counts) and binomial distribution (proportions) can be accounted for (Hughes and Madden, 1995; Collett, 2002). For example, the GLMs used in this study tested whether the abundance distribution was random (Poisson) or spatially aggregated (negative binomial). The GLM also demonstrated that the negative binomial model is considerably more robust for analysis of the abundance data compared with the LMM or the Poisson (Table 7). Using the GLMs it was possible to simultaneously consider the effect of treatments and variance heterogeneity.

While common parametric approaches, such as ANOVA are well known and convenient, their assumptions may not always be met in contexts studied by plant pathologists, entomologists and weed biologists. For example, if ANOVA shows lack of statistical significance, it may be because there is no effect or because the study design makes it unlikely that a biologically real effect would be detected. When the sample size is small and variance is high as is common in abundance and incidence data, biologically interesting phenomena may be missed because ANOVA is unlikely to yield significant results (e.g. Tables 5 and 6). Under such situations computation of statistical power is as important as significance testing. Power analysis can distinguish between these alternatives, and is therefore a critical component of designing experiments and testing results (Thomas and Krebs, 1997). For abundance and incidence data, LMMs and GLMs offer tremendous opportunities for improvement of statistical inference. Just as standard ANOVA has been expanded to LMMs, recent research has expanded GLMs to generalized linear mixed models (GLMMs) (Garrett *et al*., 2004). While biologists have traditionally stressed hypothesis testing as a statistical approach, emphasis has shifted in recent years towards information theoretic approaches (Burnham and Anderson, 2002). Information criteria such as AIC provide a more objective way of determining which model among a set of models is most appropriate for analyses of the data at hand. Often one has no *a priori* reason for selecting a specific data transformation to normality. The AIC may be used as a potentially valuable tool for selecting functions for data transformation. The major limitation in using the methods described is that they are computationally intensive. However, software that handle such computations with relative ease are appearing.

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6. References

Anscombe, F.J. 1949. The analysis of insect counts based on the negative binomial distribution. *Biometrics* 5: 165-173.

Anscombe, F.J. 1950. Sampling theory of the negative binomial and logarithmic series distributions. *Biomentriaca* 37: 358-382.

Box, G.E. 1953. Non-normality and tests on variance. *Biometrika* 40: 318 - 335.

Brunner, E. and Puri M.L. 2001. Nonparametric methods in factorial designs. *Statatistics Papers* 42: 1-52.

Burnham, K. P. and Anderson, D. R. 2002. *Model Selection and Multimodel Inference: a practical information-theoretic approach*, 2nd edition. Springer-Verlag, New York.

Cochran, W.G. 1947. Some consequences when the assumptions for the analysis of variance are not satisfied. *Biometrics* 3: 22–38.

Collett D. 2002. *Modelling Binary Data*. 2nd edition. CRS Press, Boca Raton, FL.

Cox, D.R. 1970. *Analysis of Binary Data.* Chapman and Hall, London.

Fisher, R.A. 1935. *Design of experiments*. Oliver and Boyd, Edinburgh, UK.

Fletcher, D., MacKenzie, D. and Villouta, E. 2005. Modelling skewed data with many zeros: a simple Approach combining ordinary and logistic regression. *Environmental and Ecological Statistics* 12: 45-54.

Garrett, K.A., Madden, L. V., Hughes, G. and Pfender, W.F. 2004. New applications of statistical tools in plant pathology. *Phytopathology* 94: 999-1003.

Gaston, K., Blackburn, T.M., Greenwood, J.J.D., Gregory, R. Quinn, R.M. and Lawton, J.H. 2000. Abundance-occupancy relationships. *Journal of Applied Ecology* 37: 39-59.

Hartley, H.O. and Rao, J.N.K. 1967. Maximum likelihood estimation for mixed analysis of variance models. *Biometrika* 54: 93-108.

Harville, D.A. 1977. Maximum likelihood approaches to variance component estimation and to related problems. *Journal of American Statistical Association* 72: 320-340.

Hughes, G., and Madden, L. V. 1995. Some methods allowing for aggregated patterns of diseases incidence in the analysis of data from designed experiments. *Plant Pathology* 44: 927-943.

Hurvich, C.M. and Tsai, C.L.1989 Regression and time series model selection in small samples. *Biometrika* 76: 297-307.

Johnson, N.I. and Kotz, S. 1969. *Discrete Distributions*. Houghton Mifflin Company, Boston.

Littell, R.C. 2002. Analysis of unbalanced mixed model data: A case study comparison of ANOVA versus REML/GLS. *Journal of Agricultural, Biological and Environmental Statistics* 7: 472-490.

Madden, L. V., and Hughes, G. 1995. Plant disease incidence: Distributions, heterogeneity, and temporal analysis. *Annual Review of Phytopathology* 33: 529-564.

Madden, L.V., Turechek, W.W. and Nita, M. 2002. Evaluation of generalized linear mixed models for analyzing disease incidence data in designed experiments. *Plant Disease* 86: 316-325.

Martub, T.G., Wubtek, B.A., J.R., Kuhnert,Field,P.M., S.A., Low-Choy, S.J., Tyre,A., Possingham, H.P. 2005. Aero tolerance ecology: improving ecological inference by modelling the source of zero observations. *Ecology Letters* 8: 1235-1246.

McArdle, B.H and Anderson, M.J. 2004. Variance heterogeneity, transformations, and models of species abundance: a cautionary tale. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 1294-1302.

McCullagh, P. and Nelder, J.A. 1989. *Generalized linear models*, 2nd edition , Longo, Chapman and Hall.

McRoberts, N., Hughes, G. and Madden, L.V. 1996. Incorporating spatial variability into simple disease progress models for crop pathogens. *Aspects of Applied Biology* 46: 1-8.

Peopho, HP., Büchse,A. and Emrich, K. 2003. A hitchhiker's guide to mixed for randomized experiments. *Journal of Agronomy and Crop Science* 189: 310-322.

SAS Institute Inc. 2003. *SAS/STAT,* Release 9.1, Cary, NC: SAS Institute Inc.

Shah, D.A. and Madden, L.V. 2004. Nonparametric analysis of ordinal data in designed factorial experiments. *Phytopathology* 94: 1022-1026.

Saha,K. and Paul, S. 2005. Bias-corrected maximum likelihood estimator of the negative binomial dispersion parameter. *Biometrics* 61: 179–185.

Sileshi, G. and Mafongoya, P.L. 2002. Incidence of insect pests in mixed species fallows with special emphasis on *Mesoplatys ochroptera* Stål (Coleoptera: Chrysomelidae) on *Sesbania sesban* in eastern Zambia. *Agrofoerey Systems* 56: 225-231.

Sileshi, G., Baumgaertner, J., Sithanantham,S. and Ogol, C.K.P.O. 2002. Spatial distribution and sampling plans for *Mesoplatys ochroptera* Stål (Coleoptera: Chrysomelidae) on sesbania. *Journal of Economic Entomology* 95: 499-506.

Sileshi, G. and Mafongoya, P. L. 2003. Effect of rotational fallows on abundance of soil insects and weeds in maize crops in eastern Zambia. *Applied Soil Ecology* 23: 211-222.

Sileshi, G., Mafongoya, P. L., Kwesiga F. and Nkunika, P. 2005. Termite damage to maize grown in agro forestry systems, traditional fallows and monoculture on Nitrogen-limited soils in eastern Zambia. *Agricultural and Forest Entomology* 7: 61-69.

Sileshi, G., Girma, H. and Mafongoya, P.L. 2006a. Occupancy-abundance models for predicting densities of three leaf beetles damaging the multipurpose tree *Sesbania sesban* in eastern and southern Africa. *Bulletin of Entomological Research* 96:61-69

Sileshi, G., Mafongoya, P.L. and Kuntashula, E. 2006b.The effect of agro forestry practices on parasitic and arable weeds of maize in Zambia. *Zambia Journal of Agriculture* 9: (in press)

Snedecor, G.W. and Cochran, W.G. 1989. *Statistical* Methods, 8th edition, Iowa State University, Ames.

Taylor, L.R. 1961. Aggregation, variance and the mean. *Nature* 189: 732-735.

Thomas, L. and Krebs, C.J. 1997. A review of statistical power analysis software. *Bulletin of the Ecological Society of America* 78: 126-139.

Turecheck, W.W. 2004. Nonparametric tests in plant disease epidemiology: Characterizing disease associations. *Phytopathology* 94: 1018-1021.

Turecheck, W.W. and Madden, L.V. 2002. A generalized linear modelling approach for characterizing disease incidence in spatial hierarchy. *Phytopathology* 93: 458-466.

Warton, D. I. 2005. Many zeros does not mean zero Inflation : comparing the goodness-of-fit of parametric models to multivariate abundance data. *Environ metrics* 16: 275-289.

Wolfinger, T.D. 1993. Covariance structure selection in general mixed models. *Communications in Statistics-Simulation and Computation* 22: 1079-1106.

Eco-geographic Distribution and Microcenters of Genetic Diversity in Faba Bean (*Vicia Faba* L.) and Field Pea (*Pisum Sativum* L.) Germplasm Collections from Ethiopia

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Abstract: Ethiopia is considered an important center of secondary diversity for both faba bean (*Vicia faba* L.) and field pea (*Pisum sativum* L.). However, areas of eco-geographic distribution and the microcenter of genetic diversity are not well known. Two separate trials consisting of 160 faba bean and 148 field pea accessions were conducted at Holetta and Kulumsa in 2001. Simple and alpha-lattice designs with 2 replications were used for faba bean and field pea, respectively. Cluster analysis grouped faba bean accessions into eight and field pea into five different classes. Mahalanobis's D^2 analyses showed significant genetic distances between most of the clusters in both crops. Accessions from the northern parts of the country showed tendencies of being grouped together, indicating that their genetic background may be related. Accessions from the southern parts of the country were distributed over most of the clusters showing more genetic diversity compared to those from the northern parts. This indicates that the distribution of genetic diversity among accessions is not uniform across different eco-geographical regions in Ethiopia and the microcenter of genetic diversity for both crops may be located in the southern part of the country. The existence of more genetic diversity in one region compared to the other could be due to differences in the level of variability among the original introductions to different regions, the nature and degree of both human and natural selections after introduction, and effects of ecological and agricultural conditions as major forces of evolution. Future collection, conservation and utilization programs should focus on the southern part to safeguard and exploit the tremendous genetic diversity. However, a comprehensive study involving both morpho-agronomic traits and molecular markers would be needed for a more comprehensive conclusion.

Key words: Cluster Analysis; Eco-geographic Distribution; Faba bean (*Vicia faba* L.); Field pea (*Pisum sativum* L.); Genetic Diversity; Mahalanobis's Distance (D^2); Microcenter of Genetic Diversity

1. Introduction

Agricultural biodiversity, comprising all the elements from gene to agricultural ecosystems, is one of the principal components of natural resources (Ford-Lloyd and Jackson, 1986; Chahal and Gosal, 2002; Singh, 2002; Atta-Krah, 2004), even though it is often treated separately from other natural resources in many parts of the world (Atta-Krah, 2004), including Ethiopia. A reservoir of irreplaceable genes and gene complexes of a number of crops is currently being lost at a rapid rate through genetic erosion as a result of displacement of landraces by modern varieties, dynamics of agriculture and land uses, destruction of natural habitats, and drought (Tesema and Eshetayehu, 2004). Genetic erosion, the gradual depletion of natural resources in general and crop germplasm in particular with both natural and artificial interferences is, therefore, a current topic all over the world. The conservation and management of germplasm, like that of other components of natural resources, is very crucial not only for food security but also for sustainable agriculture and environmental health.

The Mediterranean and Central Asian regions are regarded as the probable centers of origin and domestication of faba bean (*Vicia faba* L.) and field pea (*Pisum sativum* L.) (Westphal, 1974; Davies, 1976; Hagedorn, 1984; Chahal and Gosal, 2002; Singh, 2002). It is assumed that the crops were brought to Ethiopia directly from Central Asia immediately after domestication (Asfaw *et al*., 1994 a,b; Yohannes , 2000) and have been grown since antiquity (Dawit *et al*., 1994). Ethiopia is, undoubtedly, considered as one of the important centers of secondary diversity for both faba bean (Asfaw *et al*., 1994 a,b; Yohannes , 2000; Singh, 2002) and field pea (Hagedorn, 1984; Hailu *et al*., 1991; Singh, 2002). Wild and primitive forms of field pea are also known to exist in the high elevations of Ethiopia (Hagedorn, 1984), and hence, some authorities including Vavilov (1951) considered Ethiopia rather as one of the primary centers of diversity (Singh, 2002; FAO, 1998). Ethiopia is a country of great eco-geographical diversity with high and rugged mountains (EMA, 1988). This ecogeographic diversity might have resulted in diverse crop germplasm in general (Vavilov, 1951; Singh, 2002), including those of faba bean and field pea in particular (Vavilov, 1951; Harlan, 1969).

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Reports exist both from Ethiopia and elsewhere in different crop species (Ford-Lloyd and Jackson, 1986; Demissie and Bjϕrnstad, 1997; Nigussie , 2001; Chahal and Gosal, 2002; Singh, 2002) including faba bean and field pea (Singh and Tripathi, 1985; Hailu *et al*., 1991; Dawit *et al*., 1994) that diversity in germplasm may not be uniformly distributed across eco-geographic regions but rather concentrated in a particular region depending on ecological, agricultural and socio-cultural conditions in the area (Chahal and Gosal, 2002; Singh, 2002). According to Singh (2002), small areas within the large center of diversity, called microcenters, may exhibit a much greater diversity than the center as a whole. The determination of the eco-geographic distribution and microcenters with higher genetic diversity is rewarding in terms of effective germplasm collection, conservation and utilization programs (Bartual *et al*., 1985; Dale *et al*., 1985; Ford-Lloyd and Jackson, 1986; Rezai and Frey, 1990; Jaradat, 1991; Demissie and Bjϕrnstad, 1997; Chahal and Gosal, 2002; Singh, 2002). Such information is also helpful to locate sites for *in-situ* conservation and those for crop evolution studies (Singh, 2002).

Even though it is generally believed that the Ethiopian faba bean and field pea landraces have valuable genetic diversity (Harlan, 1969; Van der Maesen *et al*., 1988; Engels and Hawkes, 1991; Gemechu, K. *et al*., 2003 a,b), the eco-geographic distribution and microcenters of genetic diversity are not yet well known. This experiment was, therefore, designed to generate information on the eco-geographic distribution and microcenter of genetic diversity for faba bean and field pea germplasm in Ethiopia.

2. Materials and Methods

Accessions of 160 faba bean and 148 field pea collected from the most important faba bean and field pea producing eco-geographic regions of Ethiopia (Ethiopian Agricultural Sample Enumeration, 2002) varying in altitude, rainfall, temperature and soil type were considered for the study in two separate trials. They were collected from the most important production complexes in Wello, Gonder, Shewa and Arsi (Figure 1). The accessions included in the study from each region are given in Tables 1 a and b.

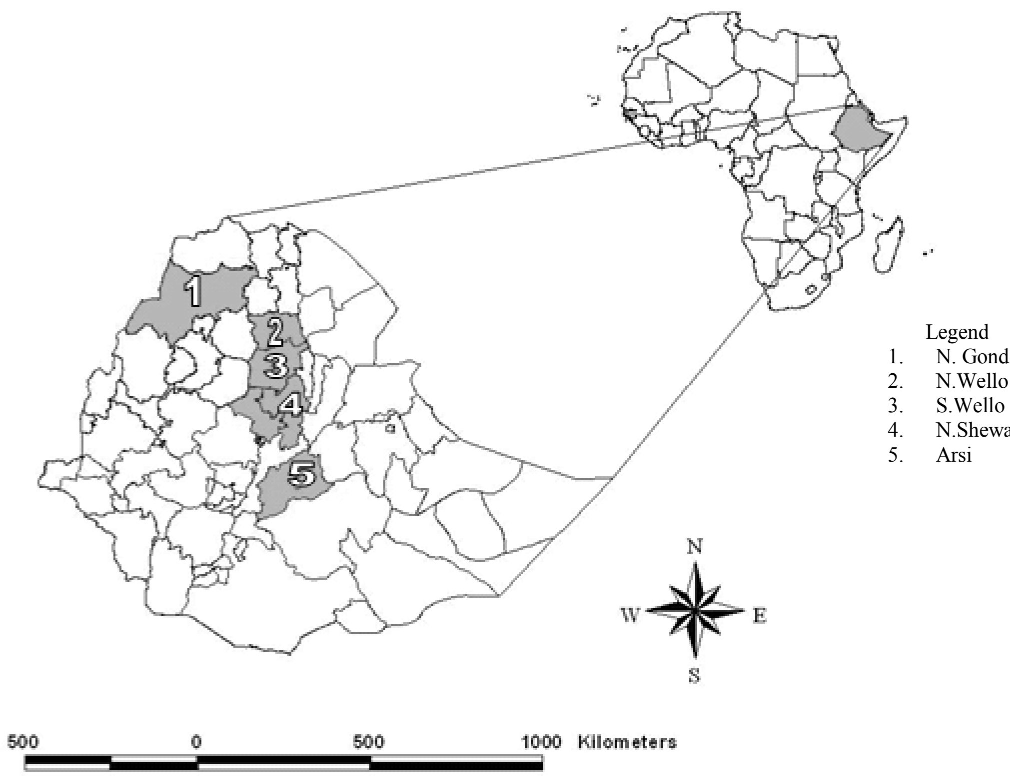


Figure 1. Map of Ethiopia showing origins of faba bean and field pea accessions considered in the study

Table 1a. Origin and designations of the test faba bean accessions

Geographic origin	Districts of origin	No. of collections evaluated	Designations
Wello	Wadla, Delanta, Wagal Tena, Ambassel, Kutaber, Tenta	29	FBColl-1/99, FBColl-2/99, FBColl-3/99, FBColl-4/99, FBColl-5/99, FBColl-6/99, FBColl-7/99, FBColl-8/99, FBColl-9/99, FBColl-10/99, FBColl-11/99, FBColl-12/99, FBColl-13/99, FBColl-14/99, FBColl-15/99,FBColl-16/99, FBColl-17/99, FBColl-18/99, FBColl-19/99, FBColl-20/99, FBColl-21/99, FBColl-22/99, FBColl-23/99, FBColl-24/99, FBColl-25/99, FBColl-26/99, FBColl-27/99, FBColl-28/99, FBColl-29/99
Gonder	Gonder Zuria, Lay Armacho, Wogera, Dabat and Dabark	40	FBColl-58/99, FBColl-59/99, FBColl-60/99, FBColl-61/99, FBColl-62/99, FBColl-63/99, FBColl-64/99, FBColl-65/99, FBColl-66/99, FBColl-67/99, FBColl-68/99, FBColl-69/99, FBColl-70/99, FBColl-71/99, FBColl-72/99, FBColl-73/99, FBColl-74/99, FBColl-75/99, FBColl-76/99, FBColl-77/99, FBColl-78/99, FBColl-79/99, FBColl-80/99, FBColl-81/99, FBColl-82/99, FBColl-83/99, FBColl-84/99, FBColl-85/99, FBColl-86/99, FBColl-87/99, FBColl-88/99, FBColl-89/99, FBColl-90/99, FBColl-91/99, FBColl-92/99, FBColl-93/99, FBColl-94/99, FBColl-95/99, FBColl-96/99, FBColl-97/99
Shewa	Basona Warana, Tarmaber, Lalomama/Molale, Lalo Mider, Mehal Meda, Gera Keya and Sela Dingay	41	FBColl-133/99, FBColl-134/99, FBColl-135/99, FBColl-136/99, FBColl-137/99, FBColl-138/99, FBColl-139/99, FBColl-140/99, FBColl-141/99, FBColl-142/99, FBColl-143/99, FBColl-144/99, FBColl-145/99, FBColl-146/99, FBColl-147/99, FBColl-148/99, FBColl-149/99, FBColl-150/99, FBColl-151/99, FBColl-152/99, FBColl-153/99, FBColl-154/99, FBColl-155/99, FBColl-156/99, FBColl-157/99, FBColl-158/99, FBColl-159/99, FBColl-160/99, FBColl-161/99, FBColl-162/99, FBColl-163/99, FBColl-164/99, FBColl-165/99, FBColl-166/99, FBColl-167/99, FBColl-168/99, FBColl-169/99, FBColl-170/99, FBColl-171/99, FBColl-172/99, FBColl-173/99
Arsi	Tiyo & Digelu, Lemu & Bilbilo, Shirka, Gedeb Asasa, Kofele, Munesa, Hetosa, Tena, Robe, Amigna, Seru, Sude, Dodota Sire, Jeju, Merti and Chole	50	FBColl-157/00, FBColl-159/00, FBColl-161/00, FBColl-163/00, FBColl-164/00, FBColl-168/00, FBColl-170/00, FBColl-172/00, FBColl-176/00, FBColl-178/00, FBColl-181/00, FBColl-184/00, FBColl-187/00, FBColl-188/00, FBColl-191/00, FBColl-193/00, FBColl-196/00, FBColl-199/00, FBColl-201/99, FBColl-204/00, FBColl-205/00, FBColl-208/00, FBColl-209/00, FBColl-211/00, FBColl-214/00, FBColl-217/00, FBColl-220/00, FBColl-222/00, FBColl-224/00, FBColl-226/00, FBColl-228/00, FBColl-231/00, FBColl-233/00, FBColl-236/00, FBColl-238/00, FBColl-240/00, FBColl-242/00, FBColl-244/00, FBColl-246/00, FBColl-248/00, FBColl-250/00, FBColl-252/00, FBColl-255/00, FBColl-257/00, FBColl-259/00, FBColl-261/00, FBColl-263/00, FBColl-265/00, FBColl-267/00, FBColl-269/00

Table 1b. Origin and designations of the test field pea accessions

Geographic origin	Districts of origin	No. of collections evaluated	Designations
Wello	Wadla, Delanta, Wagal Tena, Ambassel, Kutaber and Tenta	26	FPColl-30/99, FPColl-31/99, FPColl-32/99, FPColl-33/99, FPColl-34/99, FPColl-35/99, FPColl-36/99, FPColl-37/99, FPColl-38/99, FPColl-39/99, FPColl-40/99, FPColl-41/99, FPColl-42/99, FPColl-43/99, FPColl-44/99, FPColl-45/99, FPColl-47/99, FPColl-48/99, FPColl-49/99, FPColl-50/99, FPColl-51/99, FPColl-52/99, FPColl-53/99, FPColl-54/99, FPColl-55/99, FPColl-57/99
Gonder	Gonder Zuria, Lay Armacho, Wogera, Dabat and Dabark	31	FPColl-98/99, FPColl-99/99, FPColl-100/99, FPColl-101/99, FPColl-102/99, FPColl-103/99, FPColl-104/99, FPColl-105/99, FPColl-106/99, FPColl-107/99, FPColl-108/99, FPColl-110/99, FPColl-111/99, FPColl-112/99, FPColl-114/99, FPColl-115/99, FPColl-116/99, FPColl-117/99, FPColl-119/99, FPColl-120/99, FPColl-121/99, FPColl-122/99, FPColl-123/99, FPColl-125/99, FPColl-126/99, FPColl-127/99, FPColl-128/99, FPColl-129/99, FPColl-130/99, FPColl-131/99, FPColl-132/99
Shewa	Basona Warana, Tarmaber, Lalomama/Molale, Mehal Meda, Gera Keya and Sela Dingay	36	FPColl-182/99, FPColl-183/99, FPColl-184/99, FPColl-185/99, FPColl-186/99, FPColl-187/99, FPColl-188/99, FPColl-189/99, FPColl-190/99, FPColl-191/99, FPColl-192/99, FPColl-193/99, FPColl-194/99, FPColl-195/99, FPColl-196/99, FPColl-197/99, FPColl-198/99, FPColl-199/99, FPColl-200/99, FPColl-201/99, FPColl-202/99, FPColl-203/99, FPColl-204/99, FPColl-205/99, FPColl-206/99, FPColl-207/99, FPColl-208/99, FPColl-209/99, FPColl-210/99, FPColl-211/99, FPColl-212/99, FPColl-213/99, FPColl-214/99, FPColl-215/99, FPColl-216/99, FPColl-217/99
Arsi	Digalu & Tijo, Shirka, Lemu & Bilbilo, Gedeb Asasa, Kofele, Munesa, Hetosa, Amigna, Seru, Robe and Tena	55	FPColl-30/00, FPColl-31/00, FPColl-32/00, FPColl-33/00, FPColl-34/00, FPColl-35/00, FPColl-36/00, FPColl-37/00, FPColl-38/00, FPColl-39/00, FPColl-40/00, FPColl-41/00, FPColl-42/00, FPColl-43/00, FPColl-44/00, FPColl-45/00, FPColl-46/00, FPColl-47/00, FPColl-48/00, FPColl-49/00, FPColl-50/00, FPColl-51/00, FPColl-52/00, FPColl-53/00, FPColl-54/00, FPColl-55/00, FPColl-56/00, FPColl-57/00, FPColl-58/00, FPColl-59/00, FPColl-60/00, FPColl-61/00, FPColl-62/00, FPColl-63/99, FPColl-64/00, FPColl-65/00, FPColl-66/00, FPColl-67/00, FPColl-68/00, FPColl-69/00, FPColl-70/00, FPColl-71/00, FPColl-72/00, FPColl-73/00, FPColl-74/00, FPColl-75/00, FPColl-76/00, FPColl-77/00, FPColl-78/00, FPColl-79/00, FPColl-80/00, FPColl-81/00, FPColl-82/00, FPColl-83/00, FPColl-84/00

The accessions were evaluated at two locations, Holetta (09°00'N, 38°30'E) and Kulumsa (08°01'N, 39°09'E) in Ethiopia during the 2001 main season in a separate trial for each crop. Holetta, with an altitude of 2400 meters above sea level and average annual rainfall of 1000 mm, represents the major high-altitude production areas of the country, while Kulumsa, with an altitude of 2200 meters above sea level and average annual rainfall of 800 mm, represents the major mid-altitude production areas. Holetta is characterized by a red-brown clay soils with a pH below 5 and Kulumsa by a dark-clay loam soil with a pH of 6.0. The trials were laid down in simple and alpha-lattice designs with two replications for faba bean and field pea, respectively. Seeds were planted on plots consisting of two rows of 4 m length with a spacing of 40 cm for faba bean and 20 cm for field pea between rows and 5 cm between plants within a row for both crops. Fertilizer was applied at the rate of 46 kg ha^{-1} P_2O_5 and 18 kg N ha^{-1} while management practices followed research recommendations specific to each location. Data were collected on days to flowering, days to maturity, grain filling period (days to maturity minus days to flowering), plant height (cm), chocolate spot (*Botrytis fabae* Sard.) infestation level in faba bean and Ascochyta blight (*Mycosphaerella pinodes* Lib.) in field pea, number of nodes/plant, number of podding nodes/plant, number of pods/podding nodes, number of pods/plant, number of seeds/pod, 1000 seed weight (g), and grain yield/plot (g). Records on both chocolate spot and aschochyta blight were taken based on 1-9 scale, 1 being highly resistant and 9 highly susceptible. Records on diseases scores were pre-transformed to percentage values, which then ARCSINE transformed for statistical analysis as suggested by Little and Hills (1978). Data on all traits were pre-standardized to means of zero and variances of unity before clustering to avoid bias due to differences in measurement scales (Manly, 1986).

Clustering of accessions was performed by average linkage method of SAS software (SAS Institute, 1996) using traits that were found to be significantly different among the accessions at least at one of the locations. Points where local peaks of the pseudo F statistic join with small values of the pseudo t^2 statistic followed by a larger pseudo t^2 for the next cluster fusion were examined to decide the number of clusters (SAS Institute, 1996). Genetic distances between clusters as standardized Mahalanobis's D^2 statistics were calculated as: $D^2_{ij} = (xi - xj)' cov^{-1} (xi - xj)$Where, D^2ij = the distance between cases i and j; xi and xj = vectors of the values of the variables for cases i and j; and cov^{-1} = the pooled within groups variance-covariance matrix.

The D^2 values obtained for pairs of clusters were considered as the calculated values of Chi-square (χ^2) and were tested for significance both at 1% and 5% probability levels against the tabulated value of χ^2 for 'P' degree of freedom, where P is the number of characters considered (Singh and Chaudhary, 1985).

3. Results and Discussion

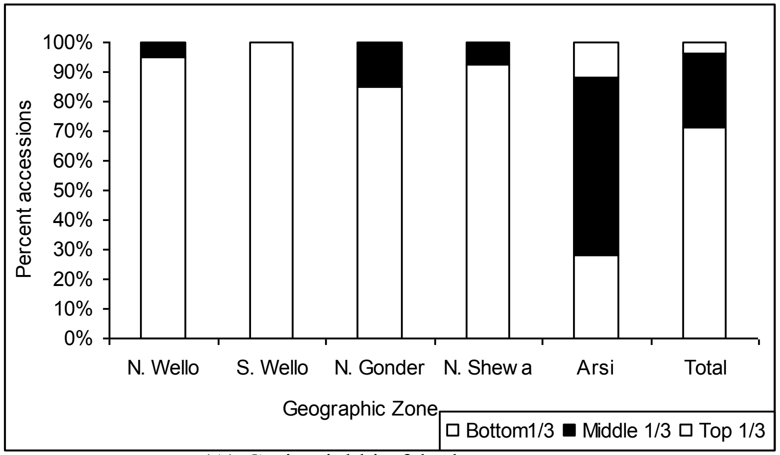
3.1. Performance of Accessions

Separate analyses of variance across the two locations showed significant differences among the accessions while pooled differences were mostly non-significant as discussed elsewhere (Gemechu Keneni *et al*., 2005 a & b). A stratified ranking diagram showed that accessions from different eco-geographical zones had more or less different pattern of distribution for the two most important economic traits (grain yield and seed size). The faba bean accessions collected from the southern parts of the country (Arsi) showed clear superiority as most of them ranked in the middle and top one-third for both traits. On the other hand, most of the faba bean collections from the northern parts of the country and those from Shewa ranked either in the bottom one-third or in the middle one-third. Performance among collections from different eco-geographical regions for grain yield and seed size was not distinct for field pea as it was for faba bean. A few accessions ranked in the top one-third not only from Arsi but also from Shewa for grain yield and Wello and Shewa for seed size while most others were either in the middle or bottom one-third (Figure 2).

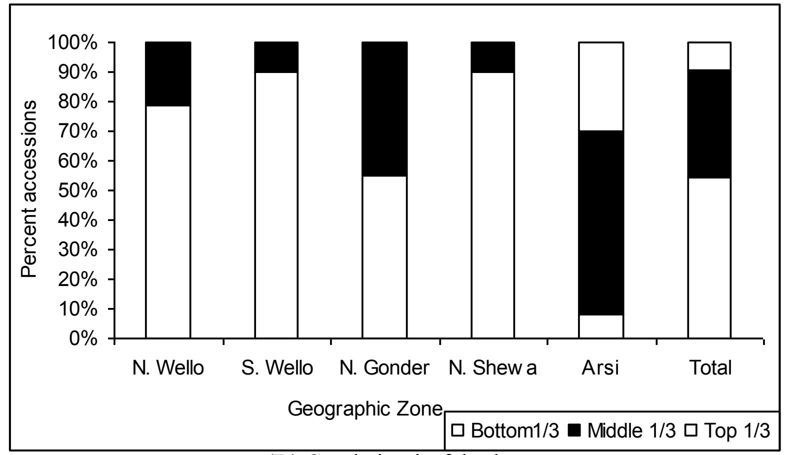
Generally, collections from Arsi revealed more concentration of desirable genes not only in terms of grain yield and seed size in both crops but also those for better pod load and chocolate spot resistance in faba bean compared to collections from other parts of the country (data not shown).

3.2. Extent and Pattern of Genetic Diversity

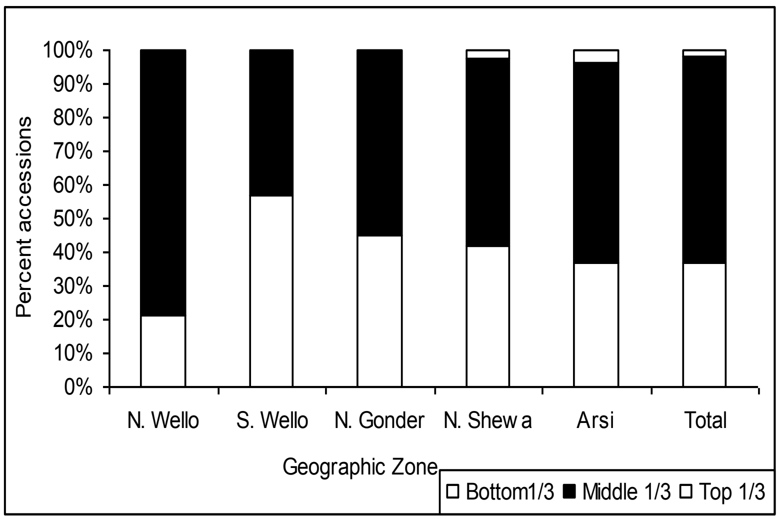
Cluster analyses showed that accessions of faba bean were grouped into eight while that of field pea were grouped into five distinct clusters. The number of accessions varied from cluster to cluster. Some clusters had only a single accession while others had as high as 50 in faba bean and 66 in field pea (Tables 2 a and b).



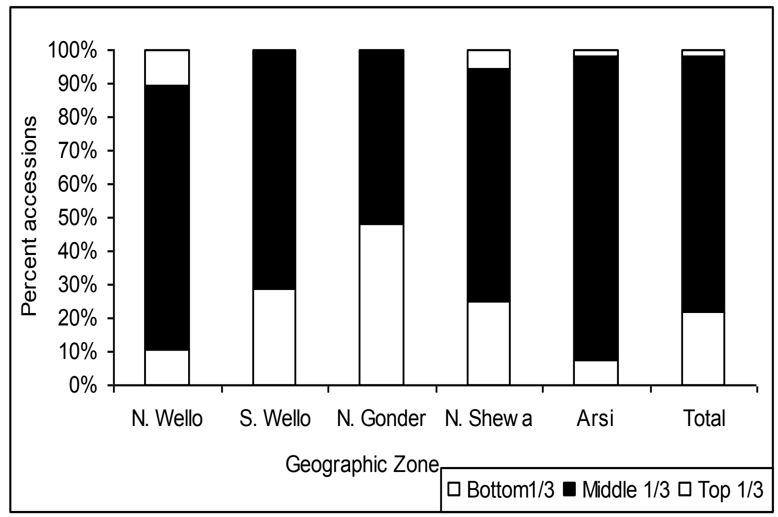
(A) Grain yield in faba bean



(B) Seed size in faba bean



(C) Grain yield in field pea



(D) Seed size in field pea

Figure 2. Stratified ranking diagram showing the distributions for two economic traits (grain yield and seed size) in 160 faba bean and 148 field pea accessions collected from different eco-geographical zones of Ethiopia

Table 2a. Grouping of 160 faba bean accessions into different clusters

Cluster	No. of accessions in cluster	Designations
C_1	30	FBColl-1/99, FBColl-2/99, FBColl-3/99, FBColl-4/99, FBColl-5/99, FBColl-7/99, FBColl-8/99, FBColl-9/99, FBColl-10/99, FBColl-11/99, FBColl-12/99, FBColl-13/99, FBColl-14/99, FBColl-15/99, FBColl-16/99, FBColl-17/99, FBColl-18/99, FBColl-19/99, FBColl-20/99, FBColl-21/99, FBColl-22/99, FBColl-24/99, FBColl-25/99, FBColl-27/99, FBColl-28/99, FBColl-136/99, FBColl-149/99, FBColl-154/99, FBColl-158/99, FBColl-166/99
C_2	50	FBColl-73/99, FBColl-78/99, FBColl-75/99, FBColl-66/99, FBColl-79/99, FBColl-68/99, FBColl-71/99, FBColl-89/99, FBColl-83/99, FBColl-80/99, FBColl-85/99, FBColl-81/99, FBColl-91/99, FBColl-62/99, FBColl-92/99, FBColl-93/99, FBColl-90/99, FBColl-69/99, FBColl-88/99, FBColl-64/99, FBColl-96/99, FBColl-84/99, FBColl-86/99, FBColl-82/99, FBColl-67/99, FBColl-77/99, FBColl-141/99, FBColl-155/99, FBColl-70/99, FBColl-72/99, FBColl-76/99, FBColl-94/99, FBColl-97/99, FBColl-263/00, FBColl-61/99, FBColl-193/00, FBColl-196/00, FBColl-238/00, FBColl-240/00, FBColl-250/00, FBColl-252/00, FBColl-63/99, FBColl-199/00, FBColl-244/00, FBColl-59/99, FBColl-95/99, FBColl-58/99, FBColl-65/99, FBColl-257/00, FBColl-269/00
C_3	38	FBColl-146/99, FBColl-152/99, FBColl-170/99, FBColl-157/99, FBColl-134/99, FBColl-168/99, FBColl-138/99, FBColl-137/99, FBColl-147/99, FBColl-161/99, FBColl-160/99, FBColl-133/99, FBColl-135/99, FBColl-148/99, FBColl-156/99, FBColl-6/99, FBColl-74/99, FBColl-171/99, FBColl-150/99, FBColl-163/99, FBColl-139/99, FBColl-169/99, FBColl-145/99, FBColl-144/99, FBColl-151/99, FBColl-142/99, FBColl-162/99, FBColl-176/00, FBColl-261/00, FBColl-259/00, FBColl-26/99, FBColl-143/99, FBColl-165/99, FBColl-140/99, FBColl-172/99, FBColl-159/99, FBColl-167/99, FBColl-23/99
C_4	5	FBColl-60/99, FBColl-153/99, FBColl-87/99, FBColl-173/99, FBColl-29/99
C_5	18	FBColl-214/00, FBColl-217/00, FBColl-224/00, FBColl-226/00, FBColl-231/00, FBColl-233/00, FBColl-208/00, FBColl-222/00, FBColl-209/00, FBColl-228/00, FBColl-211/00, FBColl-242/00, FBColl-205/00, FBColl-170/00, FBColl-191/00, FBColl-201/99, FBColl-248/00, FBColl-246/00
C_6	17	FBColl-157/00, FBColl-159/00, FBColl-161/00, FBColl-163/00, FBColl-164/00, FBColl-168/00, FBColl-172/00, FBColl-178/00, FBColl-181/00, FBColl-184/00, FBColl-187/00, FBColl-188/00, FBColl-220/00, FBColl-236/00, FBColl-255/00, FBColl-265/00, FBColl-267/00
C_7	1	FBColl-164/99
C_8	1	FBColl-204/00

Table 2b. Grouping of 148 field pea accessions into different clusters

Cluster	No. of accessions in cluster	Designations
C_1	66	FPColl-56/00, FPColl-67/00, FPColl-202/99, FPColl-57/00, FPColl-83/00, FPColl-74/00, FPColl-44/99, FPColl-186/99, FPColl-66/00, FPColl-58/00, FPColl-60/00, FPColl-65/00,FPColl-82/00, FPColl-209/99, FPColl-63/99, FPColl-189/99, FPColl-198/99, FPColl-195/99, FPColl-207/99, FPColl-77/00, FPColl-68/00, FPColl-193/99, FPColl-184/99, FPColl-59/00, FPColl-61/00, FPColl-52/99, FPColl-81/00, FPColl-54/99, FPColl-75/00, FPColl-71/00, FPColl-53/99, FPColl-194/99, FPColl-78/00, FPColl-196/99, FPColl-212/99, FPColl-37/99, FPColl-45/99, FPColl-36/99, FPColl-41/99, PColl-214/99, FPColl-215/99, FPColl-182/99, FPColl-42/99, FPColl-188/99, FPColl-76/00, FPColl-80/00, FPColl-73/00, FPColl-213/99, FPColl-45/00, PColl-72/00, FPColl-38/99, FPColl-51/99, FPColl-50/99, FPColl-79/00, FPColl-55/99, FPColl-197/99, FPColl-203/99, FPColl-210/99, FPColl-190/99, FPColl-206/99, FPColl-208/99, FPColl-57/99, FPColl-69/00, FPColl-185/99, FPColl-53/00
C_2	50	FPColl-30/99, FPColl-31/99, FPColl-32/99, FPColl-33/99, FPColl-34/99, FPColl-35/99, FPColl-39/99, FPColl-40/99, FPColl-43/99, FPColl-47/99, FPColl-48/99, FPColl-49/99, FPColl-127/99, FPColl-130/99, FPColl-187/99, FPColl-191/99, FPColl-192/99, FPColl-200/99, FPColl-201/99, FPColl-204/99, FPColl-205/99, FPColl-211/99, FPColl-216/99, FPColl-217/99, FPColl-30/00, FPColl-31/00, FPColl-32/00, FPColl-33/00, FPColl-34/00, FPColl-35/00, FPColl-36/00, FPColl-37/00, FPColl-38/00, FPColl-39/00, FPColl-40/00, FPColl-41/00, FPColl-42/00, FPColl-43/00, FPColl-44/00, FPColl-46/00, FPColl-47/00, FPColl-48/00, FPColl-50/00, FPColl-51/00, FPColl-52/00, FPColl-54/00, FPColl-55/00, FPColl-62/00, FPColl-64/00, FPColl-70/00, FPColl-84/00
C_3	30	FPColl-103/99, FPColl-106/99, FPColl-101/99, FPColl-104/99, FPColl-102/99, FPColl-100/99, FPColl-128/99, FPColl-119/99, FPColl-125/99, FPColl-107/99, FPColl-112/99, FPColl-99/99, FPColl-98/99, FPColl-122/99, FPColl-115/99, FPColl-105/99, FPColl-132/99, FPColl-129/99, FPColl-131/99, FPColl-120/99, FPColl-126/99, FPColl-116/99, FPColl-117/99, FPColl-111/99, FPColl-121/99, FPColl-108/99, FPColl-49/00, FPColl-114/99, FPColl-110/99, FPColl-123/99
C_4	1	FPColl-183/99
C_5	1	FPColl-199/99

Mahalanobis's D^2 analysis revealed that there was high genetic diversity among the Ethiopian faba bean and field pea accessions from different origins across the eco-geographic regions. Significant inter-cluster distances were recorded between most of the clusters, different members within a cluster being assumed to be more closely related in terms of the traits under consideration than those members in different clusters. The diverse agro-climatic conditions in Ethiopia might have contributed to this genetic diversity in Ethiopian faba bean and field pea accessions as suggested by Harlan (1969). Members in clusters with non-significant distances were assumed to have more close relationships with each other than they do with those in significantly distant clusters (Tables 3 a and b, and Figures 3a and b).

Table 3a. Pair wise generalized squared distances (D^2) among 160 faba bean accessions in eight clusters

Cluster	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0	41^{**}	10	288^{**}	53^{**}	41^{**}	40^{**}	84^{**}
C_2		0	19	281^{**}	13	21^{*}	50^{**}	71^{**}
C_3			0	277^{**}	34^{**}	31^{**}	24^{*}	75^{**}
C_4				0	313^{**}	292^{**}	277^{**}	310^{**}
C_5					0	21^{*}	77^{**}	35^{**}
C_6						0	74^{**}	70^{**}
C_7							0	120^{**}
C_8								0

***Indicates highly significant difference at p<0.01*

Table 3b. Pair wise generalized squared distances (D^2) among 148 field pea accessions in five clusters

Cluster	C_1	C_2	C_3	C_4	C_5
C_1	0	16	77^{**}	46^{**}	1046^{**}
C_2		0	28^{**}	70^{**}	97^{**}
C_3			0	146^{**}	1004^{**}
C_4				0	1148^{**}
C_5					0

***Indicates highly significant difference at p<0.01*

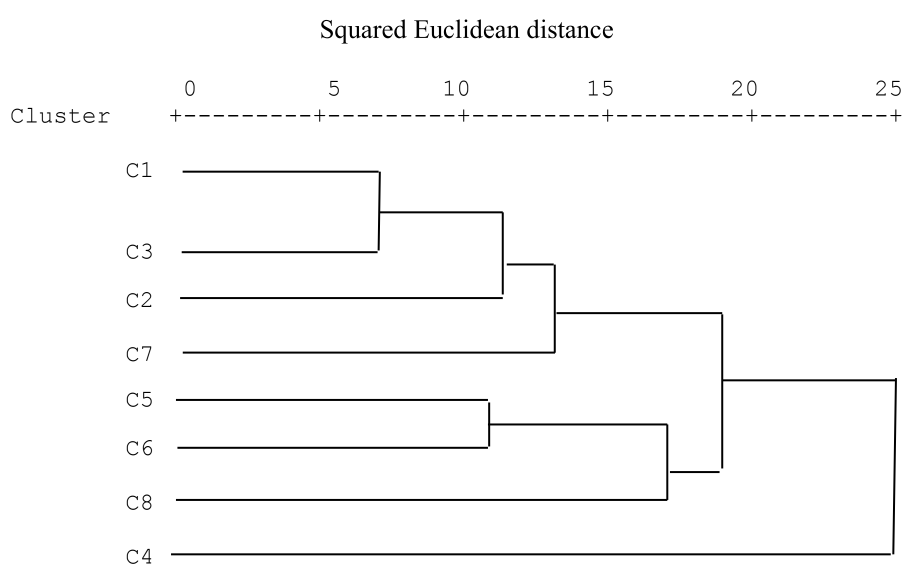


Figure 3a. Phenogram of faba bean accessions in seven clusters based on average linkage hierarchical cluster analysis between groups

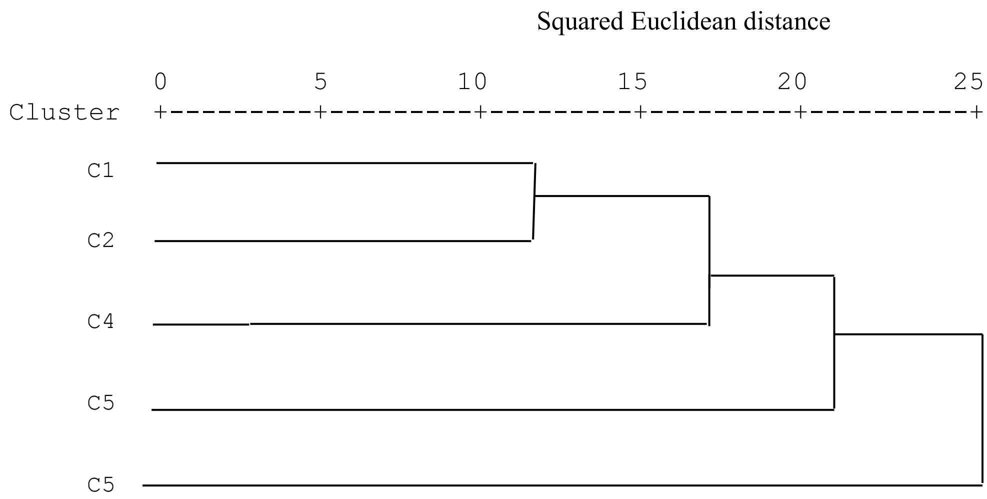


Figure 3b. Phenogram of field pea accessions in five clusters based on average linkage hierarchical cluster analysis between groups

The magnitude of genetic diversity and the relative contribution of the different morpho-agronomic traits to the differentiations of the accessions into clusters have been discussed elsewhere in detail (Gemechu *et al*., 2005 a,b) with only some difference due to pre-standardization of the data in this case.

3.3 Eco-geographic Distribution of Genetic Diversity

The distribution of strains in different clusters did not follow definite pattern with regard to geographical origins. However, accessions from the northern parts of the country (Wello and Gonder) tended to be grouped together for both crops showing their close interrelationships regardless of their geographic origin and the rugged nature of the terrain. This was clearly revealed from the fact that their distribution was limited to only three clusters for faba bean and two clusters for field pea (Tables 4 a and b).

Table 4a. Clustering pattern of 160 faba bean accessions collected from different eco-geographic regions of Ethiopia

Cluster	No. of accessions	Geographical distribution			
		Wello	Gonder	Shewa	Arsi
1	30	25	---	5	---
2	50	---	37	2	11
3	38	3	1	31	3
4	5	1	2	2	---
5	18	---	---	---	18
6	17	---	---	---	17
7	1	---	---	1	---
8	1	---	---	---	1

Table 4b. Clustering pattern of 148 field pea accessions collected from different eco-geographic regions of Ethiopia

Cluster	No. of accessions	Geographical distribution			
		Wello	Gonder	Shewa	Arsi
1	66	15	---	24	27
2	50	11	2	10	27
3	30	---	29	---	1
4	1	---	---	1	---
5	1	---	---	1	---

Populations from areas geographically far-separated with mountains and valleys, and having complex environments and varied ecological conditions are normally expected to accumulate enormous genetic diversity (Chandel and Joshi, 1983; Ford-Lloyd and Jackson, 1986; Singh, 2002) as geographical separation with physical barriers and genetic barriers to inter-crossing are believed to give rise to genetic diversity among genetic materials (Singh, 2002). Previous workers also proved that genetic diversity in accessions of both crops are not uniformly distributed across eco-geographic regions (Singh and Tripathi, 1985; Hailu *et al*., 1991; Dawit *et al*., 1994).

On the other hand, accessions from the southern part of the country (Arsi and Shewa) were distributed over most of the clusters but in an irregular pattern (Tables 4 a and b). This indicates that, unlike in the northern parts of the country, there might be more intra-regional genetic diversity in the southern parts. This finding does not concur with the early estimate that more genetic diversity in these crops might rather be located in the northern half of the country (Hailu *et al*., 1991).

Clustering sites of faba bean and field pea collections at district levels discriminated them into five distinct broad clusters in both cases. Of the five clusters of faba bean collection sites, two (C_2 and C_5) were constituted mostly from districts of Arsi with only a few exceptions. Districts from other parts did not produce a definite pattern of discrimination as different districts from the northern and southern parts of the country were grouped within the same clusters (Figures 4a). Similarly, classification of sites of field pea collections did not produce a definite pattern of discrimination as different districts from the northern and southern parts of the country were grouped within the same clusters (Figures 4b). This may indicate that distribution pattern of genetic diversity in faba bean was more influenced by geographic position than that of field pea.

Even though accessions from the northern parts of the country and those from the southern parts showed different genetic background in most of the cases, a few accessions from the two parts fell into the same clusters. This indicates that accessions from different regions may share similar genetic background. For instance, the third cluster in faba bean and the second in field pea constituted accessions from all regions. Similarly, the second and the first clusters in faba bean and field pea, respectively, comprised accessions from all regions except the absence of those from Gonder. Therefore, accessions may exhibit morpho-agronomic similarities regardless of differences in eco-geographic origins. Several possible reasons could be given for the genetic similarity among a few accessions from different corners of the country. It could be due to informal seed exchange among farmers in different eco-geographic regions of the country or a few materials might have originally been introduced from the same sources. There could also be a tendency (particularly among resource-poor farmers in marginal areas) of selecting for the same traits of interest like yield stability, resistance to diseases, insects and abiotic calamities and low dependence on the external inputs (de Boef *et al*., 1996).

3.4. Microcenters of Genetic Diversity

The higher genetic diversity in collections from Arsi and Shewa in both crops may indicate that the microcenter of genetic diversity for both crops may stretch somewhere from Arsi to Shewa. However, the reason for the higher genetic diversity in accessions collected from the southern part of the country as opposed to the ones from the northern parts of the country is not clear from this study. Differences in geographic origin appeared not to be the main cause of genetic divergence in both crops. This different pattern of diversity is probably attributed to the differences in the nature of both human and natural actions across regions as the genetic architecture of a population is generally believed to be the result of breeding system, gene flow within and between populations, isolation mechanisms and prolonged selection by various natural and artificial forces (Chandel and Joshi, 1983). There could be a tendency of selecting for the same traits of interest among farmers in the northern parts of the country as opposed to selection for different traits in the southern part that might have forced the crops to evolve in different directions. The original introduction to southern part of the country might have higher genetic differences compared to those introduced to the northern parts of the country. The nature of eco-geographic environment is also believed to be the major force in crop evolution (Ford-Lloyd and Jackson, 1986; Spagnoletti and Qualset, 1987). Rainfall distribution is the most variable elements of climate between the northern and the southern parts of Ethiopia (EMA, 1988; Asfaw *et al*., 1994 a,b) and suitable zones of faba bean and field pea production follow the pattern of rainfall distribution (Asfaw *et al*., 1994 a,b). It is believed that plants of a species growing in different environments may show different levels of diversity and that genetic diversity is higher under more suitable environments (Singh, 2002). Whether or not the lower level of genetic diversity in the northern part of the country has something to do with the recurrent drought in these parts of the country is not clear from this study. A systematic study with representative samples drawn from pre- and post-drought collections in this part of the country may enable to come up with conclusive results in this aspect. Similar results showing higher genetic diversity in accessions from Arsi as compared to those from Welo and Gojam were reported in barley (Demissie and Bjϕrnstad, 1997).

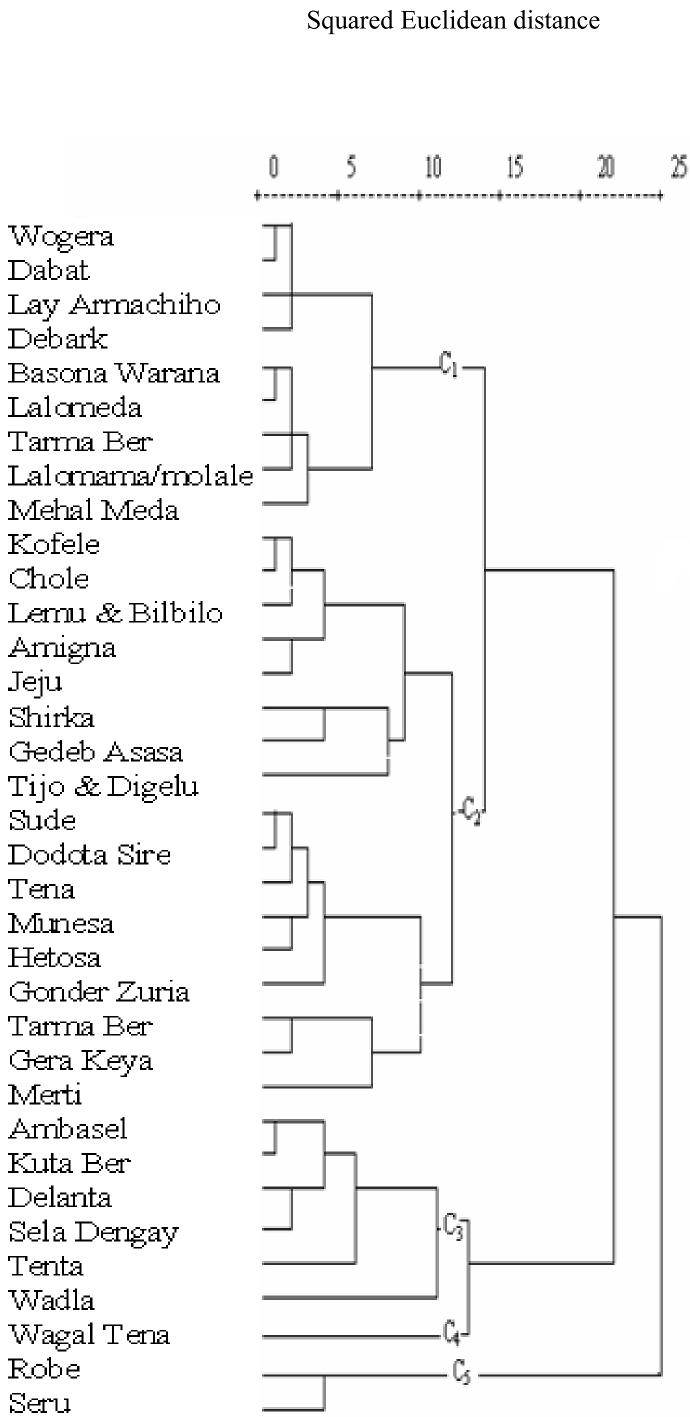


Figure 4a. Dendrogram of collection sites of faba bean accessions based on average linkage hierarchical cluster analysis between groups

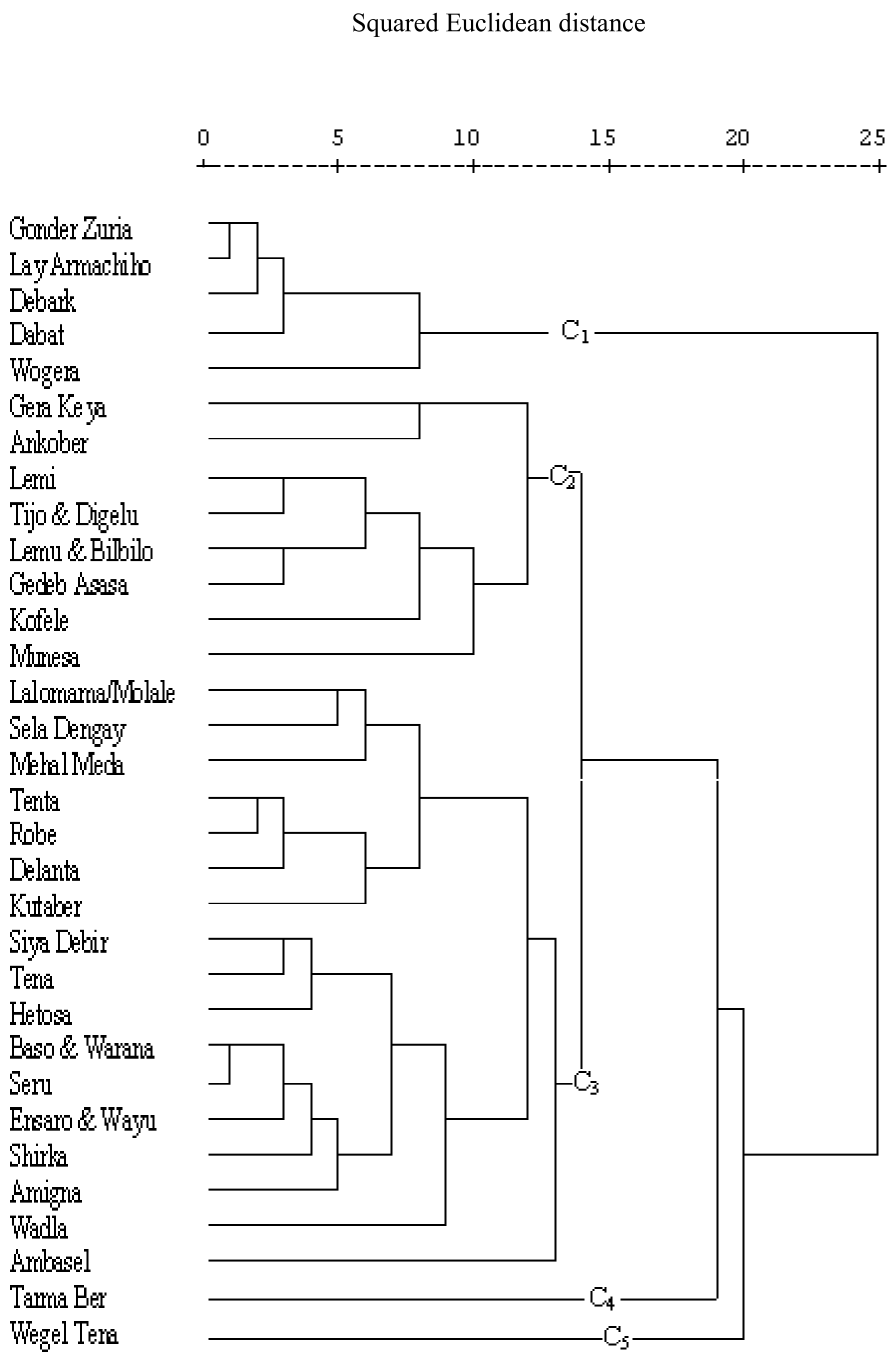


Figure 4b. Dendrogram of collection sites of field pea accessions based on average linkage hierarchical cluster analysis between groups

4. Conclusions

The present findings clearly illustrated the existance of high genetic diversity in the Ethiopian faba bean and field pea accessions even though the diversity is not uniformly distributed across the eco-geographical regions. Germplsasm accessions of both crops from the northern parts of the country were closely related regardless of their geographic origin while those from southern parts were more diverse. This indicates that, unlike in the northern parts of the country, there might be more intra-regional genetic diversity in southern parts where the microcenters of diversity for both crops are probably located. The implication is that accessions from the northern parts of the country can be represented by a few samples whereas larger number of samples is needed to represent accessions from the southern parts of the country in order to catch most of the genetic variability.

The reason for differences in the distribution of genetic diversity in accessions between the northern and the southern parts of the country could not be clearly ascertained from this study. It could probably be related to the level of genetic diversity in the original introductions, and the nature and degree of natural and artificial manipulations after introductions may vary among regions. Future collection missions and conservation strategies should prioritize the southern parts of the country to safeguard the tremendous genetic diversity from genetic erosion, and ensure the sustainable perpetuation of these valuable resources. Breeding programs should also focus on effective and efficient exploitation of intra-regional diversity in this part. However, this does not mean that the whole area of genetic diversity and the peripheral regions should not be considered for the collection and conservation of accessions. Important rare and critical genes may sometimes exist in the peripheral regions (Ford-Lloyd and Jackson, 1986; Singh, 2002) as the crops could be exposed to different environmental stresses that may result in different lines of evolution (Singh, 2002). As a result, covering peripheral regions may enable capture rare genes associated with adaptation to different agro-ecologies. However, it should be noted that this investigation could provide only preliminary information, as a morpho-agronomic study alone may not be sufficient. Therefore, a comprehensive study involving both morpho-agronomic trait and molecular markers is required to draw a more comprehensive conclusion. In addition, a similar further study on representative samples from different districts in Arsi and Shewa may help come up with the accurate location of the microcenter of genetic diversity for both crops.

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6. References

Asfaw, T., Tesfaye, G. and Beyene, D. 1994a. Genetics and breeding of faba bean. *In*: Asfaw, T., Geletu, B., Saxena, M.C., and Solh, M.B. (eds.). Cool-Season Food Legumes of Ethiopia. Proceeding of the First National Cool-Season Food Legumes Review Conference, 16-20 December 1993, Addis Ababa, Ethiopia. ICARDA/IAR. ICARDA, Syria. pp.97-121.

Asfaw, T., Beyene, D. and Tesfaye, G. 1994b. Genetics and breeding of field pea. *In*: Asfaw, T., Geletu, B., Saxena, M.C., and Solh, M.B. (eds.). Cool-Season Food Legumes of Ethiopia. Proceeding of the First national Cool-Season Food Legumes Review Conference, 16-20 December 1993, Addis Ababa, Ethiopia. ICARDA/IAR. ICARDA, Syria. pp. 122-137.

Atta-Krah, K. 2004. Natural resources management and genetic diversity: Two sides of coin for sustainable livelihoods and development. A Paper Presented to the African Highland Initiative Conference – Integrated Natural Resource Management in Practice: Enabling Communities to Improve Mountain Landscapes and Livelihoods. 12-15 October 2004, Nairobi, Kenya (in press).

Bartual, R., Carbonell, E.A. and Green, D.E., 1985. Multivariate analysis of a collection of soybean cultivars for southeastern Spain. *Euphytica* 34:113-123.

Chahal, G.S. and Gosal, S.S.. 2002. *Principles and Procedures of Plant Breeding: Biotechnological and Conventional Approaches*. Narosa Publishing House, New Delhi.

Chandel, K.P.S. and Joshi, B.S. 1983. Multivariate analysis in green-seeded pea. *Indian Journal of Agricultural Sciences* 53 (4): 198-200.

Dale, M.F.B., Ford-Lloyd, B.V. and Arnold, M.H. 1985.Variation in some agronomically important characters in a germplasm collection of beet (*Beta vulgaris* L.). *Euphytica* 34: 449-455.

Davies, D.R. 1976. Peas: *In*: Simmonds, N.W. (ed.). *Evolution of Crop Plants*. Longman, London. pp. 172-174

Dawit, T., Asfaw, T. and Geletu, B. 1994. Accessions in Ethiopia. *In*: Asfaw, T., Geletu, B., Saxena, M.C., and Solh, M.B. (eds.). Cool-Season Food Legumes of Ethiopia. Proceeding of the First National Cool-Season Food Legumes Review Conference, 16-20 December 1993, Addis Ababa, Ethiopia. ICARDA/IAR. ICARDA, Syria. pp. 79-96.

de Boef, W.S., Berg, T. and Haverkort, B. 1996. Crop accessions. *In*: Bunders J., Haverkort, B. and

Hiemstra, W. (eds). Biotechnology: Building on Farmers' Knowledge. Macmillan, London and Basingstoke. pp. 103-128.

Demissie, A. and Bjϕrnstad, A. 1997. Geographical, altitude and agro-ecological differentiation of isozyme and hordein genotypes of landrace barleys from Ethiopia: implications to germplasm conservation. *Genetic Resources and Crop Evolution* 44: 43-55.

EMA. 1988. *National Atlas of Ethiopia*. Ethiopian Mapping Authority (EMA), Addis Abeba.

Engels, J.M.M. and Hawkes, J.G. 1991. The Ethiopian gene center and its genetic diversity. *In*: Engels, J.M.M., Hawkes, J.G. and Melaku, W. (Eds.). Plant Genetic Resources of Ethiopia. Cambridge University Press. pp 23-41.

Ethiopian Agricultural Sample Enumeration. 2002. Report on the preliminary results of area, production and yield of temporary crops (meher season, private peasant holdings). Part I. Central Statistics Authority, Addis Ababa, Ethiopia.

FAO (Food and Agriculture Organization). 1998. The State of World Plant Accessions for Food and Agriculture. Rome, Italy.

Ford-Lloyd, B. and Jackson, M. 1986. *Plant Accessions: An Introduction to Their Conservation and Use*. Edward Arnold, Australia.

Gemechu, K., Mussa, J., Tezera, W. and Getnet, D. 2005a. Extent and pattern of genetic diversity for morpho-agronomic traits in Ethiopian highland pulse landraces. I. Field pea (Pisum sativum L.). *Genetic Resources and Crop Evolution* 52: 539-549.

Gemechu, K., Mussa, J., Tezera, W. and Getnet, D. 2005b. Extent and pattern of genetic diversity for morpho-agronomic traits in Ethiopian highland pulse landraces. II. faba bean (*Vicia faba* L.). *Genetic Resources and Crop Evolution* 52: 551-561.

Hagedorn, D.J. 1984. *Compendium of Pea Diseases*. University of Wisconsin-Madison.

Hailu, M., Abebe, D. and Abebe, T. 1991. Pulse crops of Ethiopia. *In*: Engels, J.M.M., Hawkes J.G. and Melaku, W. (Eds.). Plant Genetic resources of Ethiopia. Cambridge University Press.pp328-343.

Harlan, J.R. 1969. Ethiopia: A Center of Diversity. *Economic Botany* 23: 309-314.

Jaradat, A.A. 1991. Phenotypic divergence for morphological and yield related traits among landrace genotypes of durum wheat from Jordan. *Euphytica* 52:155-164.

Little, T.M. and Hills, F.J. 1978. *Agricultural Experimentation: Design and Analysis*. John Wiley and Sons. New York

Manly, B. F. J. 1986. *Multivariate Statistical Methods: A Primer*. Chapman and Hall. London.

Nigussie, A. 2001. Germplasm diversity and genetics of quality and agronomic traits in Ethiopian mustard (*Brassica carinata* A. Braun). Doctoral dissertation, Georg-August University of Göttingen, Germany.

Rezai, A. and Frey, K.J., 1990. Multivariate analysis of variation among wild oat accessions-seed traits. *Euphytica* 49:111-119.

SAS Institute. 1996. SAS/STAT guide for personal computers, version 6.12 edition. Cary, NC: SAS Institute Inc.

Singh, R.K. and Chaudhary, B.D. 1985. *Biometrical Methods in Quantitative Genetic Analysis.* Kalyani Publishers, New Delhi-Ludhiana.

Singh, S.B. and Tripathi, B.K.. 1985. Genetic divergence in pea. *Indian Journal of Genetics* 45: 389-393.

Singh, B.D. 2002. *Plant Breeding: Principles and Methods.* Kalyani Publishers, New Delhi-Ludhiana.

Spagnoletti, P.L. and Qualset, C.O. 1987. Geographical diversity for quantitative spike characters in a world collection of durum wheat. *Crop Science* 27: 235-241.

Tesema, T. and Eshetayehu, T. 2004. Collection, conservation, characterization and sustainable utilization of grain legumes in Ethiopia. A paper presented to the 2nd National Workshop on Food and Forage Legumes in Ethiopia, 22-26 Sept. 2003, Addis Ababa, Ethiopia (in press).

Van der Maesen, J.J.G, Kaiser, W.J., Marx, G.A. and Worede, M. 1988. Genetic bases for pulse crop improvement: Collection, preservation and genetic variation in relation to need traits. *In*: Summerfield (ed.), Proceedings of the International Food Legume Research Conference on Pea, Lentil, Faba Bean, Chickpea, Spokane, Washington, USA, 6-11 July, 1986. Kluwer, Dordrecht. PP. 55-66.

Vavilov, N.I. 1951. *The Origin, Variation, Immunity and Breeding of Cultivated Plants*. Chronica Botanica, Waltham, Mass, USA.

Westphal, E. 1974. *Pulses in Ethiopia: Their Taxonomy and Significance*. College of Agriculture, Haile Sellessie I University, Ethiopia/ Agriculture University, Wageningen, The Netherlands.

Yohannes, D. 2000. Faba bean (*Vicia faba*) in Ethiopia. Institute of Biodiversity Conservation and Research (IBCR). Addis Ababa, Ethiopia.

Agronomic Performance and Bread Making Quality of Advanced Bread Wheat (*Triticum aestivum*) Lines Grown in Eastern Oromia, Ethiopia

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Abstract*:* Twenty bread wheat lines selected on the basis of their average grain protein content and yield were evaluated for six agronomic and eight baking quality traits associated with bread-making quality. All the lines were grown in randomly complete block design at two locations in Eastern Oromia, Ethiopia; namely, Haramaya and Hirna in 2004/2005. Most of the quality traits had higher genotypic and phenotypic coefficients of variability than yield at both locations. Grain protein content and yield related traits had low variabilities. Three bread wheat lines (RBC/HAR800, HAR3740 and Pavon76) superior with respect to bread making quality parameters and yielding ability of above and around the grand mean were identified. These lines could be useful as donor parents for bread making quality in bread wheat improvement programs of Ethiopia. In addition, three lines (MILAN/SHA7, 609/720 and MAMBA/HAR1384) having strong flour character but of which two lines had inconsistent yielding ability and one line yielding less than the general mean yield of the experiment; and five lines (Bobitcho, ETBW4311, ETBW4315, HAR3787 and Simba) of moderate to strong flour character with yielding ability above and around the grand mean were identified.

Keywords: Agronomic Performance; Bread Making Quality; Bread Wheat; GCV; PCV

1. Introduction

Bread wheat (*Triticum aestivum*) is an introduced crop in Ethiopia although the time is not known, and its demand in Ethiopia has steadily increased in the last decades (Hailu *et al.,* 1991). It is currently cultivated as the 4th largest cereal crop (CSA, 2002) in Ethiopia. Ethiopia is the second largest wheat producers in sub-Saharan Africa, next to South Africa. Bread and durum wheat in combination covers more than 1 million hectares of land in Ethiopia (Amsal *et al.,* 2000). Estimated average yield is around 1.4 tha^{-1} (CSA, 2002), which is about 31% and 48% below the average yield for Africa and the world, respectively (FAO, 2003).

The Ethiopian wheat improvement research, since its inception (1930) has focused on improving grain yield and resistance to disease except few of them were nutritional and/or processing quality oriented (Hailu *et al*., 1991; Amsal *et al*., 2000 and Solomon *et al*., 2000). In 1998 with response to fertilizer variations, from 10 varieties, Dashen, Galama, Megal and Abola were reported of superior in bread making quality characteristics (Solomon *et al*., 2000).

Screening of wheat lines of high yielding with desirable bread making quality features are a widely recognized challenging, since yield is inversely related to various aspects of grain quality, particularly to grain protein content (GPC) in cereals (Preston *et al*., 1992; Wrigley, 2005 a). The high GPC [≥ 12%, dry basis (db)] and gluten contents, gluten strength imparted by gluten natures (gliadins and glutenins) (Preston *et. al.,* 1992; Gianibelli *et al*., 2001), grain hardness and vitreous endosperm (Ciaffi *et al*., 1996; Bushuk, 1998) are used in the selection for bread making quality. The GPC (weakly heritable) and gluten strength (heritable) are positively correlated to Pelshenke fermentation time (Monsivais *et al.,* 1983), with wheat meal sedimentation volume (Payne *et al*., 1981; AACC, 2000) Farinogram water absorption, dough stability time and strength on over mixing, and to bread loaf volume (Lill *et al.,* 1993; Gianibelli *et al*., 2001). The nature of glutenin sub-units: high molecular weight glutenin (HMW-GS) and low molecular weight glutenin (LMW-GS) fractions were factors recognized that influence dough gluten strength and quality (Gianibelli *et al*., 2001; Wrigley, 2005 b). Some fractions in HMW-GS were established as superior in influencing the gluten strength and thereby bread making quality (Payne *et al.,* 1987; Belton, 1999; Gianibelli *et al*., 2001). Starch functionality is also equally important since starch accounts approx. 70% in wheat grain (Davis, 1994). Properties like grain hardness, baking and storage quality of wheat bread are in part influenced by the starch nature (Davis, 1994; Rahman *et al*., 2000). Non-sprout damaged (Hoseney, 1994) and normal (non *-amylo* or *-waxy*) starch granules (Morita *et al.,* 2002) are preferred in bread making.

Information on the bread making quality aspect of advanced breeding lines is limited in the Ethiopian bread wheat improvement program. With the expansion of industries that process bread wheat, end use quality specification is becoming important. Therefore, the present study was conducted to identify advanced bread wheat breeding lines with good agronomic performance,

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high grain protein content and superior dough rheological characteristics that would provide donor parents for future bread wheat improvement programs.

2. Materials and Methods

2.1. Agronomic Performance

Twenty advanced bread wheat lines were selected from five advanced national variety trials of each with twenty lines (i.e., a total of 100 lines) each comprising one local check (Pavon76) and one standard (Simba) variety. The 100 lines were grown as per the regular recommended national and regional wheat trials practices during the main cropping year of 2003/2004 in a randomized complete block design with four replications at Haramaya site adjacent to each other. From the harvested grain (2003/2004) of these 100 lines, samples (30 g) were separately milled (Tomas-Willey Laboratory Mill 4, Thomas Scientific™, U.S.A.) to less than 1 mm at Haramaya University. The grain protein content [14 % moisture basis (mb)] was analyzed in duplicate by NIR spectrophotometer (Inframatic 8620 NIR, Perton, Germany). Lines (Table 1) that have average protein content greater than 10 % and higher yield than the local checks were selected. In addition, high yielding lines with protein content less than 10 % were also added to get enough variability.

Table 1. Pedigree, grain protein % and grain yield performance of the 20 selected bread wheat lines from 2003/04 harvest*

Entry	Line	Pedigree	Grain protein %	Grain yield (kg/h)
1	ETBW4307	ESTANZUELA TARARIRAS	11.6	2316.0
2	ETBW4310	TNMU/6/CEP80111/CEP1165/5/MRNG/4/YKT406/3	10.7	3589.7
3	Bobitcho	BURRLON	10.4	3355.4
4	ETBW4311	TNMU/MILAN	10.2	3636.6
5	ETBW4315	PASTOR/MUNIA/ALTAR 84	10.1	3949.1
6	ETBW4227	RECURRENT SELECTION 1	10.2	3273.0
7	ETBW4246	OCEP17//VEE#5/SARA	10.2	3105.0
8	MAMBA/HAR1384	MAMBA/HAR 1348	12.8	2276.6
9	ET12D4/HAR604	ET12D4/604	11.5	3711.7
10	RBC/HAR800	RBC/HAR800	11.2	2679.4
11	RBC/HAR921	RBC/HAR921	10.8	3847.5
12	MILAN/SHA7	MILAN/SHA7	10.4	4068.4
13	HAR3787	SUZ3/VEE#5	10.6	3756.0
14	HAR3856	NS732/HER//KAUZ	10.0	4117.8
15	HAR3740	HXL7573/*BAU	7.1	4427.6
16	HAR/3872	LFN/II58.57//PRL/3/HAHN	10.6	3143.7
17	609/720	HAR 604/HAR 720	10.1	2646.5
18	604/719	HAR604/HAR719	9.6	4402.6
19	Pavon76 (local check)	VCM//CNO"S"/7C/3/CAL/BB	9.1	3646.3
20	Simba (standard check)	PRINIA	9.7	4480.3

** Selected from 100 lines grown at Haramaya which originally were from 5 advanced national yield trails of each trail with 20 lines*

The twenty selected test lines were sown in the semi-arid tropical belt of eastern Oromia, Ethiopia during the main growing season of 2004/2005 under rain fed conditions at two locations, namely, Haramaya University [42°3` East 9°26` North; 1980 m.a.s.l; 780 mm annual average rain fall; 8.25 °C minimum and 23.4 °C maximum day temperatures] and Hirna [41°4' East 9°12' North; 1870 m.a.s.l; 990−1010 mm annual average rain fall; 24 °C average for day maximum temperatures] (FAO, 1990 and AUA, 1996).

A randomized complete block design with three replications was followed at each location. Each experimental plot (2 m x 3 m) consisted of 10 rows with 0.2 m spacing. Urea and DAP fertilizers were applied at the rate of 100 kgha^{-1} each and urea was applied in split (two times). Data on number of days from planting to 50 % flowering (DTH in days) and 75 % maturity (DTM in days) were recorded on plot basis. Data on other yield related traits were recorded at physiological maturity. Plant height (PH in cm) was recorded as average height of ten plants, tagged in each experimental plot before commencement of tillering, measured from ground level to the tip of spike, excluding awns. Thousand-kernel weight (TKW in g) was determined by measuring mass of 1000 grains sampled at random. Grain yield (GY) in gplot^{-1} at 12.5 % moisture content was recorded and converted to kgha^{-1}. Hectoliter weight (HLW) was determined by measuring mass of grains contained in specified volume (AACC, 2000 Method 55−10).

2.2. Bread Making Quality

Bread wheat grain samples (500 g) were taken at random from each experimental plot of test lines and milled (Perton laboratory mill 3100, Finland) for laboratory analysis at Dire Dawa Food Complex Share Company laboratory, Dire Dawa, Ethiopia. Moisture was determined by air draft drying oven by taking about 2 g flour samples (AACC, 2000 Method 44−15 A). Grain protein content (GPC, 14 %, mb) was estimated by NIR (Inframatic 8620, Germany), (AACC, 2000 Method 39−11). Wet gluten was obtained by hand washing using dilute salt (2 % NaCl) solution (AACC, 2000 Method 38−10). Dried gluten (DG) was determined after drying wet gluten for 24 hrs at 100 ^{O}C. Pelshenke value (PV in min.)-wheat meal fermentation time test was assessed (Monsivais *et al*. 1983 and AACC, 2000 Method 56−50).

Dough strength was measured by Farinograph (Brabander Farinograph ® E OHG, 2002, Germany) according to AACC (2000) Method 54−21 of constant dough weight method at 30±0.2 ^{O}C using a 300 g mixing bowel, operated at 63 revmin^{-1} at the Department of Food Science and Post-harvest Technology, Haramaya University. Farinograph values: water absorption (WAB in %), dough development time (DT in min), stability time (ST in min), mixing tolerance index (TI in FU) and time to breakdown (BDT in min) were evaluated by AACC method using the Farinogram software (Brabander ® Farinograph version: 2.3.6, 1996−2005, Microsoft Corporation).

Data on agronomic and bread making quality traits of the three replications were analyzed using SPAR computer software for analysis of variance, mean, standard error and path analysis. Mean of the three replications were then compared ($p< 0.05$) and Duncan's multiple range test (DMRT) of MSTAT C was used to evaluate the least significant difference (LSD).

3. Results

Yield recorded at both locations showed higher genotypic coefficient of variability (GCV) and phenotypic coefficient of variability (PCV) than yield related traits: DTH, DTM, PH, TKW and HLW (Table 2). Among the yield related traits highest GCV was recorded for TKW (Haramaya) and PH (Hirna). At both locations lowest GCV was recorded for HLW. In PCV analysis, among yield related traits TKW and HLW showed highest and lowest values, respectively, at both locations. The GPC had lowest GCV and PCV than yield and yield related traits at both locations with exceptions of DTM and HLW.

Quality characters like Pelshenke value and Farinograph parameters had high GCV and PCV than yield at both locations except WAB (Table 2). At Haramaya, stability time (ST) had highest GCV and PCV followed by Pelshenke value, BDT, TI, DT and DG. These variations were, however, low for GPC and WAB. At Hirna, ST, Pelshenke value, TI, BDT had high GCV and PCV. At this location, grain yield recorded higher GCV and PCV than DG.

The mean grain yield performance recorded at Haramaya was 4194.4kgha^{-1} (Table 3).The highest grain yield was recorded among lines ET12D4/HAR604, ETBW4315 and ETBW4311 ($p > 0.05$). The yield recorded among lines ETBW 4227, MILAN/SHA7, HAR/3872 and MAMBA/HAR1384 were the lowest. The mean GPC was 13.4 %. The highest GPC was for lines ETBW4310 (15.3 %), HAR/3872 (15.1 %) and Simba (14.7 %) ($p > 0.05$). The GPC in HAR3787 (11.8 %), ETBW4315 (12.1 %) and 609/720 (12.3 %) were low. The mean DG performance was 11.1 %. The highest DG was for lines HAR/3872 (14.9 %) followed by RBC/HAR921 (13.4 %), ETBW4310 (12.6 %) and Simba (12.4 %); and the lowest was for ETBW 4227 (5.9 %) followed by ETBW 4315 (8.7 %) and HAR3787 (9.3 %) ($p > 0.05$). The mean Pelshenke value (PV in min.) was 73.0. The highest was recorded for lines MAMBA/HAR1384 (144.9) and ETBW4310 (144.1) ($p > 0.05$). The PV in lines ET12D4/HAR604 (27.0), ETBW 4227 (27.1), RBC/HAR921 (29.8), 604/719 (32.2) and Bobitcho (33.4) were lowest. The Farinogram WAB mean was 64.8 % and the highest was for ETBW4307 (68.1 %), RBC/HAR921 (68.1 %) and HAR3856 (67.4 %) ($p > 0.05$). The lowest was for MILAN/SHA7 (59.2 %) followed by 609/720 (61.8 %), Bobitcho (62.0 %) and HAR3740 (62.2 %). The mean performance for DT (in min.), ST (in min.), TI (in FU) and BDT (in min.) were 3.8, 3.3, 92.9 and 5.7, respectively.

At Hirna, the mean grain yield was 4421.0 kgha^{-1} (Table 4).

The yield recorded by ETBW4307 and 609/720 was the lowest. The mean GPC was 14.1 %. The highest GPC was recorded for HAR/3872 (15.4 %), ETBW4310 (15.0 %) and RBC/HAR921 (14.9 %) and the lowest was for 609/720 (11.9 %) followed by HAR3787 (13.3 %) and ETBW4315 (13.5 %). The mean DG performance was 12.2 %. The highest DG was for HAR/3872 (14.6 %), RBC/HAR921 (14.4 %), 604/719 (13.9 %), Bobitcho (13.7 %) and HAR3856 (13.7 %) ($p > 0.05$). The DG level in lines 609/720 (9.7 %), ETBW 4227 (10.5 %) and ETBW 4315 (10.5 %) were low ($p > 0.05$).

The mean PV at Hirna was 70.1 min. The highest was recorded in Simba (144.0), ETBW4310 (139.7)and RBC/HAR800 (136.7) and the lowest was in lines ETBW4227 (26.8) and RBC/HAR921 (27.0) ($p > 0.05$). The mean performance of WAB was 65.3 %. The highest was for HAR3856 (69.4 %), followed by RBC/HAR921 (68.1 %), ETBW4227 (67.4 %) and ETBW4246 (67.4 %). The lowest was for MILAN/SHA7 (60.3 %) followed by ET12D4/HAR604 (61.5 %), 609/720 (62.2 %) and HAR3740 (63.0 %). The mean performance for DT (in min.), ST (in min.), TI (in FU) and BDT (in min.) were 3.7, 3.6, 89.1 and 5.9, respectively. The DT for lines MAMBA/HAR1384 and RBC/HAR800 were different ($p< 0.05$) from the rest of the lines at the respective locations (Tables 3 and 4). These two lines appeared also strong flour lines (Figure 1).

The DT for lines ETBW4227, HAR/3872, RBC/HAR921 and ET12D4/HAR604 were shortest ($p > 0.05$) at the respective sites. The ST for RBC/HAR800, MAMBA/HAR1384 and MILAN/SHA7 appeared superior ($p > 0.05$) at the respective sites.

Table 2. Range, mean, genotypic and phenotypic coefficient variabilities of 14 traits of 20 wheat lines grown at Haramaya and Hirna

		Haramaya				Hirna			
No.	Trait	Range	Mean±S.E.	GCV	PCV	Range	Mean±S.E.	GCV	PCV
1	Days to heading (DTH) (day)	55.0–71.0	63.2±2.0	6.8	7.8	56.0–78.7	67.6±1.2	10.1	10.4
2	Days to maturity (DTM) (day)	104.3–124.0	114.1±2.7	4.2	5.1	106.0–125.7	115.2±2.8	4.6	5.5
3	Plant height (PH) (cm)	88.1–119.8	102.5±5.7	6.9	9.7	83.9–120.0	101.5±4.1	10.2	11.3
4	1000 kernel weight (TKW) (g)	33.2–44.0	37.7±1.9	8.4	10.4	31.5–44.8	37.6±2.8	6.9	11.4
5	Hectoliter weight (HLW) (g/L)	748.1–828.5	799.1±14.0	1.8	2.8	757.9–832.1	807.6±16.1	1.8	3.1
6	Grain yield (GY) (kg/h)	3426–5581	4194.4±349.0	12.4	16.0	3134–5643	4421.0±600.3	13.2	21.2
7	Grain protein content (GPC) (%)	11.8–15.3	13.4±0.7	6.3	9.0	11.9 –15.4	14.1±0.5	4.7	6.6
8	Dried gluten (DG) (%)	5.9–14.9	11.1±1.3	14.6	20.1	9.7–14.6	12.2±1.0	10.0	13.9
9	Pelshenke value (PV) (min)	27.0–144.9	73.0±3.8	57.5	57.9	26.8–144.0	70.1±11.1	60.5	63.5
10	Farinograph water absorption (WAB) (%)	59.2–68.1	64.8±1.1	3.3	3.8	60.3–7.4	65.3±0.8	3.3	3.6
11	Development time (DT) (min)	1.8–7.8	3.8±0.4	38.3	39.9	1.5– 6.5	3.7±0.4	35.6	37.5
12	Stability time (ST) (min)	1.0–9.6	3.3±0.7	67.6	72.8	0.8–9.1	3.6±0.7	60.6	64.6
13	Tolerance index (TI) (FU)	29.0–198.3	92.9±15.2	49.6	53.5	23.0–217.0	89.1±16.8	56.7	61.2
14	Breakdown time (BDT) (min)	2.3–12.3	5.6±1.2	49.1	55.9	1.9–12.6	5.9±1.0	52.1	56.4

GCV=genotypic coefficient of variation, PCV=phenotypic coefficient of variation, S.E.=standard error

Table 3. The mean values of six agronomic and eight bread making quality characters for 20 bread wheat lines grown at Haramaya

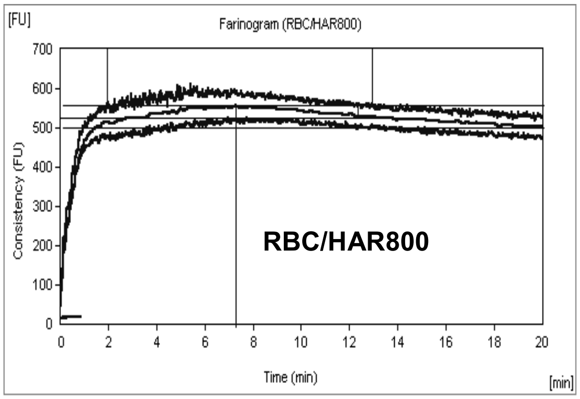
	Agronomic traits						Bread making quality traits							
Genotype/Line	DTH(day)	DTM(day)	PH(cm)	TKW(g)	HLW (g/L)	GY(kg/h)	GPC (%)	DG (%)	PV(min)	WAB (%)	DT (min)	ST (min)	TI (FU)	BDT (min)
ETBW4307	62.3	115.3	119.8	44.0	798.6	4068	13.8	11.6	43.7	68.1	2.9	2.3	120.7	3.8
ETBW4310	69.0	120.0	94.0	36.1	823.4	3947	15.3	12.6	144.1	66.3	4.0	3.0	97.3	5.0
Bobitcho	64.3	118.7	106.8	34.7	796.5	4066	13.4	11.9	33.4	62.0	2.9	2.6	90.0	4.1
ETBW4311	60.3	111.0	100.5	40.3	828.5	4853	14.0	11.6	96.4	65.0	4.1	3.3	80.3	5.3
ETBW4315	60.3	109.3	95.1	36.2	801.9	4886	12.1	8.7	91.2	63.2	4.6	2.8	76.0	6.2
ETBW4227	65.0	114.3	103.5	33.8	748.1	3426	13.6	5.9	27.1	65.1	1.8	1.0	198.3	2.3
ETBW4246	61.0	113.0	102.7	42.8	810.2	4075	13.9	11.3	113.7	66.2	3.4	1.9	111.0	4.4
MAMBA/HAR1384	68.7	117.3	98.4	33.2	796.0	3634	13.2	10.3	144.9	65.4	7.8	9.6	35.0	12.3
ET12D4/HAR604	63.0	108.3	107.9	37.5	780.3	5581	12.7	11.3	27.0	63.8	2.1	1.6	110.3	3.1
RBC/HAR800	68.7	116.7	103.8	33.6	791.0	3923	14.4	11.6	135.3	65.8	6.0	9.3	33.3	10.5
RBC/HAR921	61.7	114.0	106.7	35.0	799.2	3663	13.9	13.4	29.8	68.1	2.1	1.3	180.0	2.5
MILAN/SHA7	67.0	122.7	98.5	34.1	808.4	3491	12.4	10.2	79.0	59.2	4.8	5.0	29.0	11.5
HAR3787	60.0	115.0	101.9	41.7	788.3	4764	11.8	9.3d	49.8	64.8	3.8	2.5	73.3	5.3
HAR3856	62.0	111.3	110.0	39.5	808.2	4483	12.7	11.2	47.7	67.4	3.3	2.4	121.0	4.2
HAR3740	69.0	117.3	96.4	40.2	777.0	4252	12.8	10.8	48.6	62.2	4.8	3.6	51.5	6.9
HAR/3872	71.0	124.0	108.2	36.5	800.5	3593	15.1	14.9	50.4	66.0	2.0	1.6	163.0	2.6
609/720	61.7	112.0	94.8	39.2	795.3	4671	12.3	11.0	46.2	61.8	4.4	3.8	46.7	7.4
604/719	55.0	109.7	118.6	42.8	812.8	3911	13.4	11.8	32.2	65.1	2.7	2.7	86.0	3.8
Pavon76	58.0	107.0	94.1	35.0	816.8	4791	12.7	9.9	87.0	64.1	4.7	3.8	61.5	6.6
Simba	56.3	104.3	88.1	37.1	800.4	3813	14.7	12.4	133.2	65.8	3.6	2.7	93.3	4.8
Mean	63.2	114.2	102.5	37.7	799.1	4194.4	13.4	11.1	73.0	64.8	3.8	3.3	92.9	5.7
SE±	2.0	2.7	5.7	1.9	14.0	349.0	0.7	1.3	3.8	1.1	0.4	0.7	15.2	1.2
CV%	3.8	2.9	6.8	6.2	2.1	10.2	6.5	13.9	6.3	2.0	11.4	27.1	20.1	26.7
LSD(0.05)	4.0	5.4	3.4	3.9	28.2	706.5	1.4	2.5	7.6	2.1	0.7	1.5	30.8	2.5

Where: DTH=days to heading, DTM=days to maturity, PH=plant height, TKW=thousand kernel weight, HLW=hectoliter weight, GY=grain yield, GPC=grain protein content, DG=dried gluten percentage, PV=Pelshenke value, WAB= frarinogram water absorption, DT=dough development time, ST=stability time, TI=tolerance index, BDT=dough breakdown time, SE=standard error, CV%=coefficient of variation and LSD=least significant difference

Table 4. The mean values of six agronomic and eight bread making quality characters for 20 bread wheat lines grown at Hirna

	Agronomic traits						Bread making quality traits							
Genotype/Line	DTH (day)	DTM (day)	PH (cm)	TKW(g)	HLW (g/L)	GY (kg/h)	GPC (%)	DG (%)	PV (min)	WAB (%)	DT (min)	ST (min)	TI (FU)	BDT (min)
ETBW4307	68.7	115.7	120.0	41.0	811.4	3134	14.5	11.9	53.5	66.3	3.6	3.1	74.3	5.0
ETBW4310	75.7	125.7	97.1	35.4	832.1	4506	15.0	12.1	139.7	65.8	3.5	2.6	104.7	4.4
Bobitcho	67.3	116.3	104.7	35.2	795.7	4644	14.2	13.7	31.1	63.5	3.2	2.9	77.7	4.7
ETBW4311	65.3	116.0	94.4	37.3	822.0	4218	13.8	10.7	96.7	65.2	4.4	3.3	81.0	5.5
ETBW4315	65.0	109.3	88.2	36.8	824.1	3954	13.5	10.5	100.9	65.7	4.7	4.5	68.3	6.6
ETBW4227	67.0	115.0	104.6	34.1	778.6	3808	14.5	10.5	26.8	67.4	1.5l	0.8	217.0	1.9
ETBW4246	66.7	113.0	97.4	44.8	821.9	3626	13.7	12.0	117.4	67.4	4.0	2.7	103.0	5.1
MAMBA/HAR1384	76.7	120.3	98.1	32.2	798.1	3559	14.4	11.2	112.4	65.2	6.1	8.4	30.3	11.2
ET12D4/HAR604	67.3	112.3	106.4	37.1	792.0	5433	13.7	13.0	29.1	61.5	2.2	2.1	97.0	3.4
RBC/HAR800	76.7	122.0	100.6	31.5	797.0	4328	14.5	11.8	136.7	64.9	6.5	9.1	29.0	11.8
RBC/HAR921	62.0	110.0	115.8	38.2	810.8	4776	14.9	14.4	27.0	68.1	1.9	1.2	185.0	2.3
MILAN/SHA7	73.3	121.3	111.1	39.3	828.1	5344	13.6	12.0	35.5	60.3	4.7	7.4	23.0	12.6
HAR3787	64.0	112.7	96.3	38.8	796.6	4795	13.3	10.9	42.0	65.9	3.6	3.4	76.7	5.1
HAR3856	61.3	108.0	106.8	41.3	819.2	5302	14.6	13.7	50.6	69.4	3.0	2.3	125.3	3.7
HAR3740	76.0	120.3	95.1	39.1	798.9	4805	13.7	13.0	47.4	63.0	4.5	3.6	50.3	6.8
HAR/3872	78.7	124.0	113.8	38.6	815.1	4244	15.4	14.6	31.6	66.3	1.9l	1.4	169.3	2.5
609/720	70.3	115.7	93.0	34.9	757.9	3371	11.9	9.7	41.1	62.2	5.2	4.4	36.3	10.2
604/719	56.0	112.7	119.0	41.7	829.2	4002	14.4	13.9	34.1	65.7	2.6	2.8	88.3	4.0
Pavon76	57.7	108.0	84.0	36.8	805.3	4929	14.0	12.3	103.7	65.4	3.9	3.5	66.0	5.6
Simba	57.0	106.0	83.9	38.4	818.4	5643	14.3	12.4	144.0	65.9	3.8	2.8	79.3	5.4
Mean	67.6	115.2	101.5	37.6	807.6	4421.0	14.1	12.2	70.1	65.3	3.7	3.6	89.1	5.9
SE±	1.2	2.8	4.1	2.8	16.1	600.3	0.5	0.9	11.1	0.8	0.4	0.7	16.8	1.0
CV%	2.1	3.0	4.9	9.0	2.4	16.6	4.7	9.7	19.4	1.5	11.8	22.4	23.1	21.5
LSD(0.05)	2.4	5.6	8.3	5.6	32.5	1215	1.1	2.0	22.4	1.6	0.7	1.3	34.0	2.1

Where: DTH, DTM, PH, TKW, HLW, GY, GPC, DG, PV, WAB, DT, ST, TI, BDT, SE, CV and LSD are as given in Table 3.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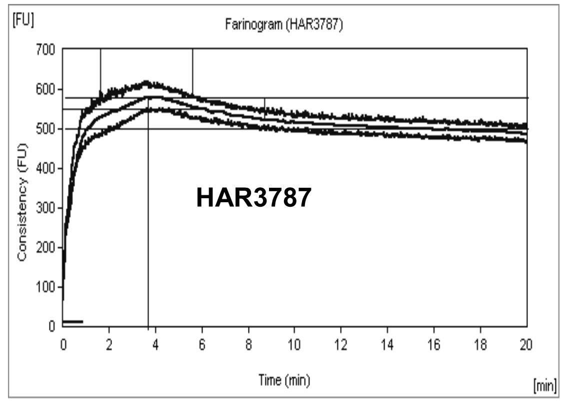
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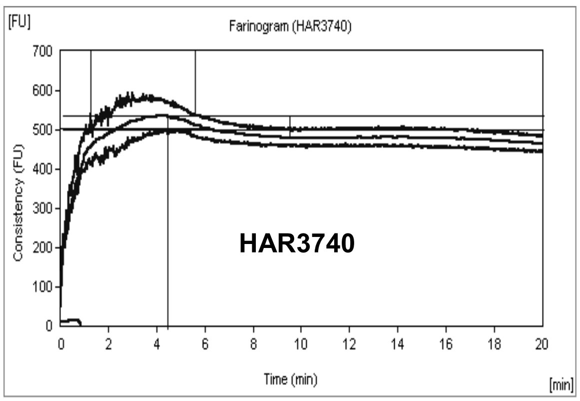
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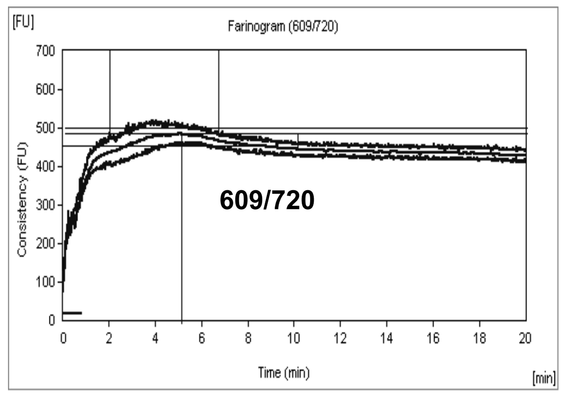
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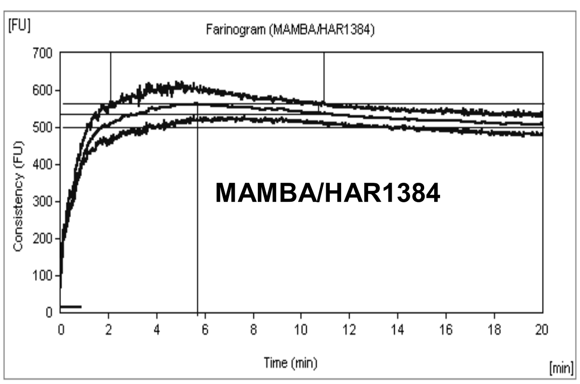
609/720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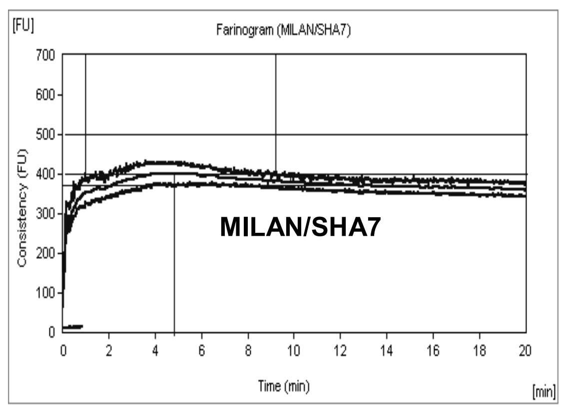
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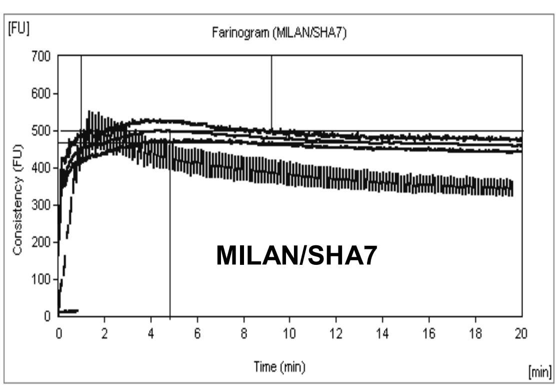
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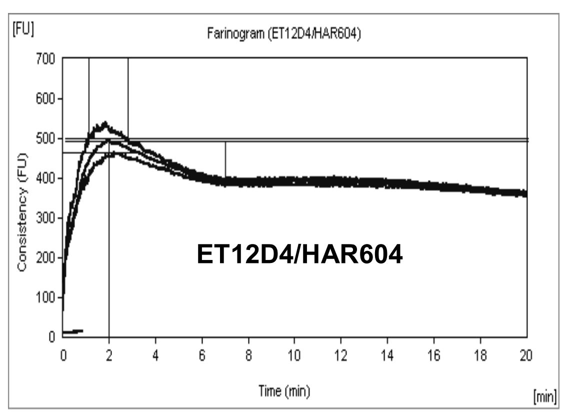
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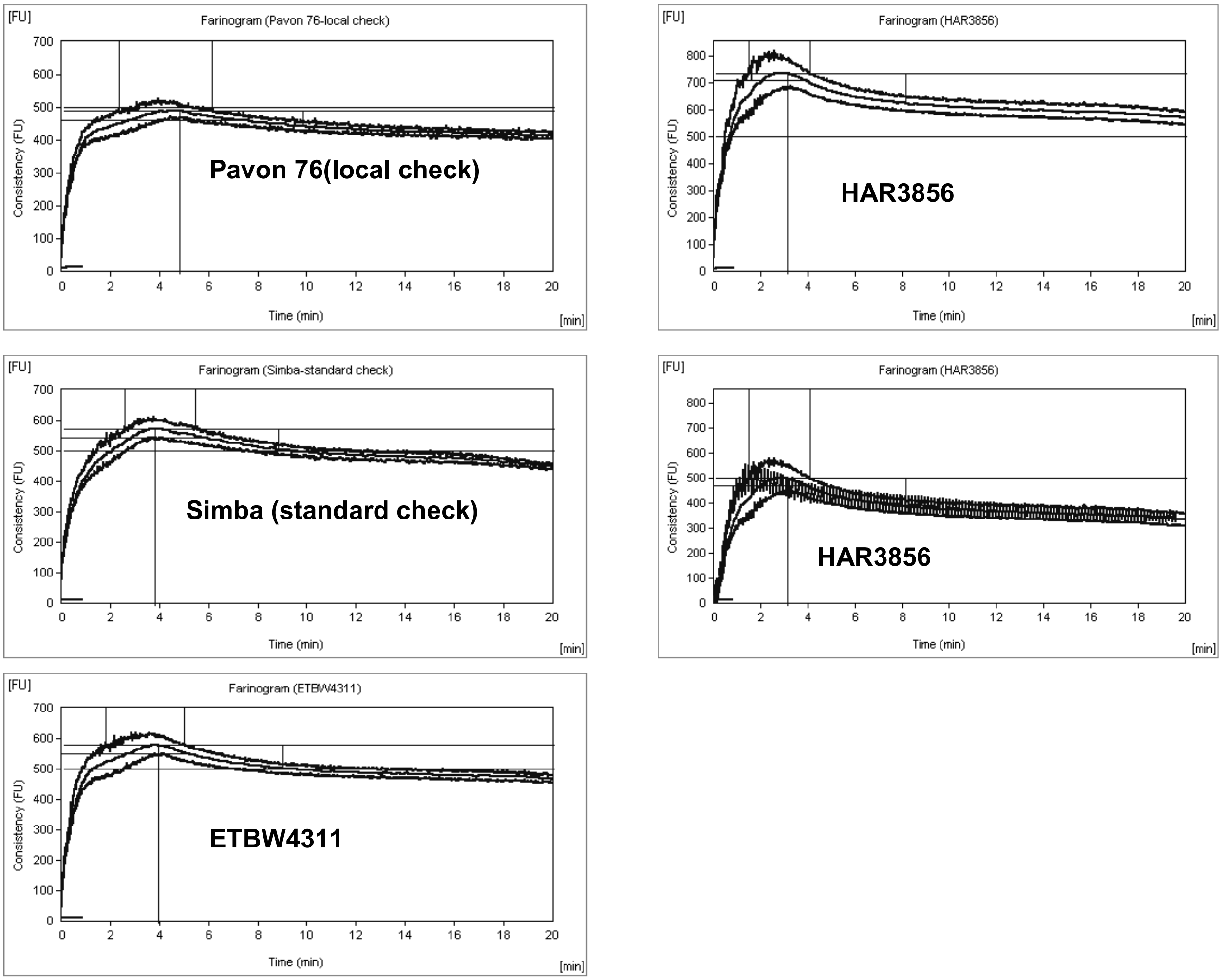

Fig. 1. Selected Farinograms for strong (RBC/HAR800, HAR3740, MAMBA/HAR1384, HAR3787, 609/720 and MILAN/SHA7), moderate (Pavon76, Simba and ETBW 4311) and weak (ET12D4/HAR604 and HAR3856) flour lines

The shortest ST was performed by ETBW4227, RBC/HAR921, ET12D4/HAR604 and HAR/3872, at the respective locations. The small TI (i.e., the smallest TI, the strong the flour is likely to be) was recorded for MILAN/SHA7, RBC/HAR800 and MAMBA/HAR1384 followed by 609/720 and HAR3740 at the respective locations ($p > 0.05$). Their BDT are also high at the respective locations; and these lines showed a characteristic of strong flour (Figure 1). The TI in lines ETBW4227, RBC/HAR921, HAR/3872, ET12D4/HAR604 and ETBW4246 were highest and apparently these lines showed a characteristic of weak flour (Tables 3 and 4).

4. Discussion

The estimates of GCV and PCV at both locations showed that most quality characters, except GPC, WAB and HLW, had high variability as compared to yield and yield related characters (Tables 2, 3 and 4). The small variability observed in GPC is because under uniform fertilizer applications and almost similar growing and drying conditions, the apparent variability in GPC (weakly heritable) is minimal and GPC is positively correlated with WAB and HLW (Bushuk, 1998; Ermias, 2005). Yield being influenced by a number of factors has been negatively correlated with various grain quality aspects, particularly with GPC (Preston *et al*., 1992; Peterson *at al.,* 1992). In 2003/2004, the high yielding lines (Simba, HAR3740, 604/719, HAR3856, MILAN/SHA7) had small GPC and vice versa (MAMBA/HAR1384 and ETBW4307) (Table 1). The correlation studied among the characters also revealed similar facts - at Haramaya site, yield of the lines showed significant ($p < 0.01$) negative correlation with GPC, and also weakly at Hirna (results not presented) (Ermias, 2005). The high yielding lines (ET12D4/HAR604 and HAR3787) were small in GPC and vice versa (RBC/HAR800 and HAR/3872) at the respective locations (Tables 3 and 4). The grain yield in line MAMBA/HAR1384 appeared low (Tables 1, 3 and 4). The highest grain yield for Simba in 2003/2004 reduced at

Haramaya site in 2004/2005. The GPC in HAR3740 in 2003/2004 was the least (Table 1) and in 2004/2005 had substantially increased, eventhough remained below grand mean (Tables 3 and 4). Lines ETBW4311, MAMBA/HAR1384, RBC/HAR800, MILAN/SHA7, HAR3787, HAR3740, 609/720, Pavon76 and Simba showed a characteristic of strong flour (high gluten strength or small TI) at the respective locations (Tables 3 and 4). This indicates, the recognized strong genetic expression for the gluten strength (Peterson *at al*., 1992; Gianibelli *et al*., 2001; Wrigley, 2005 b). Thus, in the present material, in spite of low variability for yield related characters, there was a scope to identify plausible donors for rheological quality traits as strong, normal or moderate and weak wheat flour lines.

Protein and gluten contents, Farinogram flour dough characters and high Pelshenke times are used to assess quality of bread wheat in the selection (MacRitchie, 1984; Dobraszczyk, 2004). An increase in %protein in the grain was positively correlated with bread loaf volume (Finney and Barmore, 1990; He and Hoseney, 1992; Dobraszczyk, 2004). A Farinogram of good bread making flour takes longer times to reach its maximum and shows minimum degree of softening on over mixing, whereas weak flour produces a Farinogram that rises rapidly and decreases rapidly on over mixing. Farinogram high water absorption, long dough development time, long stability time and small degree of weakening on over-mixing (i.e., small TI) are known to be positively correlated with large bread loaf volume (Lill *et al*., 1993; Dobraszczyk, 2004). In this study, lines RBC/HAR800, HAR3740 and Pavon76 were superior in bread making features i.e., strong flour characteristic (Figure 1) at both locations and their yield also appeared around grand mean (Tables 3 and 4). Lines MILAN/SHA7, 609/720 and MAMBA/HAR1384 showed a character of strong flour, but the yielding ability of MILAN/SHA7 and 609/720 appeared inconsistent (over two environments in 2004/2005) and that of MAMBA/HAR1384 appeared less than grand mean at both locations. Bobitcho, ETBW4311, ETBW4315, HAR3787 and Simba appeared to possess characteristics of moderate strong flour, and their yielding performance at both locations was inconsistent except that of HAR3787, which appeared superior.

The ET12D4/HAR604 and HAR3856 lines performed superior in yielding ability at both locations, but showed characteristics of weak flours. The yield in lines RBC/HAR921, ETBW4310 and HAR/3872 appeared inconsistent at both locations and showed characteristics of weak flour. The yield of lines ETBW4246 and ETBW4227 (weak flour); and ETBW4307 and 604/719 (moderately weak flour) appeared less than the grand mean at both locations. Even though in lines ETBW4227, HAR/3872, RBC/HAR921, ETBW4246 and ET12D4/HAR604, protein contents are above 11 %, flour strength appeared weak because dough strength is influenced not only by high protein content but also is by the gluten nature (Preston *et al.,* 1992; Anjum and Walker, 2000 and Dobraszczyk, 2004).

In conclusion, this study had furnished the following information: lines RBC/HAR800, HAR3740, MAMBA/HAR1384, 609/720, MILAN/SHA7 and Pavon76, which were superior in bread making quality parameters with yield around grand mean could be considered for release, where the objective is superior bread-making quality (Tables 3 and 4, Figure 1). However, lines MILAN/SHA7, and 609/720 (inconsistent yielding) and MAMBA/HAR1384 (low grain yielding at both sites) need further investigation at different agro-ecological areas to assess their potential for yield and bread making quality. These six lines could also serve as good donor source in bread wheat improvement breeding programs in Ethiopia. HAR3787, Bobitcho, ETBW4311, ETBW4315 and Simba showed moderate to strong flour characteristics and their yield in some cases was superior (HAR3787) and in some appeared inconsistent but is around the grand mean. These can also serve as donor parents in the future bread wheat improvement program. Lines ET12D4/HAR604, HAR3856, RBC/HAR921 and HAR/3872 appeared a characteristics of weak flour and their yield in some cases is superior (ETBW 4310, ET12D4/HAR604 and HAR3856) and in some appeared inconsistent (ETBW 4310, RBC/HAR921 and HAR/3872), hence these lines can be used as a future donor for bread wheat breeding programs intended for soft wheat products (cookies and cakes).

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6. References

AACC (American Association of Cereal Chemists). 2000. Approved Methods of the American Association of Cereal Chemists, 10th ed. American Association of Cereal Chemists. St. Paul, MN.

Amsal, T. Labuschagne, M. T. and Maartens, H. 2000. Identification of Ethiopian wheat cultivars by seed storage protein electrophoresis.The Eleventh Regional Wheat Workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia: CIMMYT. pp. 49–59.

Anjum, F. M. and Walker, C. E. 2000. Grain, flour and bread-making properties of eight Pakistani hard white spring wheat cultivars grown at three different locations for 2 years. *International Journal of Food Science and Technology* 35: 407–416.

AUA (Alemaya University of Agriculture). 1996. Proceedings of the 13th Annual Research and

Extension Review Meeting. Alemaya University of Agriculture, 26–28 February 1996, Alemaya, Ethiopia.

Belton, P. S. 1999. Mini review: on the elasticity of wheat gluten. *Journal of Cereal Science* 29: 103–107

Brabender® OHG. 2002. Brabender Measurement and Control Systems: Instruction Manual for Brabender®E with USB port. Brabender OHG, Duisburg, Germany.

Bushuk, W. 1998. Wheat breeding for end-product use. *Euphytica* 100: 137–145

Ciaffi, M. Tozzi, L. and Lafiandra, D. 1996. Relationship between flour protein composition determined by size-exclusion high pressure liquid chromatography and dough rheological parameters. *Cereal Chemistry* 73: 346-351

CSA (Central Statistical Authority). 2002. Crop Production For-cast Sample Survey. Report on For-cast of Area and Production of Major Crops (for Rural Private Peasant Holdings). *Statistical Bulletin* 271: 18–19.

Davis, E. A. 1994. Wheat starch. *Cereal Foods World* 39: 34–36

Dobraszczyk, B. J. 2004. Wheat: dough rheology. In: C. Wrigley, H. Corker and C. E. Walker (eds.). Encyclopedia of Grain Science. Vol. 3, Elsevier Ltd., Oxford, UK. pp. 400–416

Ermias, E. 2005. Assessment for Quality Traits, Yield and Yield Related Characters in Advanced Ethiopian Bread Wheat (*Triticum aestivum* L.) Breeding Lines. M.Sc. Thesis. Alemaya University, Ethiopia

FAO (Food and Agriculture Organization of the United Nations). 1990. Agrometerology Group, Remote Sensing Center. Research and Technology Division. Rome, Italy. p.120.

FAO (Food and Agriculture Organization of the United Nations). 2003. FAO Statistic Series, Vol. 57 No 177. Rome, Italy.

Finney K. F. and Barmore M. A. 1990. Loaf volume and protein content of hard winter and spring wheats. *Cereal Foods World* 35: 291–312

Gianibelli, M. C., Larroque, O. R. MacRitchie, F. and Wrigley, C. W. 2001. Biochemical, genetic and molecular characterization of wheat endosperm proteins. *Cereal Chemistry* 78: 635–646

Hailu, G. M. Tanner, D. G. and Mengistu, H. 1991. Bread Wheat Breeding and Genetics Research in Ethiopia: A Historical Perspective, Addis Ababa, IAR/CIMMYT.

He, H. and Hoseney, R.C. 1992. Effect of the quantity of wheat flour protein on bread loaf volume. *Cereal Chemistry* 69: 17–19.

Hoseney, R. C. 1994. Principles of Cereal Science and Technology. 2nd. ed., American Association of Cereal Chemists. St. Paul, MN.

Lill, D. V., Wentzel, B.S. ,Smith, M.F. and Villiers, O. T. 1993. Comparison of protein extraction procedures to assess the effect of quantitative protein composition on the bread-making quality of South African winter wheat cultivars. *South African Journal of Plant and Soil* 10: 162–167

MacRitchie, F.1984. Baking quality of wheat flours. *Advanced Food Research* 29: 201–277

Monsivais, M., Hoseney, R. C. and Finney, K. F. 1983. The Pelshenke test and its value in estimating bread-making properties of hard winter wheats. *Cereal Chemistry* 60: 51–55

Morita, N., Maeda, T., Miyazaki, M., Yamamori, M., Miura, H. and Ohtsuka, I. 2002. Dough and baking properties of high-amylose and waxy wheat flours. *Cereal Chemistry* 79:491–495

Peterson, C. J., Graybosch, R.A., Baenziger, P. S. and Grombacher, A. W. 1992. Genotype and environment effects on quality characteristics of hard red winter wheat. *Crop Science* 32: 98–103

Preston, K. R., Lukow, O. M. and Morgan, B. 1992. Analysis of relationships between flour quality properties and protein fractions in a world wheat collections. *Cereal Chemistry* 69: 560–567

Payne, P. I., Nightingale, M. A., Krattiger, A. F. and Holt, L. M. 1987. The relationship between HMW glutenin subunit composition and the bread-making quality of British-grown wheat varieties. *Journal of the Science of Food and Agriculture* 40:51–65

Payne, P. I., Holt, L. M. and Law, C. N. 1981. Structure and genetic studies on the high-molecular-weight subunits of wheat glutenin. I. Allelic variation in subunits amongst varieties of wheat (*Triticum aestivum*).*Theoretical and Applied Genetics* 60:229–236

Rahman, S. Li, Z. Batey, I. Cochrane, M. P. Appels, R. and Morell, M. 2000. Genetic alteration of starch functionality in wheat. *Journal ofCereal Science* 31: 91–110

Solomon, G., Desalegn, D., Bedada, G., Payne, T. S., Zewdie A. and Balcha, Y. 2000. Milling and baking quality of Ethiopian bread wheat cultivars.The Eleventh Regional Wheat Workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia: CIMMYT. pp. 87–96.

Wrigley, C. 2005 a. Precision agriculture-a means of improving grain quality. *Cereal Foods World* 50: 143–144

Wrigley, C. 2005b. Grain protein composition –Repeated cycles of research on dough quality. *Cereal Foods World* 50: 38–40

Growth, Photosynthetic Efficiency, Rate of Transpiration, Lodging, and Grain Yield of Tef (*Eragrostis Tef* (Zucc.) Trotter) as Influenced by Stage and Rate of Paclobutrazol Application

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Abstract: The growth response of tef (*Eragrostis Tef* (Zucc.) Trotter) to foliar spray of paclobutrazol was investigated under sub-humid and hot tropical conditions of eastern Ethiopia. At both locations, paclobutrazol was applied at tillering, jointing or panicle emergence stage at rates of 0, 1, 2, and 3 kg a.i. per ha. The results of the field trials demonstrated that paclobutrazol treatment increased leaf chlorophyll *a* and *b* content, reduced the rate of leaf transpiration, and increased photosynthetic efficiency that has a direct effect on the productivity of the tef crop. Paclobutrazol treatment had reduced plant height and total leaf area there by reduced excessive vegetative growth and lodging percentage. Paclobutrazol treatment resulted in increased number of fertile tillers, number of fertile florets per spike, and thousand seed mass there by increasing tef grain yield. It is reasonable to point out that paclobutrazol is a potential plant growth regulator for use as a height-shortening anti-lodging agent in tef with subsequent grain yield benefits. Application of 1 kg a.i. paclobutrazol per hectare seems to be optimum rate and the appropriate stage of application appeared to be between tillering and jointing.

Keywords: Eragrostis Tef; Grain Yield; Lodging; Paclobutrazol; Tef

1. Introduction

Tef (*Eragrostis tef* (Zucc.) Trotter) is a C_4 tropical cereal (Seyfu, 1997). Ethiopia is the center of origin and diversity (Vavilov, 1951). It is cultivated as a major cereal representing about 20% (2×10^6 mt) of the gross cereal production (CSA, 1997). Tef production in Ethiopia is characterized by low productivity and the national average yield is about 8.5 quintals per hectare (CSA, 1997). Lodging is one of the bottleneck problems accountable for such low yield. The problem is more serious in areas subjected to high rainfall and strong winds, particularly under growing conditions favorable for its growth and yield. Seyfu (1983) reported that 17 to 23% yield reduction of improved tef varieties is due to natural lodging. In lodged crop, light utilization is insufficient which results in poor grain filling and reduced yield (Davis and Curry, 1991). Furthermore, lodging reduces the efficiency of manual and mechanical harvesting operations.

Paclobutrazol [(2R, 3R+2S, 3S)-1-(4-chloro-phenyl) 4,4-dimethyl-2-(1,2,4-triazol-1-yl)-pentan-3-ol] (PBZ) is a broad spectrum Gibberellin (GA) biosynthesis inhibitor that belongs to triazole plant growth regulator group (Davis and Curry, 1991). The primary mode of action of PBZ is inhibition of GA biosynthesis by interfering with the *ent*-kaurene oxidase, which catalyzes the sequential oxidations from *ent*-kaurene to *ent*-kaurenoic acid (Rademacher, 1997). One of the most important uses of plant growth retardants is lodging control and widely used in wheat, rice, rye and barley (Davis and Curry, 1991). Properly timed applications of PBZ have been reported to reduce lodging and increase yield in several agronomic crops including ryegrass (Young *et al.*, 1996), rice (Street *et al.*, 1986) and wheat (Froggatt *et al.*, 1982).

Under Ethiopian conditions, plant growth regulators as means of controlling lodging problem have not been used. However, greenhouse and field experiments were undertaken to investigate the efficacy of 2-chloroethyl trimethylammonium chloride (CCC) to reduce lodging problem and promising results have been observed (Kifle, 1985). Similarly, Kebebew (1991) reported that PBZ is an effective plant growth regulator to control lodging and improve yield in tef. The response of plants to the growth regulators depends on species, cultivar, dose, method and time of application (Davis and Curry, 1991). In this paper, the results of the effect of different rates and time of PBZ application on growth, net photosynthesis, rate of transpiration, lodging, and yield and yield components of tef grown under sub-humid and hot tropical conditions of eastern Ethiopia are presented.

2. Materials and Methods

2.1. Experimental Site

The experiment was established at two locations, namely, Haramaya and Dire Dawa, both situated in the semi-arid and arid tropical belt of eastern Ethiopia, during the 2003 cropping season. Haramaya is located at 42º 3'E, 9º 26'N, at an altitude of 1980 m.a.s.l, and characterized as having sub-humid type of climate with average annual rainfall of about 790 mm with a variation between 575 mm and 1017 mm. The mean annual temperature of Alemaya is about 17 ºC with mean minimum and maximum temperatures of 3.8 ºC and 25 ºC, respectively. During the study period, the mean maximum temperature was 26 ºC and minimum temperature of 11.4 ºC. During the

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growing period a total of 177 mm precipitation was received and supplementary irrigation was applied. Mean sunshine hours were 9.7 per day, along with a relative humidity of 41%. The soil on which the experiment was conducted is a well-drained deep alluvial soil with 1.38 organic carbon, 0.14% nitrogen, 1.19 mg $100g^{-1}$ available phosphorus, 470 ppm total potassium, and pH of 7.2.

Dire Dawa is characterized by hot tropical climate and located at 41º50.4' E, 09º 36' N, at an altitude of 1176 m.a.s.l. During the growing period the total precipitation was 230 mm and supplemental irrigation was applied. The mean monthly minimum and maximum temperatures were 18 ºC and 31 ºC, respectively. The mean relative humidity was 50% with its variation from 20% to 81%. The soil of the experimental site is a well-drained deep clay loam with 2.36% organic matter, 1.36% organic carbon, 0.12% total nitrogen, 14.15 ppm phosphorus, 1.08 $meq100gm^{-1}$ exchangeable potassium, 0.533 $mmhoscm^{-1}$ electrical conductivity and a pH of 8.6.

2.2. Variety Used

The variety used was DZ-01-196. According to Hailu *et al.* (1995) it has fairly loose type of panicle with branches arranged multilaterally. Depending on the growing condition plant height ranges from 50-117 cm, the average being 82 cm. It is relatively late maturing variety that matures within 80-113 days after planting depending on the growing conditions. Due to its tallness, under favorable growing conditions it is found to be susceptible to lodging.

2.3. Experimental Design and Plant Culture

At both locations, treatments were laid down in two factor factorial experiments arranged in randomized complete block design replicated three times. Plots (2 m^2) were divided into 5 rows with inter-row spacing of 20 cm. Seeds were broadcasted within each row at a rate of 4.4 g pot^{-1} (22 kg ha^{-1}). After uniform emergence plants were thinned to intra-row spacing of 5 cm to maintain approximately 100 plants per plot. Phosphorus was applied during planting at a rate of 125 kg ha^{-1}in the form of DAP, and after thinning nitrogen was applied (topdressing) at a rate of 100 kg ha^{-1} in the form of Urea.

After good establishment, the main stem of five randomly selected plants from each of the three central rows were tagged and relevant data measurements were done on these selected plants. All the required cultural practices were applied as per the recommendations of Seyfu (1987).

2.4. Treatments

At three distinct growth stages plants were treated with PBZ at rates of 0, 1, 2 and 3 kg a.i. PBZ ha^{-1} as a foliar application using Cultar formulation (250 g a.i. PBZ per l, Zeneca Agrochemicals SA (PTY.) LTD., South Africa). A given PBZ concentration was diluted in distilled water (50 ml $plot^{-1}$) and the aqueous solution was applied uniformly to each plant as fine foliar spray using an atomizer. The control plants were treated with distilled water of equal volume.

2.5. Stage of Applications

The following three growth stages were selected on the basis of growth stages identified by Kebebew (1991).

1. **Tillering:** Thirty days after planting and the plants had an average of four developed leaves on the main stem.
2. **Jointing**: Forty-five days after planting. The plants had developed about five leaves on the main stem and the second node on the main culm of the plant was detectable.
3. **Panicle emergence**: Fifty-three days after planting: The plants had developed the maximum leaves (6 or more) on the main stem and the emergence of the tips of the panicle through the flag leaf sheath was manifested.

At Dire Dawa, due to higher growing temperature plants grew faster and reached the application stages earlier than the plants grown at Haramaya where there was relatively cool weather. Hence, the application stages were adjusted accordingly.

2.6. Data Recorded

Two weeks after the application of the last treatment stomatal conductance, rate of transpiration and photosynthesis were measured using a portable LCA4 photosynthesis system (ADC Bio Scientific Ltd., UK) and leaf chlorophyll content was determined. The measurements were made on three randomly selected tagged plants on the middle portion of the flag leaf. A crude chlorophyll extract was made using 80% acetone from leaf tissue taken from the mid portion of the flag leaf. Spectrophotometer (Pharmacia LKB, Ultrospec III) readings were taken at 663 and 645 nm and the concentration of chlorophyll *a* and *b* were assessed using the specific absorption coefficients given by Mac Kinney (1941).

Days to panicle emergence refers to the number of days elapsed from planting to the date when 50% of the plants depicted the emergence of the tips of the panicle. Days to maturity was recorded when 50% of the plants within a plot change the entire plant color from green to light yellow. Lodging index was determined using the degree of lodging on 0-5 scale according to Caldicott and Nuttall (1979), where 0 value is fully upright (90 º) and 5 equals to fully lodged.

Plant height is the length of the main shoot from the base of the main shoot to the apex of its panicle. Panicle length is the length of the panicle of the main shoot from the base to its tip. Culm length is the length from the base of the main shoot culm to the base of the panicle. Internode length refers to the average node length of each of the main shoot culm nodes. Flag leaf length and width refer to the length and the width at the broadest point of the flag leaf blade at maturity. Total leaf area is the total leaf surface area of a plant and measured with a portable

CI-202 leaf area meter (CID Inc., Vancouver, Washington state, USA). Total biomass refers to dry mass of the crop (above ground and root dry mass) dried at 72 °C to a constant mass.Number of florets is the total count of grain bearing florets per spiklet. Grain yield per plant is air-dried grain mass harvested from individual plant. Thousand-kernel weight is mass of 1000 tef grains.

2.7. Statistical Analysis

The analyses of variance were carried out using MSTAT-C statistical software (MSTAT-C, 1991). Combined analysis of variance showed significant treatments by site interactions and hence, for all of the parameters considered, the data of the two experiments were presented separately. Means were compared using Least Significant Differences (LSD) test at 5% probability level. Correlations between parameters were computed where applicable.

3. Results

3.1. Haramaya

Significant interactions between stage and rate of PBZ application were observed with respect to plant height and culm length, panicle and flag leaf length and leaf area of tef grown at Haramaya (Table 1)

Table 1. The interaction effect of stage and rate of PBZ application on plant height and culm length, panicle and flag leaf length, and leaf area of tef grown at Haramaya

PBZ application		Height (cm)		Length (cm)		Leaf area (cm^2)
Stage	Rate (kg a.i.PBZ ha^{-1})	Crop	Stem	Panicle	Flag leaf	
Tillering	0 (control)	97.4a	48.1a	49.3a	28.9a	380a
	1	56.2de	17.8cd	38.4d	12.8de	247de
	2	49.5e	17.2cd	32.3e	9.0ef	231e
	3	49.2ef	15.6d	33.6e	8.2f	223e
Jointing	0 (control)	98.7a	49.3a	49.4a	28.5a	371a
	1	64.1c	22.4c	41.7cd	15.2cd	290bc
	2	57.3de	17.9cd	39.3cd	13.1de	287bc
	3	53.8ef	18.9cd	34.9e	12.1def	262cd
Panicle emergence	0 (control)	99.9a	49.1a	50.8a	28.1a	377a
	1	82.5b	37.4b	45.1b	20.4b	296b
	2	62.4cd	19.7cd	42.7bc	19.2bc	276bc
	3	59.3cd	18.5cd	40.8bc	19.1bc	266bc
SEM		1.62	1.54	0.85	1.11	7.70

SEM: Stand error of the mean
Means within the same column sharing the same letters are not significantly different at P<0.05

At all stages of application, PBZ significantly reduced plant height with no significant difference between the moderate and higher rates. Irrespective of the concentration of PBZ applied, it reduced culm length by about 65% and 60% during early tillering and jointing stage, respectively. On the other hand, applying 1 kg a.i. PBZ ha^{-1} reduced culm length by about 24% while applying 2 or 3 kg a.i. PBZ ha^{-1} brought about 61% culm length reduction when applied during panicle emergence. PBZ treatment reduced flag leaf length by about 65%, 53%, and 30% when applied at tillering, jointing and panicle emergence, respectively. Panicle length was reduced by about 29%, 22%, and 15% in response to PBZ treatment at tillering, jointing and panicle emergence, respectively. Although not consistent PBZ reduced total leaf area irrespective of the stage and rate of application.

Both stage and concentration of PBZ treatment significantly influenced mean node length, leaf stomatal conductance, rate of transpiration, net photosynthesis, total biomass, number of fertile florets, grain yield, and thousand seed mass tef grown at Haramaya**(Table2)**

Table 2. The effect of stage and rate of PBZ application on mean node length, leaf stomatal conductance (g_s), rate of transpiration (T), net photosynthesis (P_n), total biomass, number of fertile floret, grain yield per plant, thousand seed mass (TSM), and lodging percentage of tef grown at Haramaya

Main effect	Node length (cm)	g_s (molm^{-2} s^{-1})	T (molm^{-2} s^{-1})	P_n (µmolm^{-2} s^{-1})	Total biomass	No. fertile floret	Grain yield (g)	TSM (mg)	Lodging (%)
Tillering	6.8b	0.09b	1.97b	3.02c	16.2c	456.9b	6.6a	338.3a	51.41c
Jointing	7.9a	0.11b	1.99b	2.25b	17.0b	541.6a	6.7a	341.7a	56.27b
Panicle emerg.	8.6a	0.19a	2.66a	3.49a	18.3a	518.6a	6.3b	329.8b	60.02a
SEM	0.32	0.001	0.01	0.005	0.18	13.6	0.07	1.97	1.07
0 (control)	12.2a	0.15a	2.57a	2.81d	20.6a	467.7c	5.9c	323.0c	89.31a
1 kg PBZ	7.0b	0.13ab	2.23b	3.29c	16.8b	517.6b	6.6b	335.4b	48.40b
2 kg PBZ	5.9b	0.12ab	2.12c	3.38b	16.1c	521.7a	6.8a	343.1ab	44.80c
3 kg PBZ	5.8b	0.11b	1.91d	3.54a	15.2d	515.8ab	6.7ab	344.9a	41.20d
SEM	0.37	0.001	0.01	0.006	0.20	15.8	0.08	2.27	

SEM: Stand error of the mean

Means within the same column (with in the same main effect) sharing the same letters are not significantly different (P<0.05)

Applying PBZ at early tiller development significantly reduced node length than applying during early joint and panicle emergence. Regardless of the rate, PBZ application reduced mean node length by about 50% as compared to the check.

Early and mid application of PBZ significantly reduced stomatal conductance and reduced rate of leaf transpiration than late application. Means pooled over stage of application showed that regardless of the concentration, applied PBZ reduced stomatal conductance by 21%. PBZ significantly reduced rate of leaf transpiration and there was a tendency of reducing the rate with increasing concentration. Stage of application remarkably influenced leaf net photosynthesis in such a way that late treated plants exhibited an increased rate followed by mid and early treatment. Application of 1 kg a.i. PBZ ha^{-1} increased rate of net photosynthesis by 17%, 2 kg by 20% and 3 kg by 26% over the control.

With respect to total biomass production PBZ had strong reduction effect when applied during early tiller development followed by jointing and panicle emergence. Applying 1, 2, and 3 kg a.i. PBZ ha^{-1} resulted in approximately 18%, 22%, and 26% biomass reduction respectively, as compared to the control. PBZ increased number of fertile floret per plants when applied at early jointing (542) and panicle emergence (519) in contrast to early tiller development (457). PBZ treatment brought about 11% fertile florets increment over the control. Applying PBZ during early tillering and jointing stage gave higher grain yield than late application. PBZ application at a rate of 1 kg a.i. ha^{-1} increased grain yield by about 12% while applying 2 or 3 kg gave 14.4% advantage as compared to the control. Similarly, the two early PBZ applications showed higher thousands seed mass than the late treatment. As compared to the control, application of 1 kg a.i. PBZ ha^{-1} increased thousand seed mass by about 4% while treatment with 2 or 3 kg PBZ increased by about 7%.

PBZ concentration significantly influenced days to panicle emergence and maturity, flag tef width, leaf chlorophyll content, number of fertile and total tillers of tef grown in a sub-humid growing condition.(Table 3)

Table 3. The effect of PBZ concentration on days to panicle emergence and maturity, flag leaf width, leaf chlorophyll *a* and chlorophyll *b* content, number of fertile, unfertile and total tillers of tef grown at Haramaya

Rate (kg a.i. PBZ ha^{-1})	Days to panicle emerg.	Days to maturity	Flag leaf width (mm)	Chlorophyll content (mg g^{-1}FW)		Tiller number		
				a	*b*	Fertile	Unfertile	Total
0 (control)	54.2b	100.8b	64.6a	1.30b	0.32b	8.2b	2.4a	10.5b
1	65.3a	107.4a	61.7b	1.50a	0.41a	12.7a	2.2a	14.9a
2	64.4a	108.1a	61.0b	1.57a	0.46a	13.2a	2.9a	16.12a
3	64.0a	108.9a	60.4b	1.53a	0.40a	12.5a	2.6a	15.11a
SEM	0.91	0.74	0.52	0.05	0.24	0.31	0.18	0.32

SEM: Stand error of the mean

Means within the same column sharing the same letters are not significantly different (P<0.05)

At all rates PBZ treatment delayed days required to panicle emergence and maturity by about 10 and 7 days, respectively. Irrespective of the rates of application, PBZ increased leaf chlorophyll *a* by 18% and chlorophyll *b* by 32% as compared to the check. PBZ significantly increased the number of fertile and total tillers while the number of unfertile tillers unaffected. Regardless of the concentration, the number of fertile and total tillers increased by about 56% and 46%, respectively, in response to PBZ treatment.

3.2. Dire Dawa

The interaction effect of stage and rate of PBZ application on plant height and culm, panicle, node and flag leaf length, of tef grown at Dire Dawa is presented in table 4. Both stage and rate of PBZ application significantly affected total leaf area, chlorophyll *a* and chlorophyll *b*, stomatal conductance, rate of transpiration, net hotosynthesis, total biomass, number of fertile floret, grain yield, thousand seed mass and lodging percentile of tef grown under hot tropical climate (Table 5).

Table 4. The interaction effect of stage and rate of PBZ application on plant height and culm length, panicle, node and flag leaf length, of tef grown at Dire Dawa

PBZ application		Height (cm)		Length (cm)		
Stage	Rate (kg a.i. PBZ ha^{-1})	Crop	Stem	Panicle	Node	Flag leaf
Tillering	0 (control)	105.6a	52.8a	52.9a	13.8a	31.8a
	1	63.1def	22.5cd	40.6de	7.8cd	14.1de
	2	56.2f	21.9cd	34.3f	5.4g	9.9ef
	3	55.9f	20.3d	35.6f	5.2g	9.1f
Jointing	0 (control)	106.9a	53.9a	52.9a	13.0a	31.4a
	1	71.2c	27.1c	44.2cd	7.5d	16.8cd
	2	64.1cde	22.6cd	41.5cd	6.8ef	14.5de
	3	60.6ef	23.5cd	37.1ef	6.2f	13.3def
Panicle emergence	0 (control)	108.5a	53.9a	54.6a	13.5a	31.0a
	1	90.4b	42.1b	48.3b	10.2b	22.5b
	2	69.4cd	24.4cd	45.0bc	8.2c	21.2b
	3	66.2cd	23.2cd	43.0cd	7.2de	21.1bc
SEM		1.83	1.54	1.02	0.05	1.21

SEM: Stand error of the mean
Means within the same column sharing the same letters are not significantly different (P<0.05)

Table 5. The effect of stage and rate of PBZ application on leaf area, chlorophyll a, chlorophyll b, stomatal conductance (g_s), rate of transpiration (T), net photosynthesis (P_n), total biomass, number of fertile florets, grain yield, thousand seed mass (TSM), and lodging percentage of tef grown at Dire Dawa

Main effect	Leaf area (cm^2)	Chlorophyll (mg g^{-1} FW)		g_s (mol m^{-2} s^{-1})	T (mol m^{-2}s^1)	P_n (µmol m^{-2}s^{-1})	Total biomass	No. fertile floret	Grain yield (g)	TSM (g)	Lodging (%)
		a	*b*								
Tillering	277.3b	1.44b	0.38b	0.10b	2.01b	3.32c	17.1b	427.9b	6.4a	347.5a	53.57c
Jointing	310.9a	1.46a	0.38b	0.13b	2.04b	3.58b	17.8b	498.5a	6.5a	350.8a	58.47b
Panicle emerg.	311.6a	1.46a	0.45a	0.22a	2.73a	3.83a	19.4a	474.3a	6.1b	338.6b	63.22a
SEM	5.10	0.001	0.001	0.001	0.02	0.001	0.19	10.9	0.07	2.02	1.53
0 (control)	386.2a	1.31d	0.33c	0.18a	2.63a	3.10d	21.7a	430.0b	5.8b	331.6c	94.18a
1 kg PBZ	285.1b	1.52b	0.38b	0.15ab	2.28b	3.61c	17.9b	482.6a	6.4a	344.3b	50.27b
2 kg PBZ	271.6bc	1.56a	0.44a	0.14b	2.17c	3.71b	16.9c	483.4a	6.7a	352.4ab	46.55c
3 kg PBZ	257.1c	1.44c	0.46a	0.13b	1.96d	3.89a	15.9d	471.5a	6.5a	354.2a	42.68d
SEM	8.84	0.002	0.001	0.001	0.02	0.01	0.21	12.6	0.08	2.34	1.78

SEM: Stand error of the mean
Means within the same column (with in the same main effect) sharing the same letters are not significantly different (P<0.05)

The application of PBZ at early stage (tillering) reduced total leaf area than applying at jointing and panicle emergence. Applying 1 kg a.i. PBZ ha^{-1} reduced total leaf area by about 26% and 2 or 3 kg PBZ resulted in 32% leaf surface area reduction over the control. Moderate and late application increased chlorophyll *a* content of the leaf than early application. On the other hand, late PBZ treatment resulted in higher leaf chlorophyll *b* content than early and moderate application. An increase of 16, 19, and 9% chlorophyll *a* content over the control due to the application of 1 kg, 2 kg, and 3 kg a.i. PBZ ha^{-1}, respectively. Similarly, chlorophyll *b* content was increased by about 15% in response to 1 kg a.i. PBZ ha^{-1} while application of 2 or 3 kg resulted in 36% increment.

Application of PBZ during early tillering and jointing stage reduced stomatal conductance much better than late application. Conversely, higher rate of leaf transpiration was observed during early tillering and jointing than panicle emergence. Regardless of the concentration, PBZ treatment decreased leaf stomatal conductance by about 22% compared to the control. Concomitantly, application of 1 kg, 2 kg, and 3 kg a.i. PBZ ha^{-1} reduced the rate of leaf transpiration by about 13%, 17%, and 25% as compared to the control. Plants treated during panicle emergence showed the highest rate of net photosynthesis, followed by plants treated during early jointing and tillering stage. PBZ treatment at a rate of 1 kg a.i. ha^{-1} increased net photosynthesis by 17%, 2 kg by 20% and 3 kg by 26% as compared to the control. Significantly higher number of fertile florets was recorded on plants treated during early joint development and panicle emergence stage than plants treated at the tillering stage. PBZ treatment increased the number of fertile florets by about 11% as compared to the control. Plants that received PBZ treatment during tillering and jointing stage exhibited higher grain yield than those treated at panicle emergence. Yield advantage of about 13% over the control was achieved due to PBZ treatment. Early application of PBZ significantly reduced lodging percentage than moderate and last application. Application of 1kg,2kg,3kg a.i PBZ ha^{-1} reduced lodging percentage by about 45%,51% and 55% respectively, over the control. Irrespective of the concentration PBZ treatment extended day to panicle emergence and maturity, and reduced flag leaf width. PBZ increased number of fertile and total tillers without affecting the number of unfertile tillers.(Table 6)

Table 6. The effect of PBZ concentration on days to panicle emergence and maturity, flag leaf width, number of fertile, unfertile and total tillers of tef grown at Dire Dawa

Rate (kg a.i. PBZ ha^{-1})	Days to panicle emerg.	Days to maturity	Flag leaf width (mm)	Tiller number		
				Fertile	Unfertile	Total
0 (control)	49.3b	91.7b	66.9a	8.4b	3.3a	11.7b
1	57.3a	98.1a	63.9b	13.1a	3.1a	16.2a
2	56.8a	99.4a	63.2b	13.7a	3.8a	17.5a
3	56.8a	100.6a	62.7b	12.9a	3.5a	16.4a
SEM	0.62	0.64	0.53	0.31	0.18	0.31

SEM: Stand error of the mean
Means within the same column sharing the same letters are not significantly different at P<0.05

4. Discussion

PBZ is a potent plant growth regulator and it is required in relatively low concentration to induce physiological, anatomical and morphological changes in plants.

The most striking growth response of tef to PBZ treatment was a reduction in shoot growth. Treated plants appeared to be short and compact due to the reduction in internode length and leaf area. Results of studies on cereals indicated that tallness is strongly associated with endogenous gibberellin content. Nihonbare, a tall rice variety has significantly higher gibberellin content than a semi dwarf variety, Tongil (Takahashi, 1986). Harada (1985) reported that incorporation of a dwarfing gene Dee-geo-woo-gen in rice varieties reduced gibberellin biosynthesis. Moreover, GA treatment increased plant height and encouraged shoot growth in rice (Hanada, 1964; Jung, 1986; Yim *et al.*, 1997). It is speculated that reduced gibberellins biosynthesis in response to PBZ treatment might have resulted in a reduction in cell proliferation that apparently leads to reduction in stem elongation and leaf expansion. Reduction in the endogenous gibberellin level of wheat was proportional to the concentration of PBZ treatment, and leaf length was correlated linearly to log concentration of GA_1 according to Lenton and Hedden (1987). Yim *et al.* (1997) reported that PBZ is translocated primarily apoplastically through the xylem to its site of action where it decreases the rate of cell division and elongation, ultimately resulting in reduction in vegetative growth. PBZ treatment effectively reduced plant height in wheat (Froggatt *et al.*, 1982), maize (Shanahan and Nielson, 1987), rice (Yim *et al.*, 1997), cool season grasses such as chewing’s fescue and orchard grass (Young *et al.*, 1999), and tef (Kebebew, 1991).

The remarkable reduction of lodging in tef due to PBZ treatment is attributed to reduction in excessive top growth and plant height. PBZ is more effective in reducing lodging when applied at tillering stage than applying during jointing and panicle emergence. Regardless of the concentration, PBZ sprayed at the end of tillering and early jointing stage significantly reduced lodging in tef (Kebebew, 1991). Guoping (1997) observed that about 30% of the untreated wheat plants lodged while the PBZ treated plants did not. Properly timed application of PBZ significantly reduced lodging and improved yield in *Lolium perenne* (Hampton and Hebblethwaite 1985), rice (Street *et al.*, 1986) and wheat (Forgatta *et al.*, 1982).The leaves of PBZ treated plants typically exhibited dark green color compared to the control. This is attributed to an increase in chlorophyll *a* and *b* content of the leaves either as the result of enhanced chlorophyll synthesis and/or the presence of more chloroplasts per unit leaf area of treated leaves. The observed negative correlation between total leaf area and chlorophyll *a* content (r = - 0.82); total leaf area and chlorophyll *b* content (r = - 0.91*) at Dire Dawa indicate that the reduction in total leaf area in response to PBZ treatment contributed substantially for chlorophyll *a* and *b* increment. Similarly, Yim *et al.* (1997) reported that PBZ significantly increased leaf chlorophyll content of rice seedlings. Khalil (1995) reported the existence of densely packed chloroplast per unit leaf area of cereals in response to PBZ treatment.

The higher chlorophyll content of the treated leaves and delayed physiological maturity may be related to the influence of PBZ on endogenous cytokinins content. It has been proposed that PBZ stimulates cytokinin synthesis, which increases chloroplast differentiation and chlorophyll biosynthesis, and prevents chlorophyll degradation (Fletcher *et al.*, 1982). Investigations on rice (Izumi *et al.*, 1988), soybean (Grossmann, 1992) and *Dianthus caryophyllus* (Sebastian *et al.*, 2002) showed that exogenous application of gibberellin biosynthesis inhibitors increased cytokinin content of the plant tissues. The PBZ treatments significantly reduced the rate of transpiration in tef leaves. This could be due to the partial closure of stomata in response to the treatment as indicated by the concomitant reduction in stomatal conductance. It is postulated that the reduction in stomatal conductance in response to PBZ treatment might have been mediated through its effect on endogenous ABA content (Rademacher, 1997) as ABA is involved in regulating the opening and closing of stomata (Salisbury and Ross, 1992). Asare-Boamah (1986) observed reduction in transpiration, increased diffusive resistance and a transient rise in ABA level in response to triazole treatment. Such a response may improve drought tolerance of the plant to withstand the problem of water deficit whenever there is shortage. PBZ treatment has been shown to reduce water loss and improve water use efficiency in grapevine, chrysanthemum, and beetroot (Ritchie *et al.*, 1991; Smith *et al.*, 1992; Roberts and Mathews, 1995).

Unlike its effect on the rate of transpiration, PBZ treatment increased photosynthetic efficiency of tef. This response could be linked with the increase in chlorophyll concentration. Sink regulation of photosynthesis is a well-accepted concept, possibly explaining the coordination of assimilate production and utilization (Stitt *et al.*, 1990). There are contradicting reports regarding the effects of PBZ on rate of photosynthesis. Although PBZ treatment increased chlorophyll concentration, it has little effect on rice photosynthetic efficiency (Yim *et al.*, 1997). On the contrary, an increased net photosynthesis in response to PBZ treatment had been reported in soybean rape (Zhou and Xi, 1993) and potato (Tekalign and Hammes, 2005a).

Both at Haramaya and Dire Dawa PBZ treatment increased the number of total and fertile tillers without affecting the number of unfertile tillers. This could be associated with the reduction in endogenous GA levels in response to the treatment. Inhibition of tiller production by exogenous GA treatment has been reported in rice (Jung, 1986;Yim et al.,1997). PBZ treatment stimulated tiller initiation in rice (Yim *et al.*, 1997), wheat (Guoping, 1996), and velvet grass (Hamton *et al.*, 1992).

Yield in tef is the resultant of number of fertile tillers, number of grain per tiller and mass of individual grain. PBZ treatments increased tef grain yield. This is ascribed to an increased number of fertile tillers, number of fertile florets per spiklet, and mass of individual grain. Similar studies indicated that PBZ improved seed yield of chewing's fescue and tall fescue by increasing the number of spikelets per panicle and florets per spikelets, which cumulatively resulted in significant increases in floret sites and the number of seeds produced per unit area (Young *et al.*, 1999). Albeke *et al.* (1983) reported that PBZ applied either at spikelet initiation or at floret initiation increased number of spikelets per panicle and florets per unit area without affecting number of tillers. Hampton and Hebbleth-waite (1985) reported that the beneficial effect of PBZ on perennial ryegrass seed yield is sometimes attributed to increase in the number of fertile tillers. PBZ did not increase the number of fertile tillers in cool season grasses such as chewing's fescue, tall fescue and orchard grass (Young *et al.*, 1999).

At both sites PBZ treatment significantly reduced total biomass yield. Assimilate partitioning to the different sinks is controlled by environmentally regulated hormonal balances (Almekinders and Struik, 1996). It has been suggested that the inhibition effect of vegetative growth in response to PBZ treatment alters the pattern of assimilate allocation and relative sink strength in favour of grain development. Young *et al.* (1999) reported that the increase in seed yield of cool season grass species after PBZ treatment may be due to the diversion of more assimilates to the seeds at the expense of vegetative tiller formation after anthesis. PBZ increased rye seed yield by reducing stem elongation that can directly compete with the growing spike for assimilates (Clemence and Hebblethwaite, 1985). The involvement of GA in regulating the pattern of assimilate partitioning was suggested by Yim *et al.* (1997). PBZ increased the partitioning of assimilates to economically important plant parts such as bulbs (De Resende and De Souza, 2002) and tubers (Tekalign and Hammes, 2005a).

Starch is the largest proportion in the carbohydrate fraction of tef grain (Bultosa *et al.*, 2002). An increase in an individual grain mass (as measured in thousand seed mass) may be ascribed to enhanced starch synthesis in response to PBZ treatment. PBZ treatment increased starch accumulation in the leaves, stems, crowns and roots of rice seedling while GA_3 treatment decreased starch accumulation in the leaves and crowns of the seedlings (Yim *et al.*, 1997). PBZ treatment increased root starch content in maize (Baluska *et al.*, 1993) and root and stem of potato plants (Tekalign and Hammes, 2005b).

5. Conclusion

Field trials at Alemeya and Dire Dawa demonstrated that PBZ treatment increased leaf chlorophyll content, reduced the rate of leaf transpiration, and enhanced the rate of net photosynthesis in tef which have direct effect on its productivity. The treatment had reduced plant height and total leaf area that significantly reduced excessive vegetative growth and lodging percentage. PBZ treatment had increased number of fertile tillers, number of fertile florets per spiklet, and thousand seed mass there by increased tef grain yield. It is reasonable to point out that PBZ is a potential plant growth regulator for use as a height-shortening anti-lodging agent in tef with considerable grain yield benefits. Application of 1 kg a.i PBZ ha^{-1} seems to be an optimum rate and the appropriate stage of application appeared to be between tillering and jointing. Since the trials were conducted at two locations for one season, it is recommended that these finding must be ascertained by further filed trials to reach to coherent recommendation.

6. References

Albeke, D.W., Chilcote, D.O. and Youngberg, H.W. 1983. Chemical dwarfing effect on seed yield of tall fescue (*Festuca arundinacea*) cv. Fawn, fine fescue (*Festuca rubra*) cv. Cascade, and Kentucky blue (*Poa pratensis*) cv. Newport. *Journal of Applied Seed Production* 1: 39-42.

Almekinders, C.J.M. and Struik, P.C. 1996. Shoot development and flowering in potato (*Solanum tuberosum* L.). *Potato Research* 39: 581-607.

Asare-Boamah, N.K., Hofstra, G., Fletcher, R.A. and Dumbroff, E.B. 1986. Triadimefon protects bean plants from water stress through its effects on abscisic acid. *Plant Cell Physiology* 27: 383-390.

Baluska, F., Parker, J.S. and Barlow, P.W. 1993. A role of gibberellic acid in orienting microtubules and regulating cell polarity in the maize cortex. *Planta* 191: 149-157.

Bultosa, G., Hall, A.N. and Taylor, J.R.N. 2002. Physico-chemical characterization of grain tef (*Eragrostis tef* (Zucc.) Troter) starch. *Starch/Stärke* 54: 461-468.

Caldicott, J.B. and Nuttal, A.M. 1979. A method for the assessment of lodging in cereals crops. *J. Nation. Inst. Agric. Bot.* 15: 18-19.

Clemences, T.G.A. and Hebblehwaite, P.D. 1985. An appraisal of ear, leaf and stem$^{14}CO_2$ assimilation. ^{14}C-assimilate distribution and growth in a reproductive seed crop of amenity *Lolium perenne*. *Annals of Applied Biology* 105: 319-327.

CSA (Central Statistical Authority). 1997. Agricultural samples survey, 1996/97. Report on the area and production for the major crops. Private peasant holdings. Statistical Bulletin No. 171, Addis Ababa, Ethiopia

Davis, T.D. and Curry, E.A. 1991. Chemical regulation of vegetative growth. *Critical Review in Plant Science* 10: 151-188.

De Resende, G.M. and De Souza, R.J. 2002. Effects of paclobutrazol doses on garlic crop. *Pesquisa Agropecuária Brasileira* 37 (5): 637-641.

Fletcher, R.A., Kallidumbil, V. and Steele, P. 1982. An improved bioassay for cytokinin using cucumber cotyledons. *Plant Physiology* 69: 675-677.

Froggatt, P.J., Thomas, D.W. and Batch, J.J. 1982. Opportunities for manipulation of cereal productivity. In: Hawkins A J. and Jeffcoat E. (eds.). Recent development in the use of plant growth retardants. British Plant Growth Regulator Group, Wantage. pp. 71-74.

Grossman, K. 1992. Plant growth retardants: Their mode of action and benefit for physiological research. In: Karssen C.M. and Van Loon L.C. and Vreugdenhil D. (eds.). Progress in plant growth regulations. Kluwer Academic Publisher, The Netherlands.

Guoping, Z. 1997. Gibbrellic acid modifies some growth and physiological effects of paclobutrazol (PP333) on wheat. *Journal of Plant Growth Regulation* 16: 21-25.

Hailu, T., Mulu, A. and Kebebew, A. 1995. Improved varieties of tef (*Eragrostis tef*) in Ethiopia: Releases of 1970-1995. Research bulletin No. 1, Debrezeit Agricultural Research Center, Ethiopia.

Hampton, J.G., Tolentino, M.S. and Hill, M.J. 1992. Effect of plant growth regulator on seed yield in velvet grass (*Holcus lanatus* L.) cv Massey Basyn. *New Zealand Journal of Agricultural Research* 35: 35-40.

Hampton, J.G. and Hebblethwaite, P.D. 1985. The effect of the growth regulator paclobutrazol (PP333) on the growth, development and yield of *Lolium perenne* grown for seed. *Grass Forage Science* 40: 93-101.

Hanada, K. 1964. Studies on branching habits in crop plants. 3. Effects of leaf removal or addition of gibbrellic acid through leaf blade on the growth of tillering buds in rice seedlings. *Crop Science Society of Japan* 33: 247-254.

Harada, J. 1995. High yielding semi dwarf rice and gibberellins. International seminar on plant growth regulation in agriculture, Tokyo, Japan. pp. 15-20.

Izumi, K., Nakagawa, S., Kobayashi, M., Oshio, H., Sakurai, A. and Takahashi, N. 1988. Levels of IAA, Cytokinins, ABA and ethylene in rice plants as affected by GA biosynthesis inhibitor, Uniconazole-P. *Plant Cell Physiology* 29: 97-104.

Jung, J., Rentzea, C. and Rademacher, W. 1986. Plant growth regulation with triazoles of the dioxanyl type. *Journal of Plant Growth Regulation* 4: 181-188.

Khalil, I.A. 1995. Chlorophyll and carotenoid contents in cereals as affected by growth retardants of the triazole series. *Cereal Research Communication* 23: 183-189

Kebebew, A. 1991. The effect of ethephone, CCC and paclobutrazol on yield and lodging of tef. MSc. Thesis, Alemaya University, Ethiopia.

Kifle, W. 1985. Some aspects of response of tef (*Eragrostis tef* (Zucc.) to 2-chloroethyl trimethylammonium chloride (CCC). M.Sc. Thesis, University of London, Wye College. pp. 60.

Le Guen-Le Saos, F., Hourmant, A., Esnault, F. and Chauvin, J.E. 2002. *In vitro* bulb development in shallot (*Allium cepa* L. Aggregatum Group): effects of anti-gibberellins, sucrose and light. *Annals of Botany* 89: 419-425.

Lenton, J.R. and Hedden, P. 1987. Gibberellin insensitivity and depletion in wheat: consequences for development. In: Hoad G.V., Lenton J.R., Jackson M.R. and Atkin R.K. (eds). Hormone action in plant development: A critical appraisal. Butterworths, London. pp. 145-160.

Mackinney, G. 1941. Absorption of light by chlorophyll solutions. *Journal of Biological Chemistry* 140: 315-322.

Mstat,C. 1991. A microcomputer program for design management and analysis of agronomic research experiments. Michigan State University, East Lansing, MI, USA.

Rademacher, W. 1997. Bioregulation of crop plants with inhibitors of gibberellin biosynthesis. *Proceedings of Plant Growth Regulation Society of America* 24: 27-31.

Ritchie, G.A., Short, K.C. and Davey, M.R. 1991. *In vitro* acclimatization of chrysanthemum and sugar beet plantlets by treatment with paclobutrazol and exposure to reduced humidity. *Journal of Experimental Botany* 42: 1557-1563.

Roberts, A.V. and Mathews, D. 1995. The preparation *in vitro* of chrysanthemum for transplantation to soil. 5. The 2s, 3s enantiomers of paclobutrazol improves resistance to desiccation. *Plant Cell, Tissue and Organ Culture* 40: 191-193.

Salisbury, F.B. and Ross, C.W. 1992. Plant Physiology 4th ed. Wadsworth Publishing Com., California,USA

Sebastian, B., Alberto, G., Emilio, A.C., Jose, A.F. and Juan, A.F. 2002. Growth, development and colour response of potted *Dianthus caryophyllus* cv. Mondriaan to paclobutrazol treatment. *Scientia Horticulturae*. 1767: 1-7.

Seyfu, K. 1983. Studies of lodging, floral biology, and breeding techniques in tef (*Eragrostis tef* (Zucc.) Trotter). Ph.D. thesis, University of London, Royal Hallway College. pp. 122.

Seyfu, K. 1987. Research recommendations for production and brief out-line of strategy for the improvement of tef (*Eragrostis tef* (Zucc.). Proceedings of the 19th national crop improvement conference 22-25 April, Addis Ababa.

Seyfu, K. 1997. Tef (*Eragrostis tef* (Zucc.) Trotter). Promoting the conservation and use of underutilized and neglected crops.12. Institute of Plant Genetics and Crop Plant Research, Gatersleben/ International Plant Genetics Resource Institute, Rome, Italy. pp. 1-10.

Shanahan, J.F. and Nielson, D.C. 1987. Influence of growth retardants on corn vegetative growth, water use and grain yield under different levels of water stress. *Agronomy Journal* 79(1): 103-109.

Smith, E.F., Gribaudo, I., Roberts, A.V. and Mottely, J. 1992. Paclobutrazol and reduced humidity improves resistance to wilting in micro propagated grapevine. *HortScience* 27: 111-113.

Stitt, M., Von Schaewen, A. and Willmitzer, L. 1990. 'Sink' regulation of photosynthetic metabolism in transgenic tobacco plants expressing yeast invertase in their cell wall involves a decrease of the Calvin-cycle enzymes and an increase of glycolytic enzymes. *Planta* 183: 40-50

Street, J.E., Jordan, J.H., Ebelhar, M.W. and Boykin, D.L. 1986. Plant height and yield response of rice to paclobutrazol. *Agronomy Journal* 78 (2): 288-291.

Takahashi, N. 1986. Plant growth substances in regulation of life cycle of higher plants. Proceedings International Symposium of Korean Weed Science Society. pp. 1-5.

Tekalign, T. and Hammes, P.S. 2005a. Response of potato grown in a hot tropical lowland to applied paclobutrazol. I: Shoot attributes, assimilate production and allocation. *New Zealand Journal of Crop and Horticultural Sciences* 33: 35-42.

Tekalign, T., Hammes, P.S. and Robbertse, P.J. 2005b. Paclobutrazol induced leaf, stem, and root anatomy modifications in potato. *HortScience* 40(4): 1-4.

Vavilove, W.I. 1951. The origin, variation, immunity and breeding of cultivated plants. The Ronalds Press Co., New York. pp. 37-38.

Yim, K.O., Kwon, Y.W. and Bayer, D.E. 1997. Growth responses and allocation of assimilates of rice seedlings by paclobutrazol and gibberellin treatment. *Journal of Plant Growth Regulation* 16: 35-41.

Young III, W.C., Chilcote, D.O. and Youngberg, H.W. 1996. Seed yield response of perennial ryegrass to low rates of paclobutrazol. *Agronomy Journal* 88: 951-955.

Young III, W.C., Chilcote, D.O. and Youngberg, H.W. 1999. Chemical dwarfing and the response of cool-season grass seed crops to spring applied nitrogen. *Agronomy Journal* 91: 344-350.

Zhou, W. and XI., H. 1993. Effects of mixatalol and paclobutrazol on photosynthesis and yield of rape (*Brassica napus*). *Journal of Plant Growth Regulation* 12: 157-161.

Feed Intake, Live Weight Gain and Carcass Yield Characteristics of Intact Hararghe Highland Male Goats Fed on Different Hay to Concentrate Ratios

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Abstract: Feed intake, live weight gain and carcass yield characteristics were studied using twenty-five yearling intact Hararghe highland male goats (17.6 ± 0.11 kg body weight) fed diets containing different hay to concentrate ratios, viz., 100:0, 80:20, 70:30, 60:40 and 50:50% for T1, T2, T3, T4 and T5, respectively, in a randomized complete block design experiment with five animals per treatment that lasted for 90 days. The amount of CP supplied was 3.73, 10.15, 13.36, 16.57 and 19.79% per kg DM and the ME (MJ/kg DM) was 6.64, 7.51, 7.95, 8.38 and 8.82 for the respective treatments. Dry matter and nutrient intakes were measured daily, while live weight gain and feed conversion efficiency were recorded at the weekly interval. At the end of the feeding trial, all goats from each treatment were fasted for 12 h and slaughtered after taking the slaughter weight of each goat. Measurements were also taken on empty body weight, hot carcass weight, dressing percentage (DP) and rib eye muscle area. Concentrate supplementation of goats resulted in high ($P < 0.05$) dry matter, crude protein and metabolizable energy intake, which was reflected in increased ($P < 0.05$) average daily weight gain (ADWG) and feed conversion efficiency (FCE). The empty body weight, hot carcass weight, DP and rib eye muscle area were higher ($P < 0.05$) for concentrate supplemented groups compared to those fed on hay alone. Goats on equal hay to concentrate ratio (T5) had higher empty body weight, hot carcass weight and rib eye muscle area when compared to those on T2 and T3. Different proportions of hay to concentrate did not affect the DP, but carcasses dressed from goats offered with concentrate feeds had higher ($P < 0.05$) percentages of lean and boneless meat, and lean: bone and lean + fat: bone ratios, but lower percentage of bone than the carcasses from goats fed hay alone. The percentage of boneless meat was similar between goats on T2, T4 and T5, while the percentage of total edible offal components was similar between supplemented and un-supplemented groups. The proportion of the gut content and total non-edible offal components decreased with the increasing concentrate level, while the percentage of the total saleable components increased. Correlation and regression analysis revealed a positive and significant ($P < 0.01$) relationship between dry matter intake ($r = 0.67$), slaughter weight ($r = 0.89$), hot carcass weight ($r = 0.90$), dressing percentage ($r = 0.70$), lean meat ($r = 0.95$) and rib-eye muscle area ($r = 0.92$) with the level of concentrate supplementation. However, there was a non-significant ($P > 0.05$) weak negative correlation ($r = –0.16$) between ADWG and the level of concentrate supplementation. Considering ADWG, FCE, DP and percentage of boneless meat, the diet with 20% concentrate level could be recommended for optimum live weight gain, feed conversion efficiency and carcass yield characteristics of goats.

Keywords: Body Weight Gain; Carcass Yield; Feed Intake; Hararghe Highland Goats; Hay to Concentrate Ratio

1. Introduction

In Ethiopia, the population of goats is estimated to be 13 million, which are distributed across varied agro-ecological zones (CSA, 2003). Goats are closely associated with poor households providing immediate cash income and animal protein source being widely consumed among the people owing to their comparative small size. In spite of the wide distribution of goats and acceptance of the goat meat, the level of on-farm productivity of goats in the smallholder production systems is very low with the average dressed carcass output of 8 kg per goat (FAO, 2001). The productivity of goats is constrained by a number of factors, among which seasonal fluctuations in quantity and quality of feeds is the major one (Aschalew *et al*., 2000). On the other hand, the demand for goat meat is rising due to population growth, urbanization andrisingincome (FAO, 1997), leading to frequent slaughtering of young and thinner animals. Meat production capacity of goats is higher when they are one to two years of age and slaughtering of goats at heavier weights could possibly be advantageous for producers by providing greater profits from meat sales, and for consumers by supplying matured meat with improved quality (Devendra and Burns, 1983; Manfredini *et al*., 1988). The declining demand for animal fat and the increased emphasis on red meat production also suggests a greater need for goat meat production (Ruvuna *et al*., 1992).

Improvement in the plane of nutrition by supplementation of concentrates or grains to fibrous feeds can promote faster daily live weight gain and thus enable the attainment of acceptable market weight at earlier age (Parthasarathy *et al*., 1984). Supplementation with cereal grains could usually put

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goat production in direct competition with human being. Instead, utilization of locally available agro-industrial by-products as supplementary feeds may be a feasible feeding system for stall-feeding of goats for commercial production and at the same time converting non-edible agro-industrial by-products into highly nutritious animal foods. This system would create possibilities of getting alternative feeds to ensure that the animals take complementary rather than a competitive part with man. Among the various agro-industrial by-products wheat bran, groundnut (*Arachis hypogeae*) cake and brewer's dried grain are believed to be important supplements for goats and are relatively cheap and readily available for urban and peri-urban goat producers living in the vicinity of oil extracting, flour milling and brewing plants.

Thus, this study was undertaken with the objectives of assessing the effects of feeding different levels of hay to concentrate ratios on the feed intake, live weight gain and carcass yield characteristics of yearling intact Hararghe Highland male goats.

2. Materials and Methods

2.1. Animals, Experimental Design and Treatments

The experiment was conducted at Haramaya University Dairy Goat Farm, located at an altitude of 1980 m.a.s.l, 9^o 24' N latitude and 41^o 5' E longitude (AUA, 1996). Twenty-five yearling intact Hararghe Highland male goats (17.6 ± 0.11 kg initial body weight) were used. The goats were drenched and sprayed against internal and external parasites, respectively. Animals were penned individually and allowed to adapt to the pens and feeds for 14 days prior to the commencement of the feeding trial, which lasted for 90 days. Goats were blocked into five groups based on their initial body weights and randomly assigned to one of the 5 feeding treatments, T1, T2, T3, T4 and T5, in randomized complete block design (RCBD).

2.2. Feeds and Feeding

The basal feed used in this experiment was grass hay dominated by *Hyparrhenia rufa* species, while the concentrate was composed of mixtures of 45% groundnut cake, 35% brewer's dried grain and 20% wheat bran on dry matter basis. The daily feed allowance was offered at the rate of 3.8% of the body weight on DM basis and the treatments consisted of feeding of 100% hay to 0% concentrate (T1), 80% hay to 20% concentrate (T2), 70% hay to 30% concentrate (T3), 60% hay to 40% concentrate (T4) and 50% hay to 50% concentrate (T5). The quantities of offers of hay and concentrate feeds amounted to 674 + 0, 539 + 132, 472 + 199, 404 + 266 and 337 + 337 g DM, whereas the CP contents were 37.3, 101.5, 133.6, 165.7 and 197.9 g/kg DM and the ME contents were 6.64, 7.51, 7.95, 8.38, 8.82 MJ/kg DM for the respective treatments.

Except for the control treatment, the CP level in concentrate supplemented groups was maintained to meet the nitrogen requirements of growing goats (ARC,1980). The daily amounts of hay and concentrate feeds were offered in separate troughs. The concentrate feed was offered once at 0800 h daily, whereas the hay was offered twice daily at 0800 and 1400 h. The amounts of feed offered and refused were recorded daily for each animal. Experimental goats had free access to clean water and mineral licks at all times.

Samples of feed offered were collected daily per treatment and samples of feed refused were taken daily for each animal. Sub-samples of feed offered and refused were then dried at 60^0C to constant weight, ground using a laboratory mill (Willey Mill, UK) to pass through a 1 mm mesh screen and pooled over the experimental period pending analysis.

Daily dry matter intake (DMI) was determined as a difference between the feed offered and refused. Animals were weighed weekly after overnight fasting using suspended scales with a sensitivity of 200 g. Initial and final live weights of animals were determined by weighing of animals at the start and end of the trials, respectively. The body weight gain was computed as a difference between the final and initial body weights divided by the number of experimental days.

2.3. Carcass Yield Characteristics

Goats in each treatment were fasted for about 12 hours and slaughtered immediately after taking the slaughter weight. After slaughter, the carcass was dressed as described by Ashbrook (1955). The blood was drained into bucket and weighed. After skinning and decapitation, external offal components (head and horn, skin and feet) and internal offal components (heart, trachea, lungs, liver, spleen, gall bladder, testis, penis, rectum, kidneys, omental fat, intestinal fat and kidney fat, pancreas and different parts of the gastrointestinal tract with contents) were separated from the carcass. The weight of the dressed carcass was taken as empty body weight, and the different parts of the gastrointestinal tract (rumen, reticulum, omasum, abomasum, small intestine and large intestine) were weighed with and without the contents. The weights of edible offal components (including liver, heart, kidneys, lungs, small intestine, reticulo-rumen, omaso-abomasum, omental fat, intestinal fat, kidney fat, blood and testicles) and non-edible offal components (spleen, head and horn, penis, gall bladder, gut content, pancreas, feet, rectum, tail, skin and large intestine) were also recorded. The carcass was cut longitudinally into two halves along the spine and weighed separately. The right half was weighed immediately as hot carcass weight, whereas the left half was chilled overnight at 4 ^{o}C and the chilled carcass was weighed and then separated into fore- and hindquarters which in turn were jointed into main tissue components, i.e. bone, muscle (lean) and fat. Both the right and left halves were cut between the 12th and 13th ribs perpendicular to the backbone as described by Ashbrook (1955) to measure the cross sectional area of the *longissimus dorsi* (rib-eye muscle). The cross section of the rib-eye muscle was traced onto a paper and the area of the squares that fell within the traced area was then counted. For the portions of the rib-eye muscle area that were less than a whole square, an estimated fraction value of the square was assigned. The average of the two (the right and left halves) was taken as the rib-eye muscle area.

2.4. Laboratory Analysis

Laboratory analysis of the experimental feeds was conducted at the International Livestock Research Institute (ILRI), Addis Ababa. Samples of feed offers and refusals were analyzed for dry matter (DM), ash, organic matter (OM), ether extract (EE) and nitrogen (N) according to procedures of AOAC (1990). Crude protein (CP) was estimated as N x 6.25. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were analyzed according to Van Soest *et al.* (1991). Gas production (GP) was determined following the procedure of Menke and Steingass (1988). Metabolizable energy (ME) was computed by prediction equations using the gas production technique (Menke and Steingass, 1988) as:
$ME = 2.20 + 0.1357\ GP + 0.0057CP + 0.0002859\ (EE)^2$ and $ME = 1.06 + 0.157GP + 0.0084CP + 0.0224EE - 0.0081TA$, for hay and concentrate feeds, respectively.
Where ME = Metabolizable energy (MJ/kg DM), GP = gas production (ml), CP = crude protein, EE = ether extract, TA = total ash.

2.5. Statistical Analysis

Data were subjected to analysis of variance using the general linear model (GLM) procedure SAS (1998) software. Treatment means were separated by least significant difference (LSD). The relationship between the response variables and the level of concentrate supplementation was analyzed using correlation and regression analysis.

3. Results and Discussion

3.1. Feed and Nutrients Intake, and Body Weight Gain

The control diet was characterized by its low CP, EE, ME and GP, and high ash, NDF and ADF contents (Table 1). The CP and ME contents of the control diet were too low to meet the maintenance requirements of growing goats.

Table 1. Chemical composition, metabolizable energy content and gas production of the experimental feeds

Chemical components	Treatments				
	T1	T2	T3	T4	T5
DM (%)	91.77	91.69	91.65	91.61	91.57
Ash (% DM)	8.62	7.83	7.43	7.03	6.64
OM (% DM)	91.38	92.17	92.57	92.97	93.37
EE (% DM)	1.23	2.34	2.89	3.44	4.00
CP (% DM)	3.73	10.15	13.36	16.57	19.79
NDF (% DM)	70.67	66.31	64.13	61.95	59.77
ADF (% DM)	48.32	42.58	39.70	36.83	33.96
ADL (% DM)	4.69	4.73	4.75	4.77	4.79
ME (MJ/kg DM)	6.64	7.51	7.95	8.38	8.82
GP (ml)	16.36	40.21	42.76	45.25	47.80

DM, dry matter; OM, organic matter; EE, ether extract; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; CP, crude protein; ME, metabolizable energy; GP, gas production.

On the other hand, concentrate supplementation increased the amounts of CP,EE,ME,GP, and reduced the contents of ash, NDF and ADF. The CP and ME contents were within the recommended ranges of CP and ME requirements of growing of tropical goats (ARC, 1980).

The mean daily DMI of goats was significantly different ($P < 0.05$) among treatments (Table 2).

Table 2. Dry matter and nutrient intakes and body weight change of yearling intact Hararghe Highland male goats fed with different hay to concentrate ratios

Parameters	Treatment					SEM
	T1	T2	T3	T4	T5	
Total DM intake (g/d)	478.60^{b}	519.60^{b}	492.10^{b}	522.60^{ab}	580.00^{a}	20.054
Total DM intake, g/kg MBW	55.59^{a}	56.49^{a}	54.40^{a}	56.28^{a}	60.85^{a}	1.677
Total DM intake, % BW	2.71^{a}	2.70^{a}	2.61^{a}	2.68^{a}	2.87^{a}	0.075
Nutrient intake						
NDF intake (g/d)	338.21^{a}	338.42^{a}	304.37^{a}	311.07^{a}	337.46^{a}	14.140
ADF intake (g/d)	231.30^{a}	213.20^{ab}	180.60^{c}	176.00^{c}	185.00^{bc}	9.671
CP intake (g/d)	17.85^{e}	61.75^{d}	82.32^{c}	104.90^{b}	128.10^{a}	0.078
Energy intake (MJ ME/d)	3.18^{d}	4.02^{c}	4.14^{bc}	4.63^{b}	5.30^{a}	0.133
Initial BW (kg)	17.70^{a}	17.70^{a}	17.65^{a}	17.55^{a}	17.40^{a}	0.110
Final BW (kg)	17.65^{c}	20.80^{b}	20.20^{b}	21.60^{ab}	23.10^{a}	0.620
Average daily gain/loss (g/d)	-0.56^{c}	34.44^{b}	28.33^{b}	45.00^{ab}	63.33^{a}	6.498
FCE (g feed DMI/g BW gain)	137.40^{b}	15.67^{a}	19.79^{a}	13.75^{a}	9.55^{a}	9.660

$^{a, b, c, d, e,}$ Means within the same row not bearing a common superscript letter differ at P < 0.05; DM, dry matter; CP, crude protein; SEM, standard error of mean; BW, body weight; MBW, metabolic body weight; FCE, feed conversion efficiency.

The DMI as percentage of body weight in all of the groups was within the range of the reported values of 1.7 to 4.8% of body weight for various breeds of goats in the tropics (Devendra and Burns, 1983). However, the DMI per kg metabolic BW of goats in T2, T3, T4 and T5 (Table 2) was higher than the value (54.2 g/kg MBW) reported by Pralomkarn *et al*. (1995) for Thai native male goats fed on concentrate-based diets. Getahun (2001) reported slightly higher DMI of 68.03 and 64.66 g/kg metabolic BW, under intensive management system for local Somali and Mid-Rift Valley goats, respectively. Similar amounts of DMI between goats fed with high and low energy diets had been also reported (Shahjalal *et al.,* 1992). Correlation and regression analysis indicated a positive and significant ($P < 0.01$) relationship between DMI and the level of concentrate supplementation (r=0.67).

No significant differences were observed in NDF intake, while the ADF intake of goats in T1 was found to be higher ($P < 0.05$) than the intakes recorded in T3, T4 and T5. McDonald *et al*. (2002) reported that NDF and ADF contents feeds reflect their voluntary intake and digestibility. There was a significantly ($P < 0.01$) increasing trend in CP and energy intakes with the increase in the concentrate level, the highest being in T5 and the lowest in T1 ($P < 0.01$). Goats supplemented with 20, 30, 40 and 50% concentrate levels were receiving CP levels of 2.97, 4.08, 4.88 and 5.55 per kg of metabolic body weight and per day, respectively, which were above their maintenance requirement. While the goats fed with hay only were receiving CP level of 1.01 per kg of metabolic body weight and per day, which was not meeting even their maintenance requirement. Also the energy intake of T1 was below the maintenance requirement as compared to goats in T3, T4 and T5. Devendra and Burns (1983) reported that the protein requirement of goats from tropical Africa averages 2.20 DCP per kg of metabolic body weight and per day.

Concentrate supplementation promoted daily live weight gain while feeding hay only resulted in body weight loss (Table 2). The loss in body weight of goats in T1 of the current study might be attributed to the higher ADF and lower CP and energy intakes. This is in agreement to the explanation made by McDonald *et al*. (2002) in that rumination and fermentation are slow processes, and fibrous feeds may have to spend a long time in the digestive tract for their digestible components to be extracted, posing difficulty to ruminants in processing bulky feeds despite their adaptation to utilize such feeds. In effect, ruminants could hardly meet their nutrient requirements from such types of feeds. There was no significant ($P > 0.05$) difference in feed conversion efficiency (FCE) among the concentrate fed groups. The high mean daily body weight gain of the goats on concentrate-supplements was in agreement with the findings of Galal and Kassahun (1981) in local highland goats supplemented with concentrates. The higher daily gains of concentrate-supplemented goats at the daily energy intake levels ranging from 4.02 to 5.30 MJ ME per animal revealed that the goats of this particular breed might require less energy for maintenance than the recommended for different breeds of goats. On the other hand, increasing the concentrate level in the diet resulted in a significant ($P < 0.05$) improvement in daily live weight gain in this study, which was comparable to the values reported for local Mid-Rift Valley and Somali goats (Getahun, 2001). However, correlation and regression analysis revealed a non-significant (P > 0.05) weak negative association (r= –0.16) between ADWG and the level of concentrate supplementation.

3.2. Carcass yield

The carcass yield of goats as measured by the average values of rib-eye muscle area was superior for concentrate-supplemented groups (Table 3).

Table 3. Effects of feeding different hay to concentrate ratios on some slaughter traits in yearling intact Hararghe Highland goats

Slaughter traits	Treatments					SEM
	T1	T2	T3	T4	T5	
SW (kg)	17.55^{c}	21.00^{b}	20.20^{b}	21.80^{ab}	23.20^{a}	0.600
EBW (kg)	12.78^{d}	17.00^{bc}	16.76^{c}	18.48^{ab}	19.83^{a}	0.510
HCW (kg)	6.65^{c}	9.60^{b}	9.55^{b}	10.20^{ab}	10.85^{a}	0.328
DPSW	37.79^{b}	45.82^{a}	47.30^{a}	46.70^{a}	46.70^{a}	0.840
DPEBW	51.99^{b}	56.56^{a}	57.02^{a}	55.10^{a}	54.66^{a}	0.800
REA (cm^2)	5.20^{c}	7.60^{b}	7.58^{b}	8.70^{a}	8.80^{a}	0.236

^{a,b,c,d,} Means within a row with different superscript letters are different at P < 0.05. SW, slaughter weight; EBW, empty body weight; HCW, hot carcass weight; DPSW, dressing percentage on slaughter weight basis; DPEBW, dressing percentage on empty body weight basis; REA, rib-eye muscle area; SEM, standard error of mean.

The slaughter weight and empty body weight of goats in all the groups offered with concentrate supplements were significantly heavier (P < 0.01) than the control group. Goats in T5 showed significantly higher empty body weight (P < 0.01) and heavier hot carcass weight (P < 0.05) compared with the other groups except those in T4. There was positive and significant (P < 0.01) relationship between slaughter weight (r = 0.89) as well as hot carcass weight (r = 0.90) with the level of concentrate supplementation.

Goats supplemented with concentrates had significantly higher (P < 0.01) DP compared to those fed on hay alone, but the level of concentrate had no significant effect (P > 0.05) on DP. The high (P < 0.05) DP of goats supplemented with concentrate mixtures as compared to those raised on hay only was in agreement to the findings of Warmington and Kirton (1990) who reported the effect of nutrition on DP through variation in weight of gut contents or variation in actual organ weights, but contradicted with the results of Misra and Prasad (1996), who reported similar DP for goats supplemented with concentrates and those fed with roughages only. The DP for concentrate-supplemented groups was higher than the values reported by Getahun (2001) for Somali (41.34%) and Mid-Rift Valley (41.79%) goats raised on concentrate-based diets. Dressing percentages of 45.5, 43.5, 45.4 and 45.2 were recorded for Afar, Long eared Somali, Arsi-Bale and Woyto-Guji goats, respectively (Addisu, 2001), which were relatively lower than the values recorded for the concentrate fed groups in the present study. On the other hand, DP as high as 56.2–62.9% in local Somali goats fed on a high plane of nutrition had been reported (Girma, 2000). The variations in DP reported in the present study and other similar experiments might be related with the differences in the breed of goats and in the plane of nutrition. Correlation and regression analysis revealed a positive and significant (P < 0.01) relationship between DP and the level of concentrate supplementation (r = 0.70).

Goats receiving concentrate had a significantly larger (P < 0.01) rib-eye muscle area than those not offered concentrate, confirming the fact that goats on high plane of nutrition produced carcass with larger proportion of lean meat and deposited less fat in the carcass. According to Ashbrook (1955), the rib-eye muscle area gives an indirect estimate of body musculature and the ability of animals to put relatively more flesh on the rib-eye muscle area. Moreover, goats in T4 and T5 had significantly larger (P < 0.01) rib-eye muscle area than the animals in the remaining groups. The values of rib-eye muscle area in concentrate-supplemented groups were superior to the values of 6.5 cm^2 for fattened and 4.03 cm^2 for un-fattened yearling Sudan desert entire male goats (Gaili *et al*., 1972). There was positive and significant (P < 0.01) relationship between the rib-eye muscle area (r = 0.92) and the level of concentrate supplementation.

3.3. Carcass Tissue Components

The weight of the left half cold carcass was heavier in goats fed equal proportions of hay and grass (T5) compared to those in T1, T2 and T3 (Table 4).

The weight of forequarter, hindquarter and lean were significantly (P < 0.01) higher from the goats offered with concentrate compared to those fed with hay only. Goats in T5 yielded higher (P < 0.01) lean meat than the animals in T1, T2 and T3, while goats in T2, T3 and T4 also produced more (P < 0.05) amounts of lean tissue than those in T1. Similarly, carcasses from goats supplemented with concentrate produced higher percentage of lean (P < 0.05), but carcasses from goats in T2, T3 and T4; T4 and T5 contained the same (P > 0.05) percentage of lean. Correlation and regression analysis revealed also a positive and significant (P < 0.01) relationship between the lean meat (r = 0.95) and the level of concentrate supplementation.

Table 4. Effects of feeding different hay to concentrate ratios on left half-carcass tissue components in yearling intact Hararghe Highland goats

Tissue components	Treatments					SEM
	T1	T2	T3	T4	T5	
Left half (kg)	3.50^{c}	4.70^{b}	4.80^{b}	5.15^{ab}	5.45^{a}	0.170
Forequarter (kg)	1.95^{c}	2.70^{b}	2.68^{b}	2.87^{b}	3.35^{a}	0.156
Hindquarter (kg)	1.55^{b}	2.05^{a}	2.12^{a}	2.22^{a}	2.15^{a}	0.071
Lean (kg)	2.28^{c}	3.29^{b}	3.28^{b}	3.64^{ab}	4.07^{a}	0.158
Lean (%)	64.90^{c}	70.04^{b}	68.54^{b}	70.67^{ab}	74.50^{a}	1.453
Bone (g)	848.40^{a}	901.80^{a}	964.2^{a}	892.00^{a}	918.80^{a}	44.838
Bone (%)	24.43^{a}	19.28^{bc}	20.06^{b}	17.32^{bc}	16.94^{c}	1.020
Fat (g)	374.20^{b}	509.20^{a}	531.8^{a}	567.40^{a}	573.40^{a}	37.144
Fat (%)	10.77^{a}	10.78^{a}	11.09^{a}	11.09^{a}	10.55^{a}	0.860
Boneless meat (kg)	2.65^{c}	3.80^{b}	3.82^{b}	4.20^{ab}	4.64^{a}	0.163
Boneless meat (%)	75.67^{c}	80.82^{ab}	79.63^{b}	81.76^{ab}	85.06^{a}	1.540
Fat: lean	0.17^{a}	0.15^{a}	0.16^{a}	0.16^{a}	0.14^{a}	0.014
Lean: bone	2.70^{c}	3.67^{b}	3.51^{b}	4.09^{ab}	4.41^{a}	0.231
Fat: bone	0.45^{a}	0.57^{a}	0.56^{a}	0.64^{a}	0.62^{a}	0.047
Lean + fat: bone	3.14^{c}	4.24^{b}	4.06^{b}	4.73^{ab}	5.03^{a}	0.253

^{a,b,c,} *Means within a row with different superscript letters are different at P < 0.05. SEM, standard error of mean.*

Devendra and Owen (1983) observed that lean carcass composition of goats to be about 60%, although relatively higher values of 63.6% in Iraqi black goats (Tahir *et al*., 1994) and 68.2% in Omani Batina goats (Mahgoub and Lodge, 1996) had been reported. Exceptionally lower lean meat values of 55.3 and 59% had also been recorded in local Somali and Mid-Rift Valley goats, respectively (Getahun, 2001).

No significant (P > 0.05) effect of plane of nutrition was observed on the weight of bone jointed from the carcass. However, the percentage of bone was higher (P < 0.01) for goats in T1 as compared to carcasses from the other groups. Goats fed with concentrates had higher (P < 0.05) lean: bone and lean + fat: bone ratios compared to those fed with hay only, whereas goats in T2, T3 and T4 groups and T4 and T5 groups had nearly equal (P > 0.05) lean: bone and fat + lean: bone ratios.

The percentage of bone in the present study was lower than that of Somali (31%) and Mid-Rift Valley (30.2%) goats (Getahun, 2001), but higher than the values reported by Mahgoub and Lodge (1996) for Omani Batina goats (13.9%). Carcass evaluation study by Ruvuna *et al*. (1992) showed 18% bone from 14.7 months old intact crossbred male goats. Warmington and Kirton (1990) noted an average bone percentage of 21.7 from eight goat breeds. Both of these reports are in agreement with the present finding. However, carcass composition of 34.2% bone was also recorded in Iraqi black goats (Tahir *et al*., 1994), which is higher than the present finding.

The weight of fat was significantly (P < 0.05) lower in T1 when compared to the concentrate-supplemented groups. The level of concentrate-supplement had no effect (P > 0.05) on % fat content, confirming the fact that goats have less potential to deposit fat in the carcass. The carcass fat percentage in this study was higher than the value (9.3%) reported by Warmington and Kirton (1990), but lower fat percentage of 2.1 were noted in Iraqi black goats (Tahir *et al*., 1994). Unlike the percentage of boneless meat, the fat percentage was significantly lower ($P < 0.05$) for goats fed with hay only compared with those fed with concentrate.

3.4. Edible Offal Components

Plane of nutrition resulted in a significant ($P < 0.05$) effect on most of the edible offal components. Kidney fat and omental fat of goats offered with concentrate supplements were heavier ($P < 0.01$) than those from goats in T1 (Table 5).

Table 5. Effects of feeding different hay to concentrate ratios on edible offal components in yearling intact Hararghe Highland goats

Components	Treatments					SEM
	T1	T2	T3	T4	T5	
Kidney fat (g)	49.72^{b}	125.60^{a}	150.40^{a}	153.60^{a}	150.00^{a}	11.397
Omental fat (g)	79.20^{d}	144.50^{c}	207.60^{b}	207.80^{b}	237.60^{a}	8.288
Intestinal fat (g)	98.12^{c}	105.60^{bc}	127.60^{ab}	127.90^{ab}	153.50^{a}	9.165
Total visceral fat (g)	227.00^{c}	375.70^{b}	485.60^{a}	489.30^{a}	541.10^{a}	20.340
Blood (g)	550.80^{a}	717.20^{a}	718.40^{a}	776.40^{a}	790.80^{a}	57.190
Kidneys (g)	49.90^{c}	56.70^{b}	59.20^{b}	69.02^{a}	66.20^{a}	1.807
Liver (g)	217.60^{b}	284.50^{ab}	365.60^{a}	333.04^{a}	377.08^{a}	31.251
Lungs (g)	139.90^{b}	163.08^{a}	158.40^{ab}	169.72^{a}	178.12^{a}	6.730
Heart (g)	63.84^{b}	82.12^{a}	84.80^{a}	81.74^{a}	94.48^{a}	5.167
Testicles (g)	77.20^{c}	174.38^{ab}	140.40^{b}	200.3^{a}	185.20^{ab}	17.000
Ret-rum. (g)	444.68^{a}	463.6^{a}	369.06^{a}	419.32^{a}	446.40^{a}	33.381
Oma-abom. (g)	147.38^{a}	144.4^{a}	128.94^{a}	137.26^{a}	134.00^{a}	7.770
Small intestine (g)	293.28^{b}	362.8^{a}	388.4^{a}	388.5^{a}	394.58^{a}	20.381
Total EO (kg)	2.212^{c}	2.824^{b}	2.899^{ab}	3.059^{ab}	3.208^{a}	0.115
Total EO (%)	12.63^{a}	13.46^{a}	14.38^{a}	14.08^{a}	13.78^{a}	0.426
Total edible (%)	50.42^{c}	56.85^{b}	62.15^{a}	60.78^{a}	60.51^{ab}	0.928

[a,b,c,d,] *Means within a row with different superscript letters are different at $P < 0.05$. EO, edible offal; Ret-Rum., reticulo-rumen; Oma-abom., omasso-abomasum.*

All the concentrate-supplemented groups produced nearly equal amount ($P > 0.05$) of kidney fat, but goats in T5 produced higher ($P < 0.05$) omental fat than those in T2, T3 and T4. Moreover, goats receiving the concentrate diet, except at 20% concentrate level, produced significantly higher ($P < 0.05$) intestinal fat than the animals in T1 though no differences ($P > 0.05$) were observed among those in T3, T4 and T5; and T2, T3 and T4. Goats in T3, T4 and T5 produced higher ($P < 0.01$) visceral fat (intestinal fat + kidney fat + omental fat) compared to those in T1 and T2. The results of this study substantiated the common understanding that goats deposit visceral fat when offered feeds that promote fat deposition.

The weights of blood, reticulo-rumen, omaso-abomasum and percentage of total edible offal components of the different groups did not differ ($P > 0.05$), whereas the weights of kidneys, heart, testicles, small intestine and total edible offal components were significantly higher ($P < 0.05$) in concentrate-supplemented groups than those raised on hay only.

In agreement with the present finding, Almedia *et al*. (2000) pointed out that under-nutrition created a detrimental effect on the weights of heart, liver and most of the carcass portions in young Boer goats. Considering the weight of total edible offal components, goats raised on concentrates were found to be superior ($P < 0.05$) to the goats raised only on hay. Increasing concentrate level resulted in an increase in the weight of total edible offal components, but no significant ($P > 0.05$) differences were observed between T2, T3 and T4 as well as between T3, T4 and T5. Addisu (2001) reported edible offal components of 15 and 16.5% for local Arsi-Bali and Afar goats in Ethiopia. Similarly, Verma *et al*. (1996) reported 16.2 to 17.1% edible offal components on slaughter weight basis for local goat breeds in India.

The disparities in the edible offal percentages in different findings might be partly due to differences in inclusion of individual offal in the edible proportion. For instance Verma *et al.* (1996) considered head and feet as edible offal components, which were considered as inedible in the present study. Accordingly, in comparing different findings of offal components all the parts considered, as edible should be clearly mentioned. The proportion of total edible components (carcass + edible offal) in this study was similar to the values reported for local Somali and Mid-Rift Valley goats supplemented with concentrates (Getahun, 2001).

3.5. Non-edible Offal Components

Goats offered with hay only had higher (P < 0.05) weights or percentages of gut contents and percentage of total non-edible offal components than the goats supplemented with concentrate (Table 6).

Table 6. Effects of feeding different hay to concentrate ratios on non-edible offal components in yearling intact Hararghe Highland goats

Components	Treatments					SEM
	T1	T2	T3	T4	T5	
Spleen (g)	16.84^{c}	26.36^{b}	32.4^{ab}	33.48^{ab}	36.8^{a}	2.850
RR-OA content (kg)	3.921^{a}	3.342^{ab}	2.848^{bc}	2.552^{c}	2.740^{bc}	0.204
Large intestine (g)	208.74^{b}	219.2^{b}	214.04^{b}	281.64^{a}	289.2^{a}	15.096
Gut content (kg)	4.774^{a}	3.998^{b}	3.437^{bc}	3.318^{c}	3.369^{bc}	0.218
Gut content (%)	27.34^{a}	18.98^{b}	17.02^{bc}	15.30^{c}	14.49^{c}	0.855
Skin (kg)	1.133^{c}	1.722^{b}	1.715^{b}	1.748^{b}	2.089^{a}	0.081
Feet (g)	482.8^{a}	510.4^{a}	508.00^{a}	497.2^{a}	523.60^{a}	13.420
Tail (g)	24.4^{a}	28.54^{a}	29.60^{a}	34.4^{a}	30.00^{a}	2.330
Total NEO (kg)	8.046^{a}	8.147^{a}	7.564^{a}	7.846^{a}	8.169^{a}	0.267
Total NEO (%)	45.98^{a}	38.74^{b}	37.52^{bc}	36.18^{bc}	35.25^{c}	0.950

^{a,b,c,d,} Means within a row with different superscript letters are different at P < 0.05. NEO, non-edible offal; RR-OA content ; reticulo-rumem omaso-abomasum content.

On the other hand, the weights of skin and spleen were significantly (P < 0.05) lower in goats fed only on hay. Unlike the gut content and percentage of total non-edible offal components, the weight of spleen increased as the concentrate level increased even if no significant differences (P > 0.05) were recorded among T2, T3 and T4; T3, T4 and T5. The weight of feet, tail and total non-edible offal components were the same (P > 0.05) irrespective of the concentrate proportion.

The decreasing trend of gut content with increasing concentrate level might be attributed to the relatively higher rate of digestion and faster passage rate of the diet through the tract (Misra and Prasad, 1996). In agreement with the present finding, Gaili *et al*. (1972) concluded that the gut content (digestive tract) as a proportion of live weight decreased significantly in goats fed with high quality diet. Hatendi *et al*. (1990) reported gut content varying from 10 to 23% of live weight in Botswana goats; recently Getahun (2001) also reported 18.5 and 15% gut contents in local Somali and Mid-Rift Valley goats, respectively.

4. Conclusions

Concentrate supplementation up to the level of 50% of the total diet did not result in improved DM intake(g/kg MBW and %BW) but increased nutrient intake and daily body weight gain of yearling intact Hararghe Highland male goats. Concentrate supplementation improved carcass yield characteristics as measured by slaughter weight, empty body weight, hot carcass weight, dressing percentage and rib-eye muscle area, edible and non-edible offal components and yielded carcasses having higher percentages of lean and boneless meat, but lower percentage of bone as compared to goats fed on grass hay alone. Supplementation did not have a significant effect on the percentage of carcass fat, fat: lean and fat: bone ratios, but resulted in higher lean: bone and lean + fat: bone ratios than those fed hay alone. Supplementation of yearling Hararghe Highland goats with different hay to concentrate ratios produced also higher weights of visceral fat but the percentage of total edible offal components was not affected. The gut content and total non-edible offal components decreased with the increasing the concentrate level. Correlation and regression analysis revealed a positive and significant (P < 0.01) relationship between dry matter intake (r = 0.67), slaughter weight (r = 0.89), hot carcass weight (r = 0.90), dressing percentage (r = 0.70), lean meat (r = 0.95) and rib-eye muscle area (r = 0.92) with the level of concentrate supplementation. However, there was a non-significant ($P > 0.05$) weak negative correlation ($r = -0.16$) between ADWG and the level of concentrate supplementation. Considering the fact that the concentrate supplementation levels did not result in the improvement of anyone of the parameters studied, the diet with 20% concentrate level could be considered as economically feasible and affordable level of supplement for the majority of the smallholder farms in the diets of yearling intact Hararghe Highland goats.

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6. References

Addisu, A. 2001. A comparative study on slaughter components with emphasis on edible offal of some indigenous goat types. MSc Thesis. Alemaya University, Alemaya, Ethiopia. 94 p.

Almedia, A.M., Schwalbach, L.M., Cardoso, L.A. and Greyling, J.P.C.. 2000. The effect of under-nutrition on carcass characteristics in young Boer goat bucks. International Conference on goats, 15-21 May 2000, France. p. 668.

AOAC (Association of Official Analytical Chemists). 1990. Official Methods of Analysis, 15th ed. Association of Official Analytical Chemists, Washington DC.

ARC (Agricultural Research Council). 1980. The Nutrient Requirement of Ruminant Livestock. Common Wealth Agricultural Bureaux, Slough, England.

Ashbrook, F.G., 1955. Butchering, Processing and Preservation of Meat. D-Van Nostrand Company, Inc., London. pp.105-151.

Aschalew, T., Sisay, L., Ameha, S., Abebe, M. and Zinash, S., 2000. National goat research strategy in Ethiopia. *In*: Merkel, R.C., Girma Abebe and Goetsch A.L, (eds.). The opportunities and challenges of enhancing goat production in East Africa. 10-12 November 2000, Debub University, Awassa, Ethiopia. pp.1-5.

AUA (Alemaya University of Agriculture). 1996. Proceeding of the 13th annual research and extension review meeting, Alemaya University of Agriculture, February 26-28, 1996, Alemaya, Ethiopia.

CSA (Central Statistical Authority). 2003. Agricultural sample survey statistical bulletin, Addis Ababa, Ethiopia.

Devendra, C. and Burns, M. 1983. Goat Production in the Tropics. 2nd edition. Commonwealth Agricultural Bureaux, UK. P.56.

Devendra, C. and Owen, J.E. 1983. Quantitative and qualitative aspects of meat production from goats. *World Animal Review* 47:19-29.

FAO (Food and Agricultural Organization), 1997. Tree Foliage in Ruminant Nutrition. FAO Animal Production and Health Paper 139. FAO, Rome, Italy. p. 2.

FAO (Food and Agricultural Organization). 2001. Production yearbook. Vol. 55. FAO, Rome, Italy.

Galal, E.S.E. and Kassahun, A. 1981. The effect of roughage-concentrate ratio on fattening performance in goat kids. *In*: Nutrition and systems of goat feeding symposium. Tours, France, 12-15 May 1981, pp. 363-368.

Gaili,, E.S.E., Ghanem, Y.S. and Mukhtar, A.M.S.1972. A comparative study of some carcass characteristics of Sudan Desert sheep and goats. *Animal Production* 14:351-357.

Getahun, L. 2001. Growth pattern and carcass characteristics of Somali and Mid-Rift Valley goats. MSc thesis. Alemaya University, Alemaya, Ethiopia. 123 p.

Girma, A. 2000. Carcass characteristics of Somali goats slaughtered at different ages. *In*: Seventh International Conference on goats, 15-21 May 2000, France. p.829

Hatendi, P.R., Smith, T., Ndlovu, L. and Mutisi, C. 1990. Fattening mature indigenous (Matabele) goats: Effects on animal performance, body and carcass composition. *In*: Proceedings of the first Biennial Conference of the African Small Ruminant Research Network, Nairobi, Kenya, 10-14 December 1990, ILCA, Kenya. pp. 355-365.

Mahgoub, O. and Lodge, G.A. 1996. Growth and body composition in meat production of Omani Batina goats. *Small Ruminant Research* 19(3): 233-246.

Manfredini, M., Massari, M., Cavani, C. and Falaschini, F. 1988. Carcass characteristics of male Alpine kids slaughtered at different weights. *Small Ruminant Research* 1:49-58.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D. and Morgan, C.A. 2002. Animal Nutrition. 6th ed. Prentice Hall, London. pp. 471-581.

Menke, K.H. and Steingass, H. 1988. Estimation of the energetic value obtained from chemical analysis and *in vitro* gas production using rumen fluid. *Animal Research Division* 28: 7-55.

Misra, R.K and Prasad, V.S.S. 1996. Studies on carcass characteristics of goats at different ages and feeding systems. *Indian Veterinary Journal* 73: 150-153.

Ruvuna, F., Taylor, J.F., Okeyo, M., Wanyoike, M. and Ahuya, C. 1992. Effects of breed and castration on slaughter weight and carcass composition of goats. *Small Ruminant Research* 7: 175-183.

Parthasarathy, M., Singh, D. and Rawat, P.S. 1984. Performance of feedlot kids on different dietary regimen. *Indian Journal of Animal Science* 54 (1): 130-131.

Pralomkarn, W., Kochapakdee, S., Saithanoo, S. and Norton, B.W. 1995. Energy and protein utilization for maintenance and growth of Thai native and Anglo-Nubian x Thai native male weaner goats. *Small Ruminant Research* 16(1): 13-20.

SAS. 1998.Version 7. Guide to personal computers. Cary, NC: Statistical Analysis Systems Institute.

Shahjalal, M., Galbraith, H. and Topps, J.H. 1992. The effect of changes in dietary protein and energy on growth, body composition and mohair fibre characteristics of British Angora goats. *Animal Production* 54:405-412.

Tahir, M.A., Al-Jassim, A.F. and Abdulla, A.H.H. 1994. Influence of live weight and castration on distribution of meat, fat and bone in the carcass of goats. *Small Ruminant Research* 14(3): 219-223.

Van Soest, P.J., Robertson, J.B. and Lewis, B.A. 1991. Methods for Dietary Neutral Detergent Fiber and Non-starch Polysaccharides in Relation to Animal Nutrition. *Journal of Dairy Science* 74: 3583-3597.

Verma, A.K., Sastry, V.R.B. and Agrawal, O.K. 1996. Chevon characteristics of goats fed diets with water washed neem (*Azadirachta indica*) seed kernel cake. *Small Ruminant Research* 19 (1): 55-61.

Warmington, B.G. and Kirton, A.H. 1990. Genetic and non-genetic influences on growth and carcass traits of goats. *Small Ruminant Research* 3: 147-165.

Impact of Area Enclosures on Density and Diversity of Large Wild Mammals: The Case of May Ba'ati, Douga Tembien District, Central Tigray, Ethiopia

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Abstract: In Ethiopian highlands, area enclosures have been established on degraded areas for ecological rehabilitation. However, information on the importance of area enclosures in improving wild fauna richness is lacking. Thus, this study was conducted to assess the impact of enclosures on density and diversity of large wild mammals. Direct observations along fixed width transects with three timings, total counting with two timings, and pellet drop counts were used to determine population of large wild mammals. Regression analysis and ANOVA were used to test the significance of the relationships among age of enclosures, canopy cover, density and diversity of large wild mammals. The enclosures have higher density and diversity of large wild mammals than adjacent unprotected areas. The density and diversity of large wild mammals was higher for the older enclosures with few exceptions. Diversity of woody species also showed strong relationship (r^2 = 0.77 and 0.92) with diversity of diurnal and nocturnal wild mammals. Significant relationship (at $p<0.05$) was observed between age and density as well as among canopy cover, density and diversity of large nocturnal wild mammals. The existence of both large carnivore and herbivore wild mammals indicated the effectiveness of area enclosures in biodiversity conservation. However, for further improvement of the habitat and thereby biodiversity, development of water points and vegetation management are timely needed.

Key words: Area Enclosure; Density; Diversity; Ethiopia; Large Wild Mammal

1. Introduction

Ethiopia is renowned for its richness in biodiversity. The biological diversity is made up of an estimated total of 6500–7000 plant species of which 12 are endemic. There are also 255 identified mammals, 861 birds, 201 reptiles, 63 amphibians, 150 fish and 324 butterfly species of which 31 mammals and 16 birds are endemic (Groombridge and Jenkins, 1994; EWNHS, 1996; FDRE, 2001). The degradation of these resources is widespread and severe. The major causes include land clearing for agriculture and lack of recognition of the roles and rights of local communities in the conservation and use of biological resources (FDRE, 2001).

Tigray contains many of the areas of greatest land degradation concern in Ethiopia's highlands (Fitsum *et al*., 1999). The natural forest of the region has been destroyed mainly through encroachment of subsistence cultivation. Crop production and animal husbandry potential of the region has declined severely mainly due to the degradation of natural resources (Tassew 1995; Wolde , 2004).

However, Tigray is known not only for the severity of land degradation but also since the last few years, for the concerted efforts taking place there to redress these problems including construction of stone terraces and soil bunds, area enclosure and afforestation (Fitsum *et al*., 1999). In the places where area enclosures are established particularly in the Northern part of the country, area enclosures are among the green spots with considerable species diversity (TIC, 1999; Tefera , 2001; Betru *et al*., 2005).

In enclosures, it is generally believed that all the land resources will be protected from degradation. Although the restoration and buffering effects of area enclosures have been well studied (Kindeya , 2003; Aerts *et al*., 2004, and Descheemaker *et al*., 2005), there is no study that offers quantitative information that helps to compare area enclosures with the unprotected areas with respect to wild fauna. Therefore, this study is initiated to generate quantitative information and thereby to see whether area enclosures have impact on the density and diversity of large wild mammals or not.

2. Materials and Methods

2.1. Description of the Study Area

Enclosures with ages 8, 10, 22, 29 years and a church forest were selected at May Ba'ati, located in Douga Tembien Wereda(district), central Tigray, Ethiopia (Figure 1).

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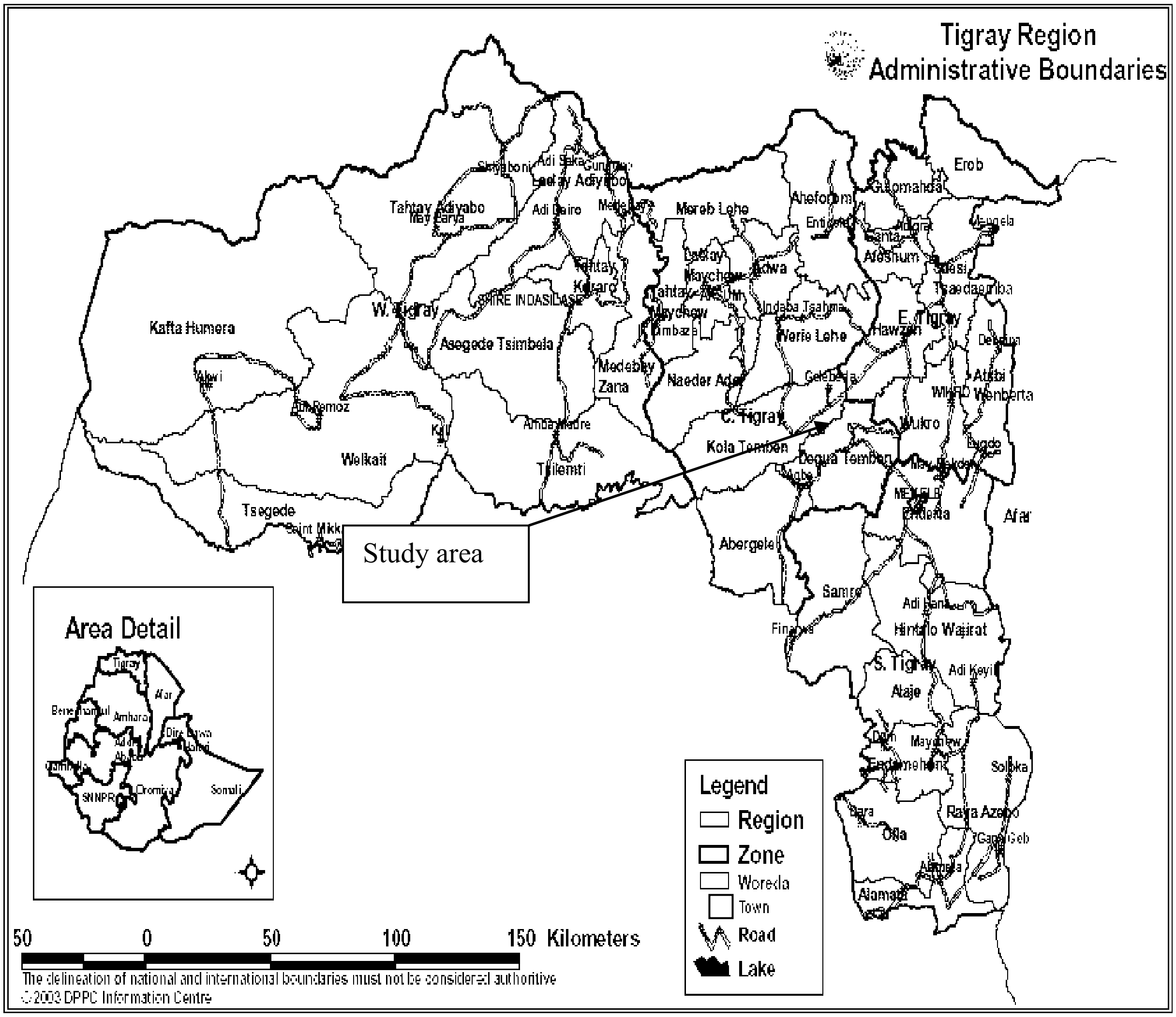

Figure 1. Location of the study area
(Source:http:www.reliefweb.int/rw/rwb.nsf/0/adbeaa25dfc96d21c1256f2d004849f2?opendocument)

May Ba'ati (13° 38' 52" N, 39° 13' 15" E) is situated at altitude ranging from 2300 to 2380 m a. s. l. The population is mainly rural, as is more than 90% of the Ethiopian population (Nyssen, 2001). The study area falls in the boundary between the "dry weyna dega" and "moist dega" (Sarah , 2003). Mean annual rainfall in the study area is 700 mm. There are natural springs that serve as source of drinking water for the dwellers and their cattle.

Euclea racemosa subsp. *schimperi, Dodonea angustifolia*, *Acacia etbaica,* and *Acokanthera schimperi* are the abundant plant species in the study area. *Acacia saligna* and *Eucalyptus tereticornis* were some of the introduced species. There are varied species of birds, mammals, reptiles, amphibians, and invertebrates. Some of the common large wild mammals include *Crocuta crocuta* and *Canis aureus.* The major land uses are enclosures of different ages, farmland, degraded grazing land and church forest. The main soil units are Calcisols, Cambisols and Phaeozems (FAO , 1998).

2.2. Experimental Design

In all the study sites, fixed width line transect were set to assess the density and diversity of large diurnal wild mammals (Figure 2).

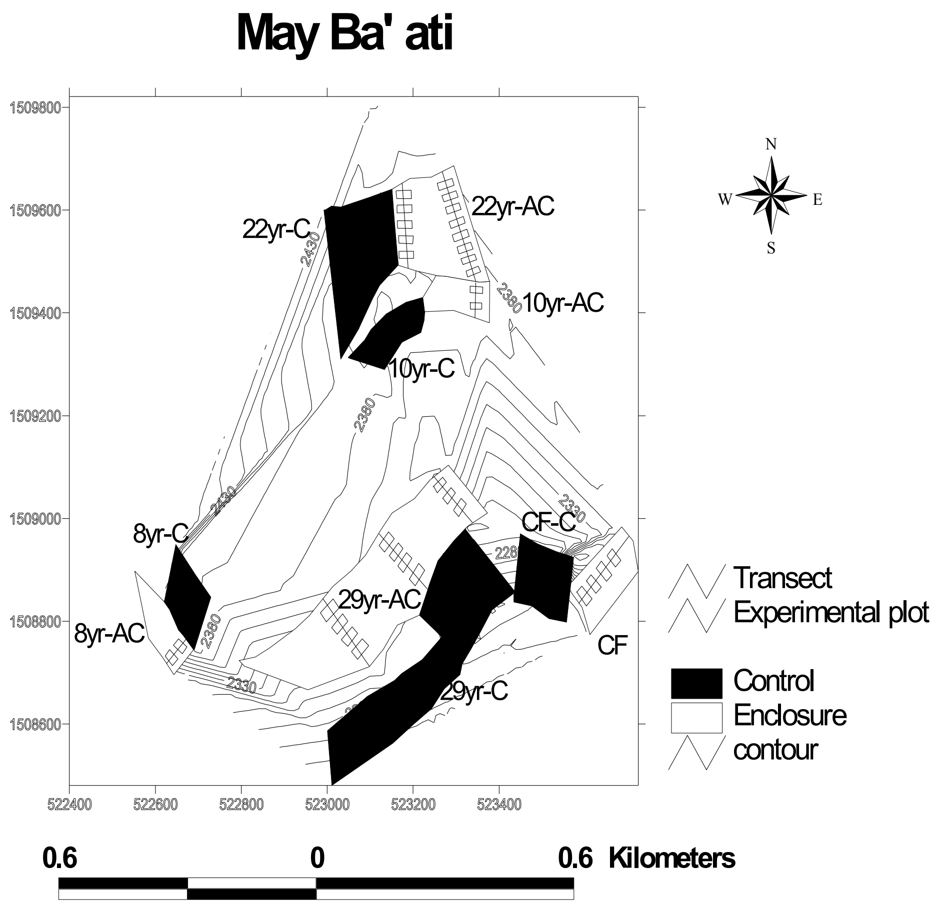

Figure 2. Design of the experiment (AC = area enclosure, CF = church forest, and C = control)

Transect width and distance between consecutive transects were 100m and 150m respectively. Three timings: 10a.m. (morning), 12a.m. (noon), and 6p.m. (dusk) were specified for census of large diurnal wild mammals. For counting large nocturnal wild mammals, timings were 8p.m. and 4a.m. (night and dawn, respectively). These timings are selected for they are the usual hours observed in which the large wild mammals come out of their homes to search for food and water.

Monitoring datasheets were prepared to record the name, number, distance and time traveled of transect, type of habitat, mean sighting distance and global position of the large wild mammals observed in each of the timings.

2.3. Data Collection

2.3.1. Direct Methods: Animal Census

Direct observations were conducted along the fixed transect widths for large diurnal wild mammals. Each observation lasted for an hour. Binoculars with 10*25 magnifying power were used for clear observation.

Total counts technique was used to assess the density and diversity of large nocturnal wild mammals. The footpaths along which the animals come out of their homes were followed for each of the large wild mammals in the area enclosures. The counting was conducted at the two specified timings. Each of the timings lasted for two consecutive hours. The counting was undertaken for 5 consecutive days.

2.3.2. Indirect Method

The fecal droppings of large wild mammals were collected along the transect widths. Photograph trapping of each pellet drops were undertaken and the pellet drops were identified (Figure 3).

Figure 3 Pellet drops of *Crocuta crocuta* (left) *Canis aureus* (right)

In pellet group counting method, the large wild mammals are not counted but something associated with them. Although this method has limitations related to knowing the rate of defecation, locating all the piles of pellets, and accurately identifying and aging the pellets, it was used to supplement and validate the direct methods of animal counting.

2.4. Data Analysis

The densities of large wild mammals were calculated by using the formula (Teshale , 2003).

$$O\left(Km^2\right) = \left(K \times S \times 2\right) Km^2$$

$$D\left(\frac{No}{Km^2}\right) = \frac{N}{O} \qquad P\left(\frac{No}{ha}\right) = \frac{N}{O} \times H$$

Where: O=observed area (Km^2), K=length of transect (Km), S=sighting distance on either side of the transect (Km), D=density of the large wild mammals, N=number of large wild mammals in the observed area, H=size of the whole conservation area, and P=total population size.

The sampling intensity ranges from 54% to 98%. For the total counting method, the abundance of large wild mammals for the two timings was calculated on per hectare basis. In the indirect method of estimating abundance, the weighted averages of pellet groups along transects were taken for each site. Then, the population of species is estimated for the season. Each season (summer, spring, winter, and autumn) was taken to have 90 days, as there are 4 seasons each lasting for 3 months in Ethiopia.

Regression analysis was used to see the significance of the relationships among age of area enclosure, canopy cover, density and diversity of large wild mammals. Density and diversity of large wild mammals were taken as dependent variables while age and canopy cover were taken as independent variables. Measures of variations such as coefficient of variation (CV) and standard error of means were used to see the variability among transect means within a site. Analysis of variance (ANOVA) was also used to test the significance of the relationships between dependent and independent variables.

Relationships among diversity of woody species with density and diversity of large wild mammals; density and diversity of large herbivore and carnivore wild mammals; direct and indirect methods of animal counting; and size of enclosures and density and diversity of large wild mammals were established. Fitting curves were drawn to see the correlation coefficient (r^2) of the relationships.

3. Results and Discussion

3.1. Density and Diversity of Large Diurnal Wild Mammals

The density of large wild mammals varied from species to species among the enclosures. The 29-year enclosure had relatively the highest density of large wild mammals while the eight-year enclosure had the lowest. The species diversity in the 10-year enclosure was the same as that of the 22-year enclosure. However, there were fewer large wild mammals in the 10-year enclosure (Table 1).

Table 1. Large diurnal wild mammals of the land uses

Land use / Species name	Church forest No./ha	29-year AC No./ha	22-year AC No./ha	10-year AC No./ha	8-year AC No./ha	Unprotected areas No./ha
Procavia capensis	2.0	4.0	0	0	0	0
Lepus capensis	0.5	8.0	9.0	2.0	1.0	0
Canis aureus	1.0	10.0	5.0	1.0	0	0
Caracal caracal	1.0	2.0	0.0	0	0	0
Number of species	4	4	2	2	1	0
Total number of individuals	4.5	24	14	3	1	0
CV of transect means	-	129.87%	20.14%	-	-	-
Std. Error of transect means	-	6.00	1.00	-	-	-
F value	age of enclosure vs. density = 0.21 ns; age of enclosure vs. diversity = 1.66 ns					

CV = Coefficient of variation for study sites having greater than one transect, AC = area enclosure, ns non significant at p<0.05

The variation in the density and diversity of large wild mammals among the land uses could arise from the variation in factors such as food, cover, breeding site, degree of disturbance, type of habitat, and the location of enclosures. A study conducted by Bolen and Robinson (1999) had given similar explanation to such variation. The highest species diversity of the 29-year enclosure could be explained by the presence of rugged habitats that can aid the wild animals to get food, shelter and breeding sites. The presence of water point in the church forest and the relatively little disturbance could contribute to its species richness when compared to the younger enclosures. The big variability among transect means (Table1) in the 29-year enclosure can be explained by the difference in the position of transects and specific site situation (Mastewal , 2006).

The church forest was expected to have the largest animal population for it is >1000 years old and relatively undisturbed (Sarah , 2003). But the wild animals usually prefer rugged environments that can provide varied types of niches rather than the one that is dominated by large trees (Kumar, 1986; Johnson and Walter, 2000). Besides, the relatively small size (2.66 ha) of the church forest could also contribute for the low population of large wild mammals. The lower density and diversity of the 10-year enclosure could result from the disturbance created since the enclosure is located near a road. In addition, there is visible interference (Figure 4) of people and domestic animals in it.

Figure 4 Human interference in enclosures of the study area

For most species, partial correlation analysis revealed positive correlation (r = 0.31, 0.31 and 0.33) between age of area enclosure and density of large diurnal wild mammals. But negative correlation (r = -0.26) was found for *Canis aureus.* This could arise from the difference in habitat requirements among the large wild mammals. It also revealed a positive correlation (r = 0.597) between age and diversity. However, both relationships were not significant (at $p<0.05$).

3.2. Density and Diversity of Large Nocturnal Wild Mammals

The species diversity in the church forest and the 29-year enclosure were almost the same (Table 2).

Table 2 Large nocturnal wild mammals of the land uses

Land use Species name	CF No./ha	29-year AC No./ha	22-year AC No./ha	10-year AC No./ha	8- year AC No./ha	Unprotected areas No./ha
Hystrix cristata	1.68	0.43	0.09	0	0.19	0
Mellivora capensis	0.38	0.02	0	0	0	0
Ictonyx striatus	0.27	0.05	0	0	0.10	0
Crocuta crocuta	0.84	0.36	0	0	1.36	0
Leptailurus serval	0.08	0.02	0	0	0	0
Civettictis civetta	0.11	0.02	0	0	0	0
Galerella sanguinea	0	0.08	0	0	0	0
Number of species	6	7	1	0	3	0
Total number of individuals	3.36	0.98	0.09	0	1.65	0
F value	age of enclosure vs. density = 10.06*; age of enclosure vs. diversity = 0.93^{ns}					

*AC = area enclosure, CF = church forest, * significant at $p<0.05$, ^{ns} non-significant at $p<0.05$*

The density of the large wild mammals in the church forest was the highest of the land uses; especially *Hystrix cristata* (porcupine) was found to be highly abundant in the church forest. This indicates that the habitat could be suitable for this species in terms of its requirements such as food and shelter.In the 10-year enclosure, no large wild mammal was observed (Table 2).The 10-year enclosure could not be suitable for the large nocturnal wild mammals due to absence of varied habitats and intense human interference. The eight-year enclosure had a remarkable density and diversity of large nocturnal wild mammals. This can be explained by the potential of the site to provide hiding places for nocturnal species because the enclosure has high stone cover and is located at a relatively far distance from human residence.

Partial correlation analysis revealed positive correlation (r = 0.88) between age of area enclosure and density of large nocturnal wild mammals. Besides, it revealed positive correlation (r = 0.488) between age and diversity. Although the relationship between age and diversity is not significant ($p>0.05$), both regression and analysis of variance showed a significant relationship ($p<0.05$) between age and density.

3.3. Indirect Estimation of Density and Diversity of Large Wild Mammals

The indirect method also showed that the density and diversity of species varied among the land uses. The church forest, 29-year and 22-year enclosures had higher density and diversity of large wild mammals than the 10 and eight-year old enclosures. No pellet drops of large wild mammals were encountered in the adjacent unprotected areas (Table 3).

Table 3. Fecal drop counts of the land uses

Land use	CF	29-year AC	22-year AC	10-year AC	8-year AC	Unprotected areas
Species name	P/ha-season	P/ha-season	P/ha-season	P/ha-season	P/ha-season	P/ha-season
Canis aureus	0.27	0.07	0.06	0.58	0.06	0
Procavia capensis	0.02	0	0	0	0	0
Crocuta crocuta	0.01	0.04	0.02	0.01	0.05	0
Hystrix cristata	0.03	0.01	0	0	0	0
Caracal caracal	0	0.01	0.01	0.03	0	0
Lepus capensis	0	-	0.01	0	0	0
CV of P/ha-season among transects	-	58.48%	15.55%	-	-	-
Std. Error of P/ha-season	-	0.05	0.01	-	-	-

AC = area enclosure, CF = church forest, P = population, and CV = Coefficient of variation for study sites having greater than one transect

Both direct and indirect methods revealed that the density and diversity of species were higher for the older enclosures and the church forest with few exceptions. Big variability of total population among transects (Table 3) in the 29-year enclosure was also revealed by the indirect method. However, the effectiveness of the two methods in estimating the density of large wild mammals varied from species to species as it is shown by the correlation values of the relationship between them (Figure 5).

This could arise from the difference in the behavior of the wild species like sensitivity to human disturbance and selection of sites for defecation. Studies conducted by Fay (1991) and Srikosamatara (1993) also explained that wild animals vary in behavior and this could have an implication in the effectiveness of the different methods of animal counting.

3.4. Relationship Between Large Herbivore and Carnivore Wild Mammals

In the study, both large carnivore and herbivore wild mammals were encountered which have different impact on the food resources available. Species like *Procavia capensis* (hyrax) and *Hystrix cristata* feed on plant parts mainly roots and insects associated with roots. Others such as *Lepus capensis* (hare) feed mainly on grasses. Large carnivore wild mammals namely *Crocuta crocuta*, *Caracal caracal* (caracal), *Leptailurus serval* (serval cat) were also encountered.

The presence of heterogeneous microhabitats in a site helps organisms to coexist being incorporated in different niches (Kumar, 1986; Yosef , 1998). The abundance of large carnivore wild mammals depends on the availability of prey and suitability of other physical and behavioral factors. As they are both components of food chain, the presence of herbivores and carnivores are highly interlinked since one affects the abundance of the other. If carnivores dominate an area, the number of herbivores will be reduced. If the dominant species are herbivores, the available food resource will be consumed exceeding the production. Because each of the various links in food chain is a clear reference to the method by which energy and matter normally move through ecosystems (Schaller, 1967, 1972; Smuts, 1978; Rabinowitz and Walker, 1991; Bolen and Robinson, 1999).

In the study, the herbivore-carnivore density and diversity correlation values were higher for both large diurnal and nocturnal wild mammals (Figure 6 and 7).

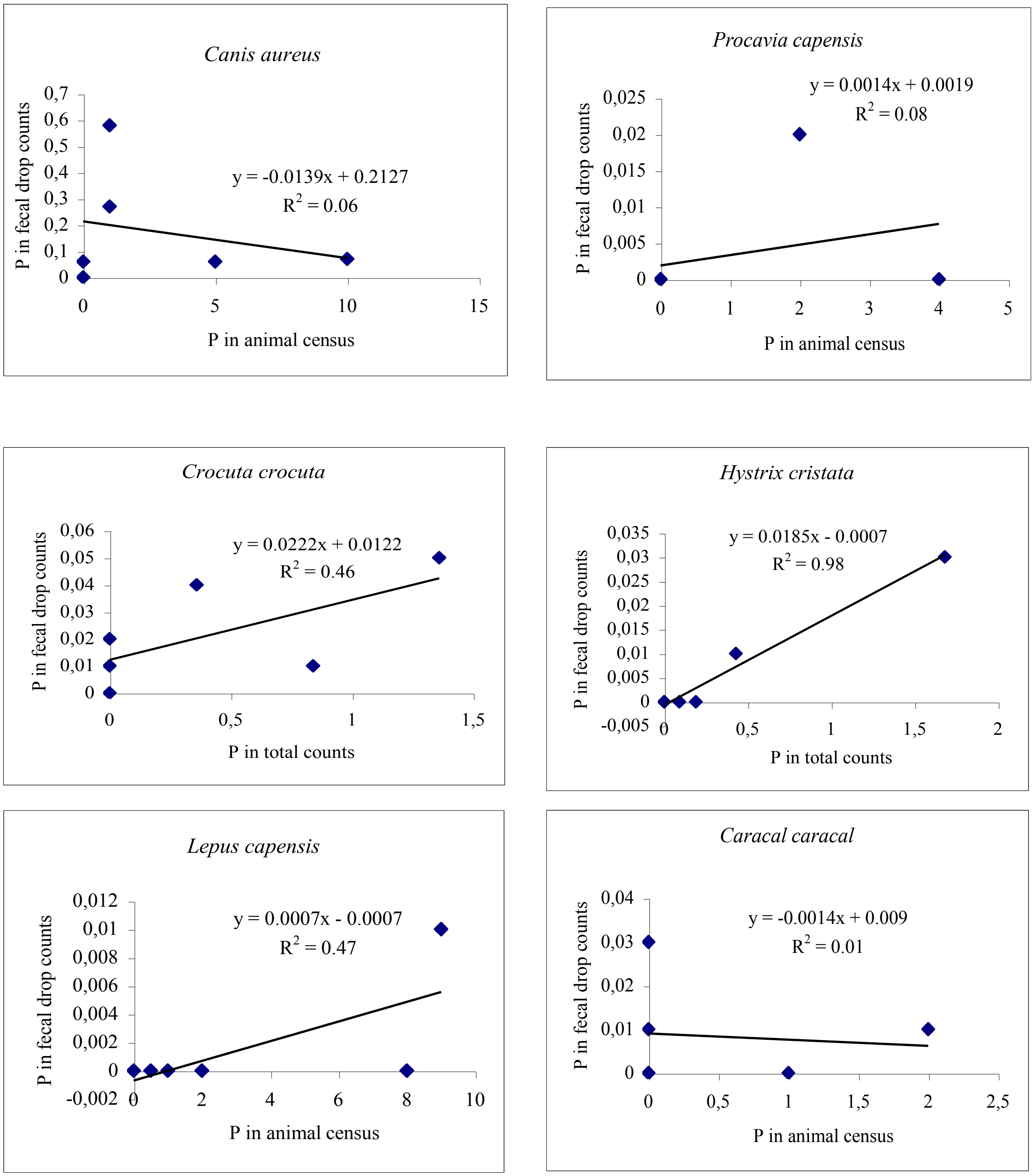

Figure 5. Relationship between direct and indirect methods of animal counting; P (No./ha)

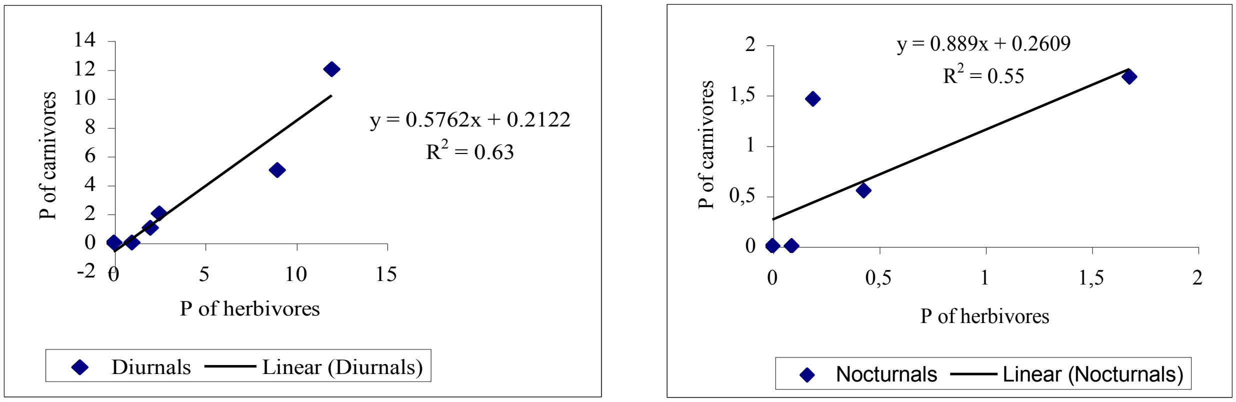

Figure 6. Relationship between density (No./ha) of herbivores and carnivores for large diurnal (left) and nocturnal (right) wild mammals

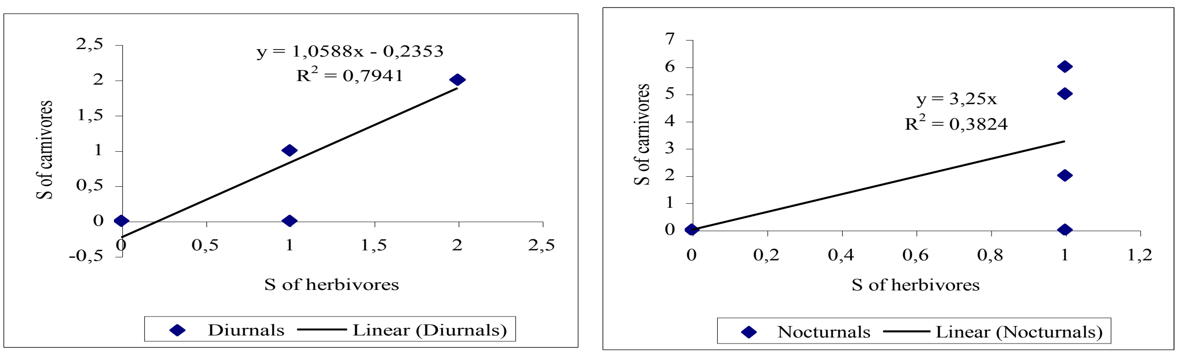

Figure 7. Relationship between diversity of herbivores and carnivores for large diurnal (left) and nocturnal (right) wild mammals

This could be explained by the improved vegetation status of the area which in turn improves the density and diversity of herbivores. A study conducted by Johnson and Walter (2000) also indicated that the food management activities will usually focus on herbivores. By improving the habitat quality for herbivores, their numbers may increase, thus improving the food supply for carnivores. The regular presence of carnivores is a good indication of successful management for prey species.

3.5 Relationship Between Large Wild Mammals and Canopy Cover

The density and diversity of large diurnal wild mammals was highest for the 29-year enclosure and the church forest, followed by the 22-year, 10-year and eight-year enclosures. The canopy cover estimates (Table 4)

Table 4. Canopy cover estimates of the land uses

Land uses	Estimated canopy cover (%)
CF	55.53
29-yr AC	38.00
22-yr AC	21.91
10-yr AC	2.05
Eight-yr AC	18.5
Unprotected areas	0

AC= area enclosure, CF=church forest

showed that vegetation improvement does not always increase with age since canopy cover estimate was higher for the eight-year enclosure than the 10-year enclosure. This could be explained by the anthropogenic and physical factors that can affect the effectiveness of the management.

The density and diversity of large wild mammals was higher for the old aged enclosures with few exceptions. Positive correlations (r = 0.292, 0.812; r = 0.797, 0.863) were found for the relationships of canopy cover with density and diversity of large diurnal and nocturnal wild mammals respectively. The relationships among canopy cover, density, and diversity of large nocturnal wild mammals were significant ($p<0.05$). This result was also verified by the relatively higher correlation coefficient (r^2) for the relationships among canopy cover, density and diversity of large nocturnal wild mammals (Figure 8).

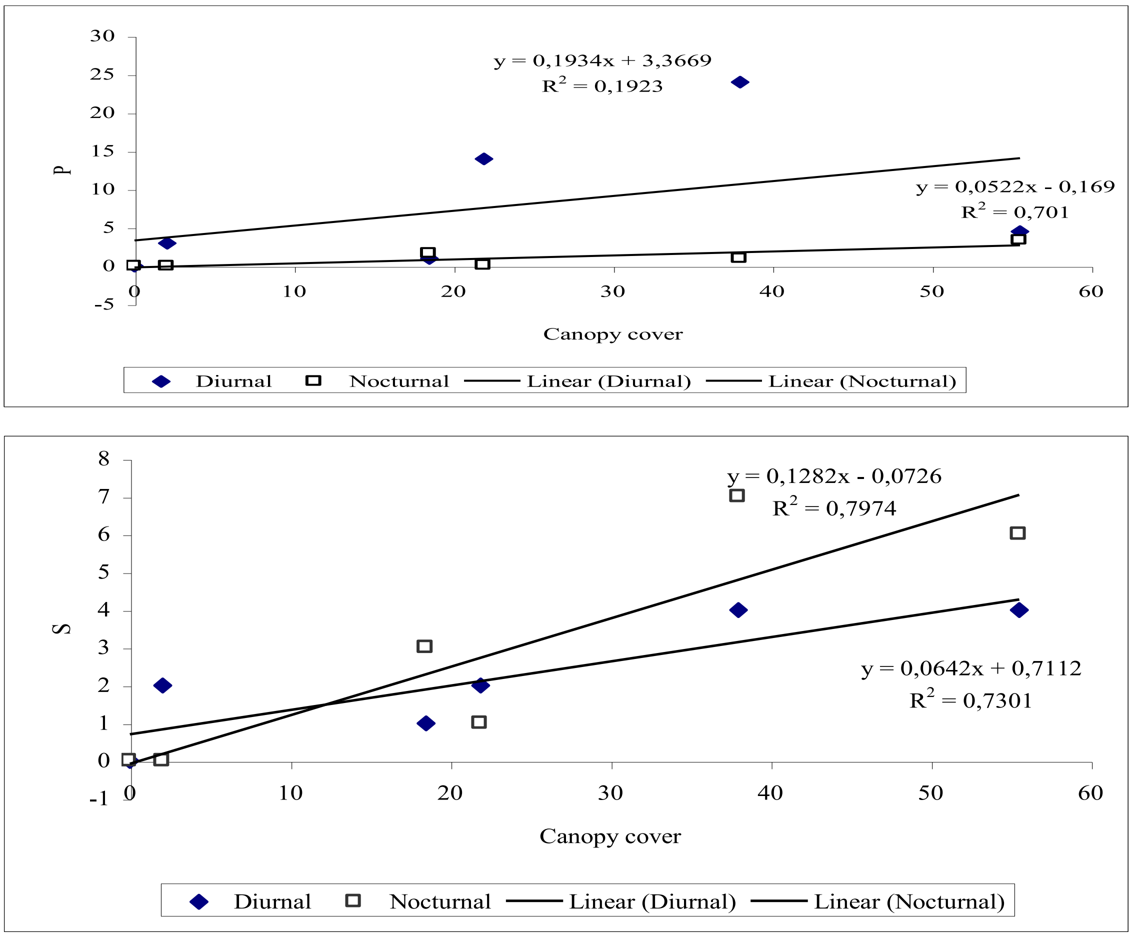

Figure 8. Relationships among canopy cover, density and diversity of large wild mammals

The lower density and diversity of large nocturnal wild mammals in the 10-year enclosure could be due to the absence of rugged microhabitats (Yosef , 1998). Besides, although in many cases the older enclosures are rich in both plant and large wild mammal composition, the physical and human-related factors could affect both vegetation and large wild mammal density and diversity.

Large wild mammals respond to cover changes. The vegetation cover of an area affects the number of individuals that can be supported by the site. This could be due to the importance of cover in providing shelter, food, nesting opportunities, and protection from predators (Baxter *et al*., 2005). Bolen and Robinson (1999) also concluded that any factor that has an impact on the composition of plant species is expected to affect the type and population of wild fauna that can be supported by the habitat. Besides, many of the wildlife species found in the forest have very specific cover needs during their lifetime (Johnson and Walter, 2000). Also, an animal's cover needs change with season.

3.6. Relationship Between Diversity of Woody Species and Large Wild Mammals

The relationship between diversity of woody species and large wild mammals was relatively strong than the relationship between diversity of woody species and density of large wild mammals (Figure 9).

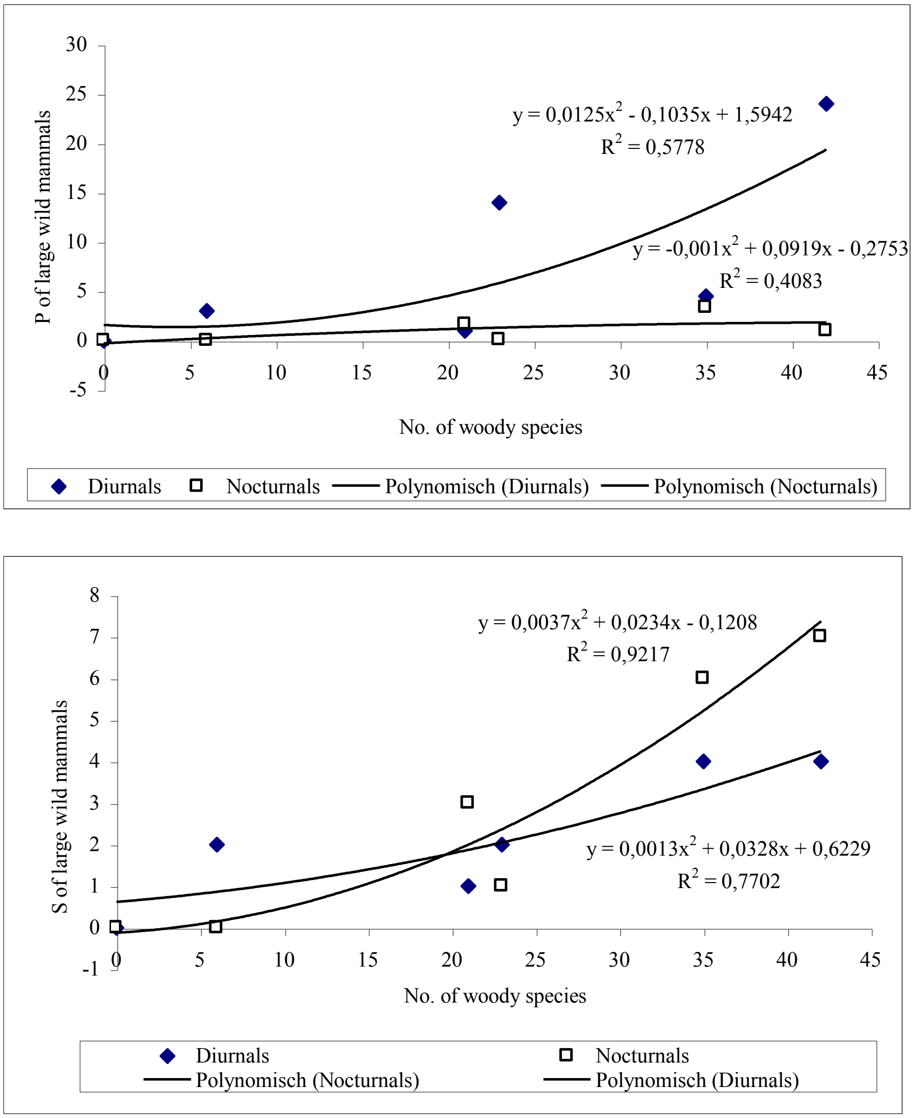

Figure 9. Relationship among number of woody species and density and diversity of large wild mammals

This could be explained by the presence of varied food resources that can meet the demand of different large wild mammals.

The relatively lower correlation values between number of woody species and density of large wild mammals could result from the inadequate food resources. It is also indicated in researches that wild animals usually eat the most nutritious and palatable foods that are available in their habitat (Johnson and Walter, 2000). Both the quantity and quality of food in a site have an impact on the density and diversity of large wild mammals (Karanth and Sunquist, 1992; Bolen and Robinson, 1999). In addition, the structure, composition and function of plant communities change with time. The way in which vegetation is managed has an important influence on its value as a habitat in the long term (Bennett *et al*., 2005).

3.7. Relationship Between Size of Enclosures and Density and Diversity of Large Wild Mammals

In most cases, the density and diversity of large wild mammals encountered in the study increased with the size of the enclosures. This is because larger enclosures have more different kinds of habitats and support larger populations. Valone and Hoffman (2003) also indicated that only larger patches are likely to contain enough habitats to support species like larger mammals that require larger areas.

The study also revealed that the relationship between size of enclosures and density and diversity varies among large diurnal and nocturnal wild mammals. The density and diversity of large diurnal wild mammals showed strong relationship with size of the habitat (Figure 10).

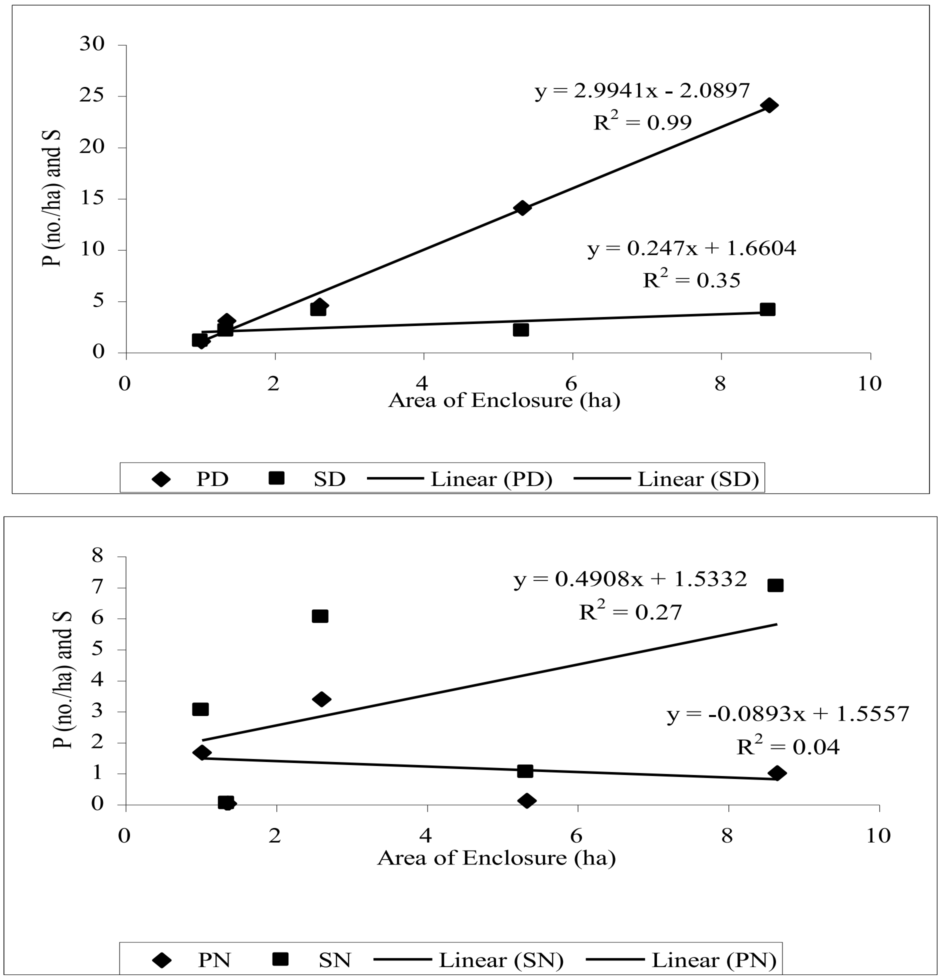

Figure 10. Relationship between size of enclosures with density and diversity of large diurnal and nocturnal wild mammals where: PN, SN, PD, and SD are density and diversity of large nocturnal and diurnal wild mammals respectively

This variation could arise from the difference in sensitivity towards the size and type of the habitat. Studies conducted on wild animals suggest that the effect of patch size may be species dependent (Foster and Gaines, 1991). Many species are area sensitive, which means that they are absent from or rare in small patches of habitat and more abundant within extensive areas of undeveloped land. Besides, some surveys (Cody, 1975) have investigated the hypothesis that animal species diversity increases with increasing habitat complexity, because more complex habitats offer greater variety of niches for different species, therefore harbour higher diversity of fauna.

4. Conclusions

The density and diversity of large wild mammals varied among land uses. This could result from the variation in ruggedness, resource availability, and interference among the land uses. It is observed that the older enclosures have higher density and diversity of large wild mammals than the younger enclosures and adjacent unprotected areas. The study also revealed that relationship exists between size of enclosures and density and diversity of large wild mammals. The existence of both large carnivore and herbivore wild mammals indicated the effectiveness of area enclosures in biodiversity conservation. However, for further improvement of the habitats and thereby biodiversity, development of water points and vegetation management are timely needed. There is a need of further research on the relationship between size and shape of enclosures with species richness. In addition, researches that generate quantitative information on other wild faunal groups are timely needed so that the potential of enclosures in biodiversity conservation can be quantified.

5. Acknowledgements

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6. References

Aerts, R., Wagendrop, T., November, E., Mintesinot B., Deckers, J., Muys, B. 2004. Ecosystem thermal buffer capacity as an indicator of the restoration status of protected areas in the Northern Ethiopian Highlands. *Restoration Ecology* 12: 586-596.

Baxter, G., Spencer, R., Cavanough, V., and Kennedy, M. 2005. Adult free zones in Australian small mammal populations: Response of Australian native rodents to reduced cover. *Austral Ecology* 30 (8): 868-876.

Bennett, A., Kimber, S., and Ryan, P. 2005. Revegetation and Wildlife: A Guide to Enhancing Revegetation Habitats for Wildlife Conservation in Rural Environments. Bushcare National and Research and Development Program Research Report 2/00. Australia. Common Wealth of Australia.

Betru, N., Jawad, A., and Ingrid, N. 2005. Exploring Ecological and Socio-Economic Issues for the Improvement of Area Enclosure Management. A Case Study from Ethiopia. Dryland Coordination Group Report No. 38. Oslo, Norway. pp. 63. http://www.drylands-group.org. (accessed on 25/08/2006).

Bolen, G., and Robinson, L. 1999. *Wildlife Ecology and Management*. 4th Edition. USA. Prentice-Hall, Inc. pp. 482.

Cody, M. 1975. Towards a theory of continental species diversity. *In*: Cody, M. and Diamond, J. (eds.). Ecology and evolution of communities. Belknap, Cambridge, Massachusetts, USA.

Deschemaeker, K., Nyssen, J., Rossi, J., Poesen, J., Mitiku H., Moeyerson, J., Deckers, J. 2005. Sediment deposition and pedogenesis in exclosures in the Tigray Highlands, Ethiopia. *Geoderma.* In press. pp. 24.

EWNHS (Ethiopian Wildlife and Natural History Society). 1996. Important bird areas of Ethiopia: A first inventory. Addis Ababa, Ethiopia. Samayota Press.

FAO (Food and Agricultural Organization), ISRIC (International Soil Reference and Information Center), ISSS (International Soil Science Society). 1998. World reference base of soil resources. World Soil Resources Reports, Vol. 84. Rome, Italy. pp. 88.

Fay, M. 1991. An elephant (*Loxodonta africana*) survey using dung counts in the forests of the Central African Republic. *Journal of Tropical Ecology* 7: 25-36.

FDRE (Federal Democratic Republic of Ethiopia). 2001. National Agenda 21. Implementation Review Report. Environmental Protection Authority.

Fitsum, H., Pender, J., Nega,G. 1999. Land degradation in the highlands of Tigray, and strategies for sustainable land management. Socio-economic and policy research working paper No. 25. International Livestock Research Institute, Addis Ababa, Ethiopia. pp. 78.

Foster, J. and Gaines, M. 1991. The effects of a successional habitat mosaic on a small mammal community. *Ecology* 72(4): 1358-1373.

Groombridge, B. and Jenkins, E. 1994. *Biodiversity Data Sourcebook*. UK. World Conservation Press.

Johnson, E. and Walter, T. 2000. Moving Toward Sustainable Forestry: Strategies for Forest Landowners. Virginia State University. Publication Number: 420-144.

Karanth, U. and Sunquist, E. 1992. Population structure, density and biomass of large herbivores in the tropical forests of Nagarahole, India. *Journal of Tropical Ecology* 8: 21-35.

Kindeya, G. 2003. Ecology and management of *Boswellia papyearifera* (Del.) Hochst. Dry forests in Tigray, Northern Ethiopia. Doctoral Dissertation. Georg-August University of Göttingen. Germany. pp. 182.

Kumar, D. 1986. *Modern Concepts of Ecology*. 1st Edition. Sweden. Vikas Publishing House Pvt Ltd.

Mastewal, Y. 2006. Impact of area enclosures on density and diversity of large wild mammals and woody plants in Douga Tembien, Tigray, Ethiopia. MSc. Thesis. Mekelle University.Ethiopia. pp. 115.

Nyssen, J. 2001. Erosion processes and soil conservation in a tropical mountain catchment under threat of anthropogenic desertification: a case study from Northern

Ethiopia. PhD Thesis, KU Leuven, Belgium. pp. 380.

Rabinowitz, R. and Walker, R. 1991. The carnivore community in a dry tropical forest mosaic in Huai Kha Khaeng Wildlife Sanctuary, Thailand. *Journal of Tropical Ecology* 7: 37-47.

Sarah, T. 2003. Vegetation improvement in closed areas, grazing land and protected forest in Tigray, Ethiopia. MSc. Thesis. Georg-August University of Göttingen. Germany. pp. 114.

Schaller, G. 1967. The deer and the tiger: A study of wildlife in India. Chicago. University of Chicago Press. pp. 370.

Schaller, G. 1972. The Serengeti Lion: A study of prey-predator relations. Chicago. University of Chicago Press. pp. 480.

Smuts, G. 1978. Interrelations between predators, prey, and their environment. *Bioscience* 28 (5): 316-320.

Srikosamatara, S. 1993. Density and biomass of large herbivores and other mammals in a dry tropical forest, Western Thailand. *Journal of Tropical Ecology* 9: 33-43.

Tassew, W. 1995. Forest policy analysis and woodland clearing in a closed economy: the Ethiopian case. Wagneningen Agricultural University. The Netherlands. pp. 61.

Tefera, M. 2001. The role of area closures of the recovery vegetation in degraded hillsides of Biyo and Tiya, Central and Northern Ethiopia. MSc. Thesis. Swedish University of Agricultural Sciences. Sweden. pp. 35-60.

Teshale, A. 2003. Prevention measures for the conflicts between farmers and wild animals. Training manual. Bureau of agriculture and natural resource development of Tigray region. Unpublished. pp. 29.

TIC (Triangular Institutional Cooperation). 1999. A comparative study of common pool resource management with respect to forest and natural regeneration in Ethiopia and India. Forestry South-South links in the management of natural resources in semi arid areas.

Valone, T. and Hoffman, C. 2003. Population stability is higher in more diverse annual plant communities. *Ecology Letters* 6: 90-95.

Wolde, M. 2004. Impacts of land use changes on soil nutrients and erosion in Tigray, Ethiopia. MSc. Thesis. Georg-August University of Göttingen. Germany. pp. 50.

Yosef, M. 1998. A handout on introductory course in wildlife conservation and management. Debub University. Wondo Genet College of Forestry. Basic Sciences Department. Unpublished. pp. 71.

Potential, Distribution, Ethno-botany and Tapping Procedures of Gum Producing *Acacia* Species in the Somali Region, Southeastern Ethiopia

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Abstract: A survey study was undertaken in eight districts of the Somali Region, southeastern Ethiopia to identify gum producing species; their distribution and abundance; gum-tapping practices; and local uses. Nine gum producing *Acacia* species; widely known by pastoralists and agro-pastoralists in the Region were identified. Dihun and Gerbo Districts in Fik Zone were the high potential areas for gum arabic *(Acacia Senegal(L.) wild.)* and gum talh *(Acacia seyal Del.)* production based on the abundance of the source species. Degahamedow District in Degahabur Zone was another promising gum production area following the Districts in Fik Zone. However, both *A. senegal* and *A. seyal* were abundantly found in all study Districts, with the former being the most abundant and widely distributed throughout the study Zones. The gum resource in the Somali Region appeared under-exploited due to lack of proper tapping and extraction skills in the area. Apart from gum tapping, the woody vegetation of the Region supports livestock production, mitigates desertification, ensures biodiversity maintenance, and provides immense non-wood forest products. Therefore, promotion of gum extraction in the Somali Region both for economic benefit of the community and sustainable management of the fragile ecosystem is recommended.

Key words: *Acacia*, Bushland; Gum Arabic; Gum Talh; Somali Region

1. Introduction

Gum has been used by man for millennia and remains to be an important article of commerce to the present day. Natural gums obtained from incisions of stems and branches of several *Acacia* species growing in arid and semi arid agroecologies are used for making different beverages, medicines, and water-soluble glues (EFAP, 1994; FAO, 1995a). In food industry, gum is used as thickening, stabilizing, emulsifying and suspending agent, besides their applications in making foods and drinks. In pharmaceutical industry, gum is used as a binding agent in tablets and as a suspending and emulsifying agent in creams and lotions (FAO, 1995b). Some of the technical applications of gums are in the printing and textile industries where advantage is taken of their filming and sizing properties, respectively (Cossalter, 1991). Local medicinal uses have been claimed to serve as smoothening and softening agent, taken internally for cough, diarrhea, dysentery, hemorrhage; and externally in the treatment of local inflammations and nodular leprosy (FAO, 1995a, 1995b).

Africa is the world's leading producer and exporter of gum arabic from *A. senegal*. Sudan accounts for 80% of the world's gum arabic production, followed by Senegal, Nigeria, Mauritania, Mali, Ethiopia, Chad, Tanzania and Niger, according to their importance (Seif el Din and Zarroung, 1996). Total gum production in Ethiopia is approximately 3000 tones per annum and only an estimated 50% of the produce is exported through formal trading channels (EFAP,1994).

Gum represents a group of non-wood forest products, which have played and continue to play a significant role in the economies of the Somali people in Ethiopia. Though the Somali Region is one of the major gum-producing regions of Ethiopia, the actual production and trade data on gum from this region is hard to come by. Information on the production and marketing of these products is inadequately documented.

Furthermore, the extent of variations in the nature, quality, characteristics and use of the products compounds the situation. Nevertheless, gum collection plays an important role in the livelihood of the rural communities of Somali Region (Mulugeta *et al*., 2003). The degradation and loss of ecosystem and the gradual destruction of natural resources, on which the collection of gum depends, appear to be among the biggest threats to the development of this sector in the Somali Region. The major problems affecting production and trade of gum in Somali Region are related to inadequate knowledge of botanical sources, lack of proper market information, poor infrastructural development, and poor production and handling of the products. The information on the ecology and distribution of the species is scanty. Sound and sustainable management of this natural resource is required to ensure socio-economic benefits, processing and product development of gum arabic (Mulugeta *et al*., 2003). This can be achieved by undertaking investigations targeted at understanding of the ecology of the species, the socio-economic impacts of the products as well as their potentials for investment,

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employment and income opportunities for the rural population in Somali Region. The data generated from such study should enable to create awareness of issues on the part of policy-makers, to gain policy and legislative support in the development, management and conservation of this natural resource to ensure sustainability of gum production, trade and marketing in the Somali Region. Therefore, the objectives of this study were to identify gum producing species and their distribution in the Somali Region; assess the ethno-botanical and cultural values of the gum producing species; and assess gum tapping procedures used by the local community.

2. Material and Methods

2.1. Description of the study area

The study was conducted in three Zones of the Somali National Regional State (SNRS), namely, Gode, Fik and Degahabur. Potential Districts within each Zone were identified based on the available information from the regional agricultural bureau. Accordingly, Gode, Kelafo and Mustahil Districts of Gode Zone; Segeg, Dihun and Gerbo Districts of Fik Zone; and Degahamedow and Aware Districts of Degahabur Zone were selected for the study (Figure 1).

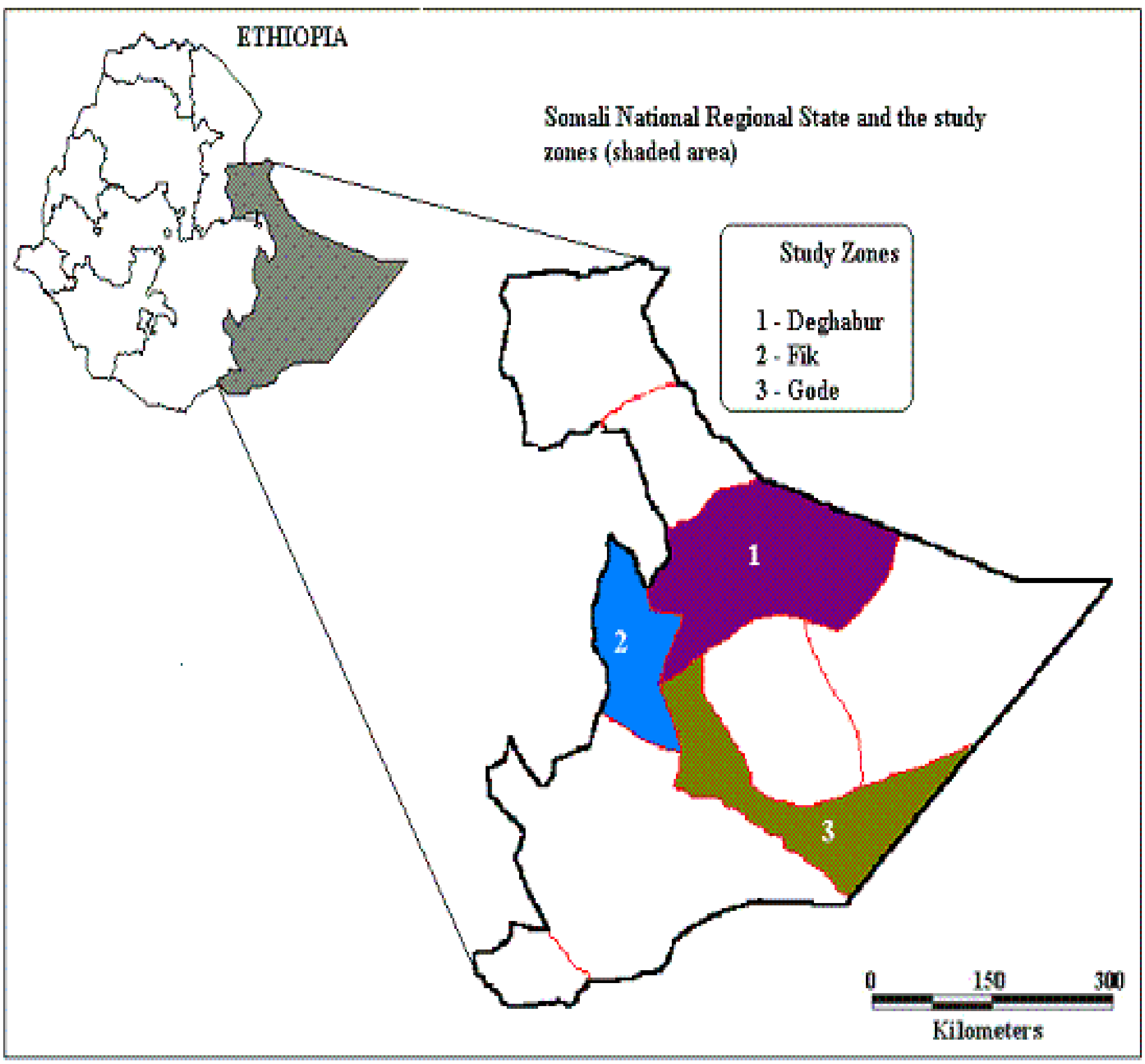

Figure 1. Map of Ethiopia showing the Somali Region and the study zones of the Region

The altitudes of the study districts range from 250 – 560 m in Gode, 600 – 1370 m in Fik and 900 – 1200 m in Degahabur. The climate is arid to semi arid with mean annual rainfall ranging from 190 mm at Kelafo to 700 mm at Jijiga (Ethiopian Meteorological Agency, 2002). According to the Ethiopian Meteorological Agency (2002), the mean annual rainfall at the Gode, Degahabur and Fik weather stations are 252.0, 328.5 and 458.7 mm, respectively. The soils of the Somali Region can broadly be described as loose red sands, dark brown, reddish brown to yellowish brown and gray soils varying from very coarse (sandy) to heavy clay soils in texture (Murphy, 1968; UNDP/RRC, 1984; Mohamed and Mishra, 2005). The majority of the population is pastoralist, and sedentary to settled agriculture is practiced near or around major towns and villages. Livestock includes cattle, camels, black-headed sheep and goats. Extensive livestock grazing and browsing is a major environmental threat in the study districts of the Somali Region.

Floristically, *Acacia-Commiphora* deciduous bushland and thickets form the dominant vegetation cover in the study areas (Friis, 1992). In the southern and southeastern Ethiopia this vegetation type constitutes dense bushes of up to 7 m high with scattered trees of up to ten meters high. The flora is dominated by species of *Acacia, Commiphora, Grewia* and *Capparidaceae*, although considerable variation occurs from place to place (Friis and Mesfin, 1991; WCMC, 1991).

2.2. Survey and Data Collection

The study was conducted in eight Districts of the SNRS: Aware, Dihun, Degahamedow, Gerbo, Gode, Kelafo, Mustahil and Segeg, from July 1999 to June 2000. In each of the selected District, 20 sample plots of 20 x 20 m (400 m^2) were laid in a systematic sampling procedure. Topographic maps of 1:50,000 scales were used as references for sampling. The boundaries of the study area were first marked and accessible roads were identified on the maps. Parallel transect lines, 8 to 15 km away from each other depending on the size of the district, were laid along a south to north direction starting from the south west border of each study district. Sample plots were laid down on the transects at intervals of five kilometers distance. In each sample plot, vernacular names of species and number of mature trees of each gum producing acacia species were recorded. Since species identification at seedling and sapling stages on the field were not possible, all seedlings and saplings of acacias in the plot were counted and considered together. The height, diameter at breast height (DBH) and crown diameter of all mature trees of the different species were measured. Voucher specimens of the gum producing acacia species collected from each sample plot were identified and the corresponding scientific names were assigned. The nomenclature followed the Flora of Ethiopia and the Flora of Tropical East Africa (e.g. Hedberg and Edwards, 1989; Thulin, 1989; Friis, 1992; FAO, 1995b; Demel, 1996). Since the districts were newly demarcated and it was not possible to get the exact area of each district, plant density was presented on hectare basis.

An open-ended questionnaire was prepared to interview gum collectors nearby each sampling plot regarding propagation of the plants, gum tapping and collection techniques, gum processing, gum grading and storage, estimate of gum production per tree, local uses of gums and gum producing trees, gum quality affecting factors, and trends in the vegetation cover. For this purpose a total of 160 informants, that is, twenty persons per district were interviewed.

2.3. Methods of Data Analysis

Tools of descriptive statistics such as mean, percentage, standard deviation, standard error and coefficient of variability were used to analyze, organize and describe the different data sets collected from the field and questionnaire survey studies of the study areas. The statistical packages of Microsoft Excel and SPSS for Windows were employed to undertake the descriptive analysis.

3. Results

3.1. Distribution, Density, Diameter and Height of Gum Producing *Acacia* Species

The scientific and local Somali names of the identified gum producing *Acacia* species are given in Table 1 while their distribution in Ethiopia and elsewhere are presented in Table 2. Plant nomenclature in the Somali Region is very local. A species may have several local names. For instance, *A. senegal* and *A. seyal* are known by six and four different names, respectively, in different localities. There are also cases where two or more species are called by same local name. Therefore, reference to specimens may be required when local names are used. Most of the gum producing *Acacia* species identified in the Somali Region are also common in East and Northeast Africa.

Table 1. Scientific and local Somali names of gum producing *Acacia* species in eight districts of the Somali Region, southeastern Ethiopia

Scientific name	Somali name
Acacia etbaica Schweinf.	Qansax, Qudhac
Acacia horrida (L.) Willd.	Sarmaan
Acacia mellifera (Vahl.) Benth.	Bilcil
Acacia oerfota (Forssk.) Schweinf.	Gumar, Gumaro, Quule
Acacia senegal (L.) Willd.	Marah, Cadad, Cadaad-dhaadheer, Cadaad-madow, Jaleefan, Waylo-Qonjida
Acacia seyal Del.	Galool, Qaydar, Waadhi, Jiiq
Acacia sieberiana DC.	Jeerin
Other Acacia sp.	Gabro
Acacia stuhlmannii Taub.	Gahaydher

Table 2. Distribution of the gum producing *Acacia* species identified from eight districts of the Somali Region, Ethiopia. Distribution in Ethiopia follows the description used in the flora of Ethiopia, viz., AF = Afar, AR = Arsi, BA = Bale, GD = Gondar, GG = Gamo Gofa, GJ = Gojam, HA = Hararghe, IL = Illubabor, KF = Kefa, SD = Sidamo, SU = Shewa, TU = Tigray, WG = Welega, WU = Welo region.

Species	Altitude (m)	Distribution in Ethiopia	Distribution elsewhere
A. etbaica	500-2300	AR, HA, WU, SD	Eritrea, Somalia, Kenya, Sudan, Uganda, Tanzania and Saudi Arabia
A. horrida	500-1700	HA, BA, KF, SD, GG	Somalia, Kenya, Sudan, Uganda
A. mellifera	400-2500	WU, SD, SU, HA, BA, KF, GG	Africa and Arabia
A. oerfota	100-1600	WU, SD, SU, HA, BA, AF, TU	Eritrea, Somali, Kenya, Sudan, Uganda, Tanzania, Egypt, Arabia
A. senegal	600-1700	AF, WU, SU, AR, BA, SD, HA, GG	Africa, Arabia, India and Pakistan
A. seyal	500-2300	TU, WU, GD, GG, SU, AR, HA, IL, KF, SD	Tropical Africa
A. sieberiana	500-2200	WU, SU, WG, IL, KF, SD, TU, GD, AR, HA	Tropical Africa
A. stuhlmannii	-	HA	Somalia, Kenya, Tanzania Zambia, Botswana, Transvaal

Sources: von Breitenbach (1963), White (1983), Kuchar (1988), Thulin (1989), Friis (1992), FAO (1995b) and Demel (1996).

Higher stockings of mature gum-yielding *Acacia* species were found in Gerbo and Segeg as well as in Dihun Districts of Fik Zone (Figure 2).

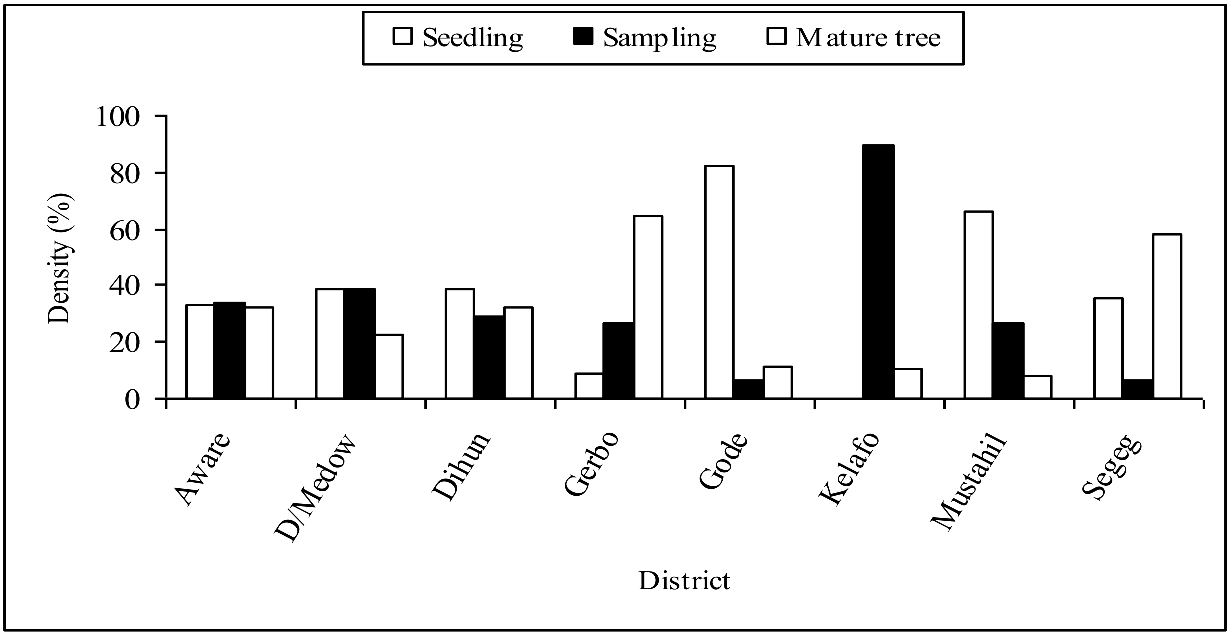

Figure 2. Mean seedling, sapling and mature plant densities of gum producing acacia species in the eight districts of the Somali Region, southeastern Ethiopia. From left to right, at each district, the bars stand for seedling, sampling and mature tree, respectively.

Based on seedling and sapling densities, the natural regeneration of the gum-yielding species were higher at Mustahil followed by Kelafo and Gode of Gode Zone. Among the nine gum producing acacias identified, *A. senegal* and *A. seyal* were widely distributed in all of the study districts and scored higher mean stocking tree densities compared to all the other species (Figure 3).

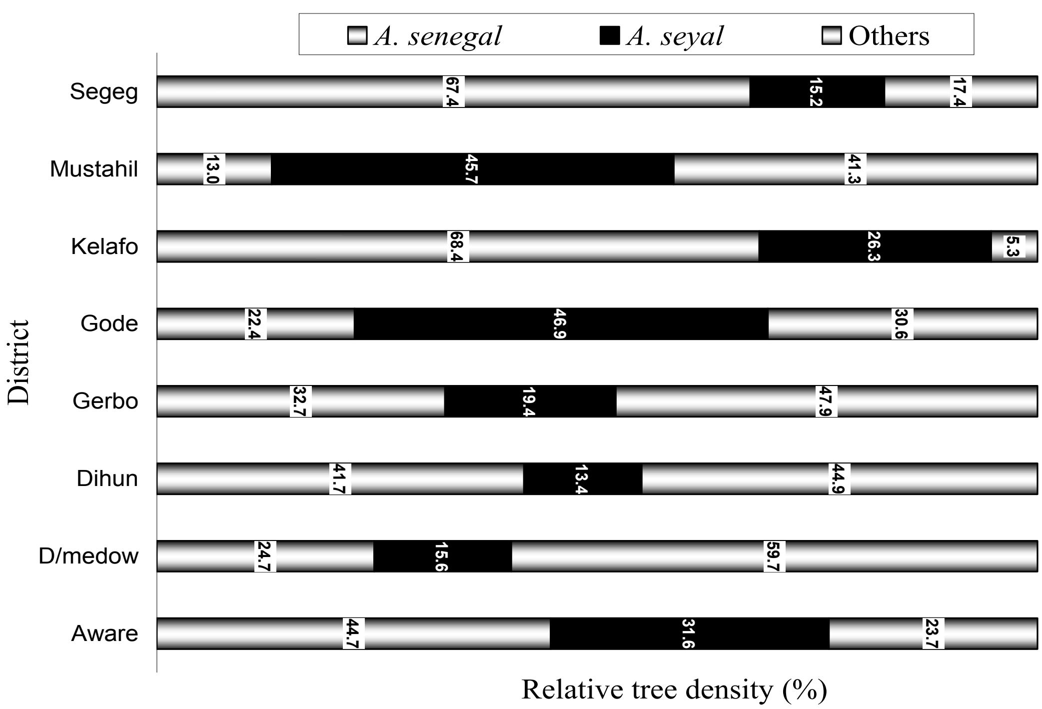

Figure 3. The relative abundance/density of the two major and other gum producing Acacia species in eight districts of the Somali Region, southeastern Ethiopia. The bar representing each district has three sections: bottom, middle and top, representing *A.sengaal*, *A.seyal* and others, respectively.

On the other hand, *A. etbaica* and *A. seyal* were larger both in terms of diameter at breast height (DBH) and height among the gum producing acacias (Table 3). These two species and *A. senegal* form large and umbrella-like crowns. The crown diameter of the acacias in the study areas at least equals the height of the tree (Tables 3 and 4). The other species with rather shrubby habits are short-stemmed, multi-branched and, in most cases, the main stem is established from branches. The highest diameter (at breast height) was recorded in Kelafo for *A. senegal* and in Segeg for *A. seyal* (Table 4).

Table 3. Mean (± SE) diameter at breast height (DBH), height, crown diameter and abundance of gum producing acacia species observed in eight districts of the Somali Region

Species	DBH (cm)	Height (m)	Crown diameter (m)
A. etbaica	11.1 ± 0.78	5.4 ± 0.24	5.7 ± 0.26
A. horrida	7.5 ± 0.82	2.8 ± 0.69	4.3 ± 0.44
A. mellifera	8.9 ± 0.76	3.7 ± 0.36	3.8 ± 0.21
A. oerfota	5.9 ± 0.82	3.5 ± 0.27	3.4 ± 0.20
A. Senegal	10.2 ± 0.67	4.2 ± 0.15	4.2 ± 0.20
A. seyal	11.8 ± 0.78	5.0 ± 0.27	4.4 ± 0.22
A. sieberiana	7.2 ± 1.86	4.3 ± 0.55	3.7 ± 0.30
A. stuhlmannii	4.8 ± 1.29	2.5 ± 0.57	2.5 ± 0.32
Other Acacia sp.	12.7 ± 1.13	5.2 ± 1.22	4.2 ± 0.73

Table 4. Mean (± SE) diameter at breast height (DBH), height and crown diameter of *A. senegal* and *A. seyal* in eight districts of the Somali Region, Ethiopia

District	DBH (cm)		Height (m)		Crown diameter (m)	
	A. senegal	*A. seyal*	*A. senegal*	*A. seyal*	*A. senegal*	*A. seyal*
Aware	9.5 ± 0.71	9.2 ± 0.60	3.1 ± 0.10	3.4 ± 0.89	3.1 ± 0.19	3.2 ± 0.24
D/Medow	10.8 ± .86	15.8 ± 0.94	3.9 ± 0.35	6.0 ± 0.30	4.1 ± 0.28	4.7 ± 0.52
Dihun	6.2 ± 0.79	8.1 ± 1.30	4.4 ± 0.32	4.9 ± 0.88	4.7 ± 0.57	5.5 ± 1.04
Gerbo	6.9 ± 1.00	9.9 ± 1.12	3.6 ± 0.31	4.4 ± 0.28	3.8 ± 0.10	4.4 ± 0.62
Gode	6.2 ± 0.77	6.1 ± 0.74	3.6 ± 0.34	3.7 ± 0.78	2.7 ± 0.29	2.5 ± 0.15
Kelafo	24.6 ± 1.60	25.5 ± 1.97	5.5 ± 0.27	5.3 ± 1.20	6.1 ± 0.38	6.2 ± 0.65
Mustahil	3.9 ± 0.86	8.0 ± 0.77	5.8 ± 0.23	6.3 ± 0.22	6.6 ± 1.37	6.0 ± 0.17
Segeg	12.7 ± 1.58	18.3 ± 1.63	4.5 ± 0.65	6.5 ± 0.34	3.5 ± 0.30	4.2 ± 0.87

3.2. Local Uses of the Gum Producing Tree Species

Unlike gums from *A. senegal* and *A. seyal* that were widely traded, the uses of gums from the other species were, however, limited to local consumption: chewing, and the trees are used for construction, fuel wood, animal browse and traditional medicine (Table 5). Discussion with collectors and traders of gum in the study area indicated a possibility of mixing products from different species. Gum arabic (from *A. senegal*) might be contaminated with gum talh (from *A. seyal*) or others at least in the initial stages of collection and processing which may result in adulteration.

Table 5. Local uses of gum producing *Acacia* species in eight districts of the Somali Region

Species	Chewing	Construction	Fuel wood	Animal browse	Medicine
A. etbaica	X	X		X	X
A. horrida	X			X	
A. mellifera	X	X	X	X	X
A. oerfota		X	X	X	
A. senegal	X	X	X	X	X
A. seyal	X	X	X	X	X
A. sieberiana	X	X	X	X	
A. stuhlmannii	X			X	

The interview with the farmers revealed that in addition to gum production, acacias have multiple local uses (Table 5) that can be categorized either as wood or non-wood products. The Somali in the study area have developed a wealthy of ethno-botanical knowledge, of which traditional medicine is one. Wood from acacias is highly valued for construction and fuel. Although charcoal extraction from various acacia species is widely practiced in the upper catchments of the region, mainly around Jijiga and along the main road to Harar, the practice was not developed in Gode Zone. However, acacias were the major sources of firewood in the zones of all studied districts. Although acacias are crooked and their woods are not suitable for timber, they are the main sources of construction wood in the Somali Region. All of the farmers interviewed preferred wood of acacias to any other species due to their strength and durability. Furthermore, most of the respondent farmers considered acacias to form excellent cover of palatable browse for their livestock and some believed that life would not be possible in the area without the acacias.

3.3. Regeneration, Tree Planting Culture and Status of the Natural Vegetation

Respondent farmers in all study districts of Somali Region indicated that all the gum producing species could be propagated by seeds. In all the study districts, none of the interviewed farmers practiced tree planting at all indicating that all the gum producing acacia trees of the region were components of the natural vegetation established naturally.

Over two-third of the farmers interviewed were aware of the declining of the natural regeneration capacity and vegetation cover of their surrounding. Frequent drought, increasing human and livestock populations, poor management and absence of proper ecosystem conservation policies and practices have been identified as the major causes of the deterioration of the vegetation cover and biodiversity in the region.

3.4. Tapping, Quantity and Quality of Gum

Depending on the type of species and altitude, gum producing acacia trees reach productive age (i.e., the beginning of tapping) from 6 to 10 years. In the lower altitude areas: Gode, Mustahil and Kelafo, trees reach productive age slower compared to the districts of higher altitudes. Furthermore, collectors estimated gum yield to range from 1 to 3 kg per tree per annum. Estimates of production per tree were higher in the lower altitude areas compared to higher altitude areas.

Tapping, which is the practice of wounding/incision of trees to facilitate the flow of exudes from the trees, is a very important operation in harvesting gum. Usually, only the bark of the gum producing trees is wounded and the exudates which start oozing just after each wounding dries within two to three weeks and become ready for collection. Tapping and gum collection takes place during the dry season and the wounds are healed when vegetative growth is initiated during the rainy season. Tapping heights on the tree range from 30 cm to 4 m depending on the locality and tree species. Tapping directly affects both quality and quantity of the products, and without proper tapping maximum potential of the tree may not be exploited.

However, unlike in other parts of the country and elsewhere from which gum is collected, farmers in the SNRS do not practice proper tapping with the exception of few collectors. In most of the areas, exudes are simply collected when the tree trunk naturally oozes. In the areas where collectors practiced wounding of the trees, only very poor and traditional tapping techniques are followed. In such areas, trees that are mature for extraction are wounded either by cutting or piercing by local hand tools such as scissors, peelers, knives, axes, sickles, stones, metal or any sharpened material. In most cases, tapping is done twice a year although a tree might be tapped up to five times a year depending on localities and tree species .

In all the study areas, no attention has been given to the direction of tapping and the trees are wounded in all directions. However, there were some exceptional respondents in Aware and Segeg Districts who preferred tapping to be made against wind direction.

Since exudation takes place slowly, granules are collected from two to three weeks after wounding. Local household utensils or materials such as clothes, plastic sacks, barks, bowls, cups and plates were used to collect and transport the produce. The collector farmers practiced some traditional post-harvest processing and storage involving removal of impurities by hand or sieving, grading the produce by color and size of granules and short-term storage in cool places either in the house or under trees. Although color of exudes vary from species to species, high quality gums, according to the respondents, are usually transparent and sticky and any deviation from this, especially darkness, is an indication of poor quality. Impurities at collection, adulteration and long storage were some of the factors identified by majority of the respondents to alter the color and reduce the quality of gums. As a result, collectors seldom store gum for long time. Most collectors transport the products to local market soon after collection. The large majority of the rural community in the Somali Region considered the material and economic benefits from gum collection as secondary to livestock herding and growing crops.

4. Discussion

4.1. Gum Resource Potential

Although about 40% of the 58 species of *Acacia* known to grow in Ethiopia were reported from the Somali Region (Thulin, 1989), only nine were identified as gum producing species in the current study area (Table 1). More than 20 species of acacias were reported to produce edible gums and/or have some medicinal uses in Africa (White, 1983; FAO, 1995b). Among the gum products, the most important are gum arabic from *A. senegal* and gum talh from *A. seyal* (Seif el Din and Zarroung, 1996). Although gum production by *A. etbaica, A. horrida, A. mellifera, A. oerfota, A. sieberiana* and *A. stuhlmannii* had also been reported from elsewhere in tropical Africa (FAO, 1995b), gums produced from these species is limited to local uses in the SNRS.

Unlike in many African countries (Pandey and Chadha, 1996), gum-bearing plants found in the SNRS regenerate naturally and extraction of gums solely depends on the conditions of the natural stock. The fairly good distribution and abundance of gum producing species in the Region (Figures 2 and 3) suggest a considerable potential for sustained production and utilization of gum products. Former studies also indicate that acacias and commiphoras are the dominant species of bushlands and tickets over a vast area of semi arid and arid east and northeast tropical Africa (von Brietenbach, 1963; Friis, 1992; Millington *et al*., 1994).

The quantity and quality of gums that may be obtained from a particular species depend on a number of factors. The most important of these include ambient temperature, rainfall, tree diameter and crown size, method of tapping and length of tapping seasons (FAO, 1995c). The gum producing acacia species in the SNRS State grow in a climate of high diurnal mean temperature, low mean annual rainfall and rapid evaporation (Kuchar, 1988; Millington *et al*., 1994) that strongly favor gum exudation.

The crown size and DBH of a tree are indicatives of site productivity. Crown size represents the assimilatory surface area of the plant. High crown size is usually associated with high leaf area. Photosynthesis, the process for accumulation of carbon compounds including resins, is directly proportional to leaf area if the leaves in the canopy do not shade each other heavily. Under same set of environmental conditions, therefore, a plant with wider canopy produces more resin compared to one with narrower canopy. Within a species, a plant with wider canopy usually has larger diameter compared to one with narrow canopy. Thus, it can be safely stated that the greater the diameter of the tree tapped and the bigger the proportion of live crown size, the greater the gum yield.

4.2. Local Uses of The Gum Producing Tree Species

Wood from acacias is highly valued for construction and fuel among the pastoralists and agro-pastoralists of the SNRS. The gum producing acacias identified in the current study are reported to meet the desirable criteria for firewood (FAO, 1995b). The acacias are the main sources of wood for construction in the Region. The Somali in the study area have developed a wealthy knowledge of traditional medicine which may be promoted for the well-being and economic benefits of the local communities in the region.

According to Newman (1970), bushlands and thickets are generally considered as hindrances to cattle production, and this is true for dry *Acacia - Commiphora* bushlands, which sometimes can hinder stock movement and, due to their density, have only a sparse grass layer. However, under heavy range use, these bushlands tend to be decimated and eliminated rather than stimulated by intensive pastoral activities. This is because most of the important acacias are sources of browse for livestock, especially camel and goat (Table 5). Similar to the Somali Region, the foliages and pods of *A. senegal*, *A. seyal*, *A. etbaica, A. mellifera, A sieberian, A. oerfota* and *A. stuhlmannii* are widely used for animal browse in various countries of Sahelian Africa (Skerman *et al*., 1988; Seif el Din, 1991; FAO, 1995b).

Owing to their N-fixing and soil stabilizing abilities and provision of browse (Rocheleau *et al*., 1988; FAO, 1995b) the *Acacia* species identified in this study can be managed under agroforestry land use and management practices (Mulugeta *et al*., 2003). In the

Sudan, *A. senegal* is incorporated in an agroforestry practice called bush fallow system (Seif el Din and Zarroung, 1996). In this system, the gum producing acacia trees are allowed to grow on farm plots during a fallow period, during which they improve soil fertility to ensure adequate crop production. Thus, the trees protect the soil from erosion, improve its fertility and provide the farmer with cash from the sell of gum during the dry season.

4.3. Regeneration, Tree Planting Culture and Status of the Natural Vegetation

Under natural conditions of the Somali Region, natural regeneration from seeds does not appear satisfactory except in three of the study Districts: Dihun, Gode and Mustahil. The less abundance of seedlings and saplings may either be due to poor germination of seeds or dieback of seedlings and saplings due to moisture stress or animal browsing and trampling. According to Demel (1996), in areas with very variable rainfall, like in arid and semi-arid areas, there is a high level of seed dormancy. As a result, plants of dry regions do not germinate uniformly and rapidly. His study on *A. senegal*, *A. seyal*, *A. oerfota* and *A. sieberiana* indicate that mechanical scarification and acid treatment greatly improve seed germination rate. Soaking seeds of *A. sieberiana* in boiling water also increased germination from less than 10 to 80%. Additional sources (Azene *et al*., 1993) also indicate that most of the acacias adapted to the lowlands require pre-treatment to enhance germination.

4.4. Tapping, Quantity and Quality of Gum

Tapping is a very important operation in the harvesting of gum. It directly affects both quality and quantity of the product. Without proper tapping maximum potential of the tree may not be exploited. Studies carried out in the Sudan (Seif el Din and Zarroung, 1996) indicated that tapping facilitates exudation in *A. senegal*. In addition to facilitating the flow of exudes, tapping creates accumulation site on the tree, which would avoid the contamination of the gum with bark of the tree. Collection of the exudates is also easier from tapped trees. Under the current traditional practice, the average gum yield in the Somali Region ranges from 1-3 kg per tree per annum, which is higher compared to gum arabic production from the Sudan (Seif el Din and Zarroung, 1996). On the other hand, it is relatively lower than the gum yields of 3.4±2.6 and 4.4 ±1.3 kg per tree per year reported by Mulugeta *et al.* (2003) for *A. senegal* and *A. seyal,* respectively, in Liban Zone of the Somali Region. With proper tapping and handling procedures to improve quality and yield, future exploitation of gum resource in the SNRS could be improved enormously.

5. Conclusion

The Somali Region has been known for its production of several non-wood forest products exploited from extensive cover of the *Acacia-Commiphora* dominated vegetation. The present study has identified nine potential gum producing *Acacia* species in the arid and semi arid lands of the Region. Besides of being paramount national and international commodity, these species render multiple local uses such as food, dry season fodder, local construction timber, fuel wood, medicine and maintenance of the environment. Under the existing situation carefully planned and managed exploitation of gum in the Somali Region not only generates local, national and foreign incomes but also ensures a sustainable system of production. Apart from natural regeneration of the gum-yielding species, development of plantation of these species is imperative to ensure the sustainable production and utilization of the gum to benefit the region economically.

Disregarding gum extraction, which would cause almost no damage to the tree, the vegetation is important for livestock production, combating desertification, biodiversity maintenance and provision of the immense non-wood forest products and services. However, the increasing livestock population may cause severe interference to the rather fragile dry bushland and thicket ecosystem. Therefore, integration of gum extraction with other production and conservation programs should also be considered for sustainable production and utilization.

Any damage to the vegetation of the Somali region could be exacerbated by the high temperature, moisture stress as well as the degraded soil. Once damaged, the reclamation of such fragile ecosystem is almost impossible or at least very costly. Thus, the extraction of gum could be a very good option to promote local level accountability for the management of the resources. The lack of basic infrastructure, such as road and other communication facilities, at least for the moment, are the bottlenecks to attract investors from outside of the local community. Therefore, the communities of the study areas seem to be the potential group to develop, manage and conserve or sustainably utilize the vegetation resource. Proper management system that promotes the extraction of gums to meet the short-term needs of the local people and the long-term sustainability of the resource base must be designed to ensure a healthy co-existence of the vegetation, livestock and people in the ecologically fragile Somali Region of Ethiopia.

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7. References

Azene, B., Birnier, A. and Tengnas, B. 1993. Useful Trees and Shrubs of Ethiopia: Identification, Propagation, and Management for Agricultural and Pastoral Communities. Regional Soil Conservation Unit. Technical Handbook. Kenya.

Cossalter, C. 1991. *Acacia senegal*: gum tree for promise for agroforestry. NFT Highlights, NFTA 91-02. Nitrogen Fixing Tree Association, Hawaii.

Demel, T. 1996. Germination ecology of twelve indigenous and eight exotic multipurpose leguminous species of Ethiopia. For. *Ecol. and Manage.* 80: 209-223.

EFAP (Ethiopian Forestry Action Program). 1994. Ethiopian Forestry Action Program, Vol. II. The Challenge for Development. Ministry of Natural Resources Development and Environmental Protection, Addis Ababa.

Ethiopian Meteorological Agency. 2002. Report on meteorological data recorded on the different Weather Stations in Ethiopia.

FAO (Food and Agriculture Organization). 1995a. Non-Wood Forest Products for Rural Income and Sustainable Forestry. FAO, Rome.

FAO (Food and Agriculture Organization). 1995b. Role of Acacia Species in the Rural Economy of Dry Africa and the Near East. FAO Conservation Guide 27, Rome.

FAO (Food and Agriculture Organization). 1995c. Report on International Experts Consultation on Non-Wood Forest Products. FAO, Rome.

Friis, I. and Mesfin, T. 1991. The evergreen forests of tropical northeast Africa. *Mitt. Inst. Allg. Bot.* 23: 249-263.

Friis, I. 1992. Forest and forest trees of north east tropical Africa. *Kew Bulletin* 15:1-396.

Hedberg, I. and Edwards, S. 1989. Flora of Ethiopia, Vol. III: Pittosporaceae to Araliaceae. Addis Ababa University, Ethiopia and Uppsala University, Sweden.

Kuchar, P. 1988. The Plants of Somalia: An Overview and Checklist. Revised Draft, LBII- USAID, CRDP, Mogadishu.

Millington, A.C. Critchley, R.W. Douglas, T.D. and Ryan, P. 1994. Estimating Woody Biomass in Sub-Saharan Africa. The World Bank. Washington DC.

Mohamed, B. and Mishra, B.B. 2005. Characterization of some soils of Jijiga plain, eastern Ethiopia (in press)

Mulugeta, L. Tarekegn, A. and Olsson, M. 2003. Gum and resin resources from some *Acacia, Boswellia* and *Commiphora* species and their economic contributions in Liban, south-east Ethiopia. *J. Arid Environ*. 55: 465-482.

Murphy, H.F. 1968. A Report on the Fertility Status and Other Data on Some Soils of Ethiopia. Experimental Station Bulletin No. 44. College of Agriculture, Haile Selassie I University, Ethiopia.

Newman, J.L. 1970. The Ecological Basis for Subsistence Change among the Sandawe of Tanzania. Nat. Acad. Sci., Washington, DC.

Pandey, S.N. and Chadha, A. 1996. Economic Botany. Vol. III. Vikas Publishing House, Pvt. Ltd. Bombay.

Rocheleau, D., Weber, F. and Field-Juma, A. 1988. Agroforestry in Dryland Africa. Science and Practice of Agroforestry, ICRAF, Nairobi.

Seif el Din, A.G. 1991. Acacia species in Rural Development in Dry Land Africa. Arid zone forestry and desertification control. FAO, Rome.

Seif el Din, A.G. and Zarroung, M. 1996. Production and Commercialization of Gum Arabic in Sudan. *In*: Leakey, R.R.B. Temu, A.B. Melnyk, M. and Vantomme, P. (eds.) Domestication and Commercialization of Non-Timber Forest Products in Agroforestry Systems, FAO-NWFP 9.

Skerman, P.J., Cameron, D.G. and Riveros, F. 1988. Tropical Forage Legumes, Second Edition. Plant Production and Protection Series No. 2. FAO, Rome.

Thulin, M. 1989. Fabaceae, In: Hedberg, I., Edwards, S., (Eds.), Flora of Ethiopia, Vol. III: Pittosporaceae to Araliaceae. Addis Ababa University, Ethiopia and Uppsala University, Sweden.

UNDP/RRC (United Nations Development Program/Relief and Rehabilitation Commission), 1984. The Nomadic Areas of Ethiopia. Study Report, Part-II. The Physical Land Resources. Addis Ababa, Ethiopia.

von Breitenbach, F. 1963. The Indigenous Trees of Ethiopia. Second Edition. Addis Ababa.

WCMC (World Conservation Monitoring Center). 1991. Biodiversity Guide to Ethiopia. World Conservation Monitoring Center, Cambridge.

White, F. 1983. The Vegetation of Africa. A Descriptive Memoir to Accompany the UNESCO/AETFAT/UNSO Vegetation Map of Africa. *Natural Resources Research* 20: 1-356.

Adding Benzene to Fire: Overlapping Seasonality as a Pull Factor to Producer Prices in Ethiopia

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Abstract: Coupled with the seasonal nature of agricultural production, seasonality of farmers' cash demand influences the level of actual market supply and price of agricultural products. This study investigates the seasonal behaviours of producer prices and farmers' cash demand for two crops (white teff and white wheat) that serve as staples and sources of cash income around Ambo, Ethiopia. Descriptive studies on price time series show that producer prices for the two crops get low during the harvest and immediate post harvest seasons and survey results show that most farmers have a high demand for cash during same seasons and, as a result, sell a great proportion of their marketable stock of the two crops during such seasons. This creates overlapping seasonality between agricultural production, on the one hand, and high cash demand of farmers, on the other. This overlapping seasonality due to the high cash demand of farmers is expected to aggravate the seasonal decline of producer prices already resulted from the seasonal supply of agricultural production. A most likely policy implication, to raise and stabilize producer prices, is therefore to influence the seasonal behaviour of farmers' high cash demand in such a way that it coincides with the lean seasons of agricultural supply. This could be approached through rescheduling the time of fertilizer debt and land use tax payment, those important factors that put farmers into selling a large proportion of their marketable crops during such seasons of low producer prices. By raising and stabilizing farmers' income from crop sales, such policy will promote the economic incentive of smallholder farmers to increase their productivity.

Keywords: Producer Price; Farmers' Cash Demand; Overlapping Seasonality; Sub-Saharan Africa; Ethiopia

1. Introduction

A large volume of literature on the evaluation results of the market reform process implemented in Sub-Saharan Africa countries witness a shortfall in achieving the outcomes expected from the reform process (for example, Badiane, 2000; Thorbeke, 2000; Kherallah *et al*., 2002). The agricultural supply response, especially that of food crops, is found very limited to abate the problem of chronic food insecurity challenging the people in the region. While a number of factors might be held accountable for this limited supply response, underdevelopment of domestic agricultural markets (or market failure) in the sense of lacking basic premises to enable a wider participation of the private sector through transaction cost reduction and through vested risk management and risk absorption capacity remains undoubted explanatory factor for much of the shortfall. The resulting price levels and variability affect the choice set and decisions of farmers, which, in turn, determine the productivity and supply response of farmers to the market reform process.

The results of price response analyses towards understanding whether the previously suppressed agricultural prices in the developing countries shifted positively following the market liberalization are inconclusive. In fact, Sahn *et al*. (1996), Seppala (1997), Valdes (1996), and Badiane (2000) found quite similar results about agricultural product prices after the market reform. Sahn *et al.* (1996) concluded that the real producer prices of cash crops and tradable food crops did not show proportionate rise to the level of devaluation, which is one of the liberalization measures. Seppala (1997), from his comparative study in Sub-Saharan Africa countries, concluded that liberalization is accompanied by a decline in real prices of food crops, in some countries, and by a moderate increase in others. In an analysis of producer prices between 1986 and 1995, Valdes (1997) found that all major producer prices had declined in real terms, in seven out of eight Latin American countries, following market liberalization. Results due to Alderman and Shively (1996), for the real wholesale Ghanaian food prices, evidence a continuously downward trend in the post-reform period. Badiane (2000), in his study of the effects of market reforms on local market prices for Benin, Malawi, and Ghana (six regional markets for each country), found that rural prices in most markets have declined during the market reform period.

Whereas market failure might be part of the problem, the seasonality of agricultural production and seasonality of farmers' cash demand may also contribute towards decline in agricultural product prices. Since food crop production is rooted in the biological process of agricultural production, seasonality is a common phenomenon in agricultural production, supply, and price. As a matter of fact, agricultural prices tend to be seasonally low during the harvest and immediate post-harvest seasons even for storable products, typically so where the role of market to promote temporal arbitrage is limited. In absence or limitation of other income sources, seasonal cash demand of farmers puts them into selling much of their

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marketable crop surplus within a certain period of time to fulfil their quick cash requirements. This becomes a potential source for major price decline when it overlaps with the season of low agricultural prices (i.e., the season of high agricultural product supply).

As a result of transformations in traditional agriculture (from subsistence to semi-commercial agriculture), cash requirements of smallholder farmers are growing even among those producing mainly food crops (Getnet, 2005). As such, it might be necessary to assess the role of farmers' seasonal cash requirement in terms of influencing the market supply of products and, thereby, agricultural prices and farmers' economic incentives. The investigation would help to generate useful information to guide intervention so as to influence the pattern of farmers' seasonal cash demand in such a way that it does not overlap with the season of low agricultural prices (the season of high agricultural product supply). This study tries to address such issues around Ambo (Ethiopia) based on information generated from secondary data with regard to the seasonal behaviours of producer prices and from primary data with regard to the seasonality of farmers' cash demand, for two staples in the country, namely white teff and white wheat.

The remaining part of the paper is organized as follows: First, the seasonal behaviours of producer prices are investigated using descriptive methods. Second, survey results on farmers' seasonal cash requirements and perceptions on price seasonality are discussed together with the main factors affecting their cash demand. Finally, conclusions and policy implications are set forth.

2. The Seasonal Behaviours of Producer Prices

The analysis on the seasonal behaviour of producer prices is based on real producer price data of white teff (PWT) and real producer price data of white wheat (PWW) observed at monthly frequencies starting from 1996M1 to 2000M2 in a typical grain market (Ambo), a surplus production area located in central west Ethiopia. The time period is chosen on the basis of availability of continuous monthly price data in the post-liberalization period along with country level consumer price indices useful to adjust the price data for possible inflation (deflation) to obtain real producer prices.

The seasonal property of the real producer price series for each crop was identified using the seasonal dummy coefficient method in which the sign and magnitude of a dummy coefficient for a month indicate the position and importance of a given month's departure from the month considered as a reference. For example, if January is considered as a reference month in terms of exhibiting very low producer prices (so is the case in this study)[1], the rest of the months are expected to depart from it positively but with different magnitude of departure depending on their closeness to it[2]. Whereas those months near to January are expected to have similar properties, hence limited magnitude of departure (because more or less demand and supply situations in such months remain the same like that of January), those months distant from January are expected to have different properties and hence significant magnitude of departure. Accordingly, the resulting information can be used to have useful insight into the seasonal properties of the producer prices. Table 1 shows the relative position and magnitude of departure of prices in the rest of the months from that of the reference month, January, which is considered as a constant in the specification and estimation procedure.

Since the coefficients reflect the magnitude of deviation of each respective month's price from that of January's price (the reference month with the lowest producer price), months with nearly similar seasonal behaviour to that of January have only small deviation from that of the January's price (hence small magnitude of seasonal dummy coefficient). If deviations have small magnitude, *t*-ratios also become insignificant. This is typically true for December, February, March, April, and May in the case of each crop, with November added for that of white wheat. Hence, it could be argued that these months have seasonal effect on producer prices with no significant difference from that of January's price whereas the rest of the months show seasonal behaviour with significant difference from that of the reference month's price. Accordingly, December, January, February, March, April, and May (harvest and immediate post-harvest seasons) could be considered as months in which real producer prices for white teff and white wheat are low, relatively speaking, with November included in the case of white wheat. On the other hand June, July, August, September, and October (lean seasons) could be considered as months in which real producer prices for white teff and white wheat are high, relatively speaking, with November excluded in the case of white wheat.

Additional information about the seasonal behaviours of producer prices could also be obtained by isolating the seasonal component of prices from other components using the classical multiplicative model techniques of time series data decomposition into trend, cyclical, seasonal, and irregular components. Using this descriptive approach, the Grand Seasonal Index (GSI) of each month (which is the indicator of the seasonal properties of the real producer prices) is obtained by averaging the ratio-to-moving average of each month observed over the five years (1996M1 to 2000M12). Then, the seasonal properties of real producer prices could be understood by observing the position of such GSI figures of each month vis-à-vis the annual average producer price observed over the sample period. GSI for some months fall below the annual average and for other months fall above the annual average[3].

Table 1. Seasonal dummy coefficients of real PWT and real PWW (1996M1-2000M12)

PWT			PWW	
	Dummy coefficient [a]	*t*-ratio	Dummy coefficient [a]	*t*-ratio
Constant	162.0	16.43***	112.0	9.34***
February	7.0	0.50	4.2	0.25
March	4.6	0.33	4.0	0.24
April	4.0	0.29	3.0	0.18
May	22.4	1.61	20.2	1.19
June	34.4	2.47**	29.2	1.72*
July	34.6	2.48**	29.8	1.76*
August	33.2	2.38**	31.0	1.83*
September	27.2	1.95*	34.4	2.03**
October	26.6	1.91*	35.8	2.11**
November	27.7	1.96*	18.2	1.07
December	12.6	0.90	10.6	0.62

*Note: ***, **, and * = t-ratio is significant at 1%, 5%, and 10% significance level, respectively.*
[a] These coefficients are calculated using OLS estimation of regression equation in which the 11 months (February to December) are used as dummy variables and January is omitted for serving as a constant. All the coefficients are positive indicating that January is the month with the lowest real producer prices in the case of each food crop. Should another month be omitted in the regression, there could also be negative coefficients.

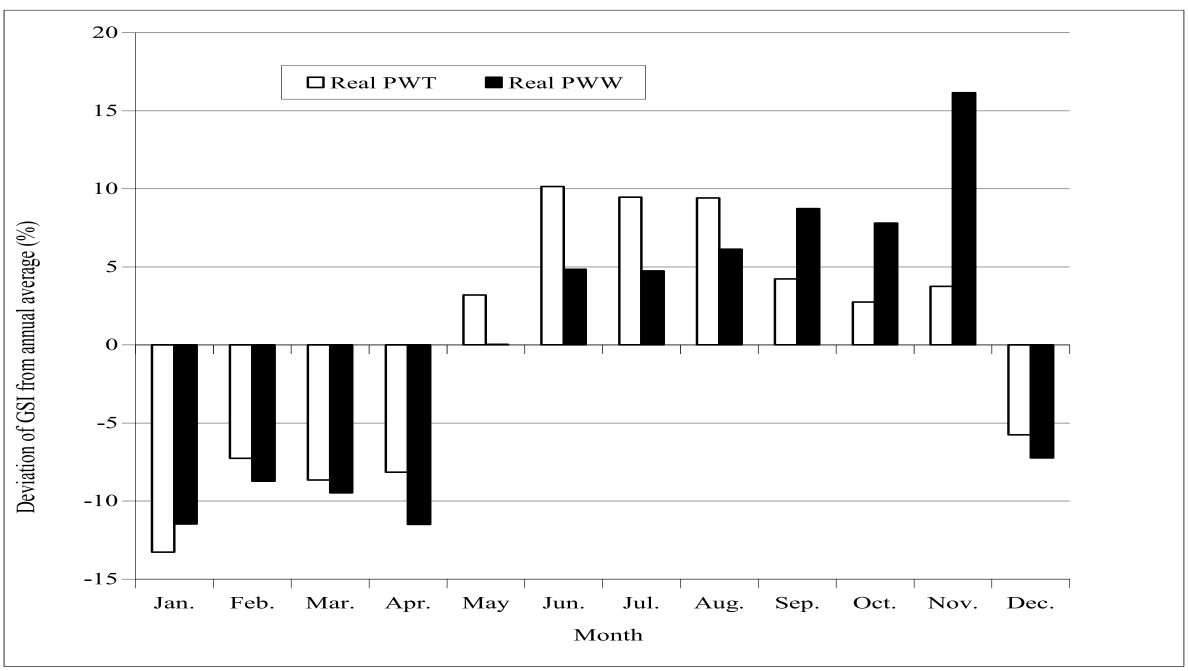


Figure 1. GSI for white teff and White wheat (1996M1-2000M12)

As shown in Figure 1, the position of the deviation of each month's GSI value from the annual average provides sufficient evidence in confirmation of the results shown in Table 1. Negative deviation in the GSI of a month from the annual average indicates that the price observed in that month is lower than the annual average price and positive deviation indicates that the price observed in that month is higher than the annual average price.

Based on the evidences obtained from the above two approaches employed to understand the seasonal properties of producer prices, December, January, February, March, and April can be considered as months with relatively low producer prices and June, July, August, September, and October as months with relatively high prices for white teff and white wheat. In circumstances when the cash demand of the farmers of such crops overlaps with such months in which producer prices are relatively low, producer prices will decline further to make it very difficult for the farmers even to cover production costs incurred in the production process of the crops. Hence, overlapping seasonality between the farmers' high cash demand, on the one hand, and the harvest and immediate post-harvest seasons for their crops, on the other, becomes a pull factor to producer prices – adding benzene to fire. If farmers happen to sell a large proportion of their products during such months, the low prices they receive will discourage them not to increase their production and the impact of the market reform process will remain limited in terms of achieving food self-sufficiency and food security in the country.

3. Farmers' Perceptions about Price Movements and the Seasonal Properties of their Cash Demand

In addition to their resource bases and production objectives, farmers' perceptions about the prices of their products are very important in terms of guiding their production and marketing decisions. Difference in the perceptions of any two farmers about the price level of products would possibly lead them to different production decisions even if they might have similar resource base and production objective. On the other hand, it is possible that any two farmers with different resource bases and production objectives but with similar perceptions about the price level of products and about the resulting risk or benefit take similar production decisions. In this section, survey results on farmers' perceptions about the month-to-month variations of producer prices are presented. The need to know farmers' perceptions about the prices of their products is related to the critical need to know what bearings such perceptions have on the production and marketing decision making behaviours of the farmers. Specifically, farmers' perceptions about the monthly variations in the producer prices of the two crops are thought to influence their storage and marketing decisions.

3.1. Farmers' Perceptions about Monthly Price Variations

As it is mentioned under the descriptive study, producer prices of white teff and white wheat, like any other agricultural product, have seasonal patterns. Though the knowledge about such seasonal patterns of producer prices does not necessarily help farmers to plan and change their production period accordingly, because production period depends on environmental factors, it definitely helps them to plan their storage and marketing activities. Therefore, appropriate perceptions by farmers about the seasonal patterns of producer prices of their products are important in terms of guiding their storage and marketing decisions.

What are the months in which farmers perceive producer prices to be too high and too low?[4] Farmers perceive producer prices of both crops to be too high in August, July, and June and to be too low in January, December, and February, in their decreasing order of importance. Such perceptions of farmers about the seasonal patterns of producer prices (concerning the low price scenarios) coincide with the results obtained from the descriptive study on the time series price data. With regard to the high price scenarios, too, there is a similarity between the results obtained from the descriptive study and those from the survey study in that the months identified by the survey study as months with high producer prices, i.e., June, July, and August, fall within the range of those months identified by the descriptive study as months with high real producer price indices (June, July, August, September, October, and November). One exception in this aspect is that November is the month with the highest real producer price index for white wheat, in the descriptive study, while it is August in the survey study. This difference might be attributed to the fact that the descriptive study used real prices while farmers' perceptions used in the survey are based on nominal prices.

3.2. Seasonal Properties of Farmers' Cash Demand

Generally speaking, months perceived by the farmers as those with low and high producer prices fall within the domain of those months identified by the descriptive study as months with low and high producer price indices, respectively. In view of this fact, it would be recommended, without fallacy, that storage is feasible in December, January, and February (when the producer prices are low) and selling is feasible in June, July, and August (when the producer prices are high), for both products. Getnet *et al*. (2005) have shown that grain storage at the level of such smallholder farmers is economically feasible during December, January, and February. Exploitation of the advantages from such timing of storage and selling activities becomes possible provided that those factors that put farmers into selling their crops during the months with low producer prices are manipulated. Farmers have compelling reasons that put them into selling their products during such months of low producer prices with no possibility to postpone the crop sales. The survey results show that farmers, in spite of their perception of low producer prices in these months, sell the largest quantity of their marketable white teff and white wheat in January, December, and February, in their decreasing order of importance (see Figure 2).

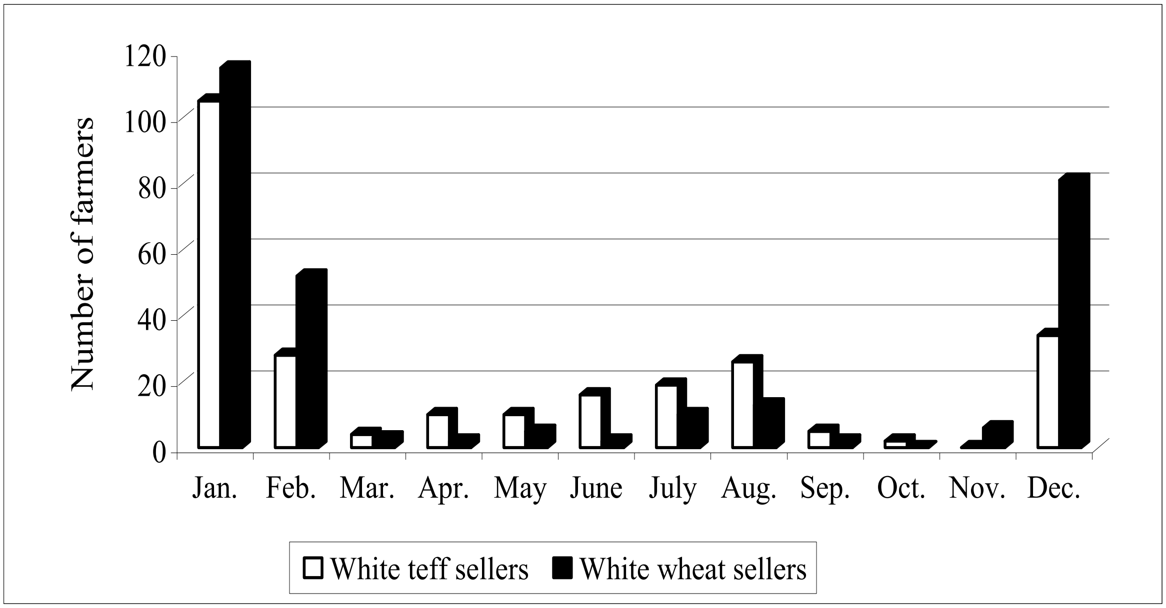
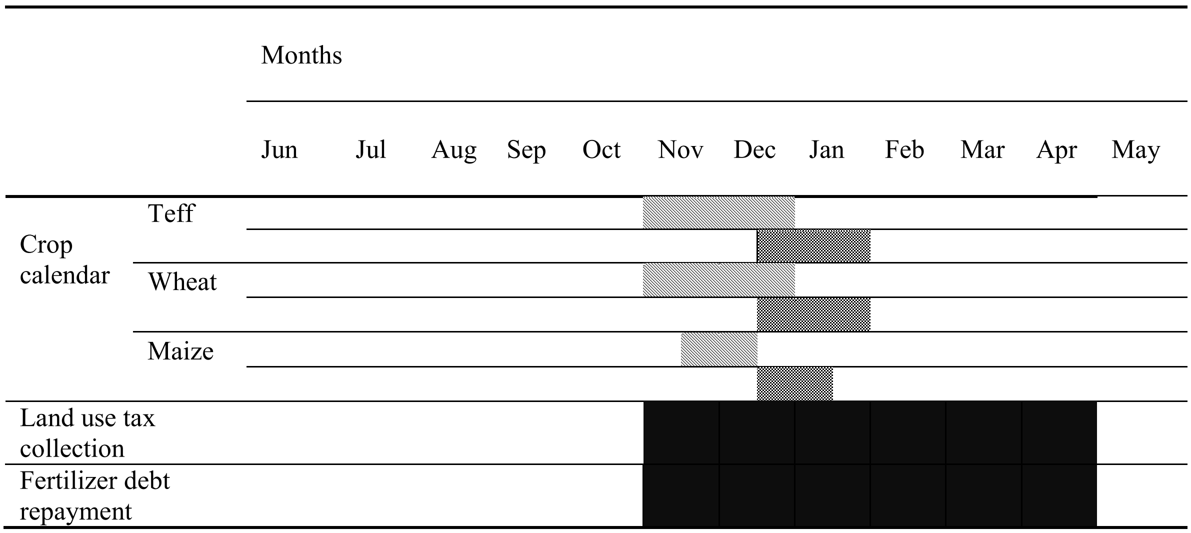


Figure 2. Farmers' responses on the timing of their white teff and white wheat sale

It is important, therefore, to identify the reasons for which farmers are forced to sell their products during such months in which producer prices are relatively low, in spite of their knowledge about the nature of the seasonal price variations that turn against their advantage in December, January, and February. If these factors are subject to manipulation, both at the level of the farmers and government, the identification could help farmers to benefit from appropriate timing of their storage and selling activities according to the seasonal behaviours of prices. In order to fulfil this, the survey study tries to identify the reasons for which farmers are forced to sell their products during such months in which producer prices are low. According to the survey results, *land use tax* and *fertilizer loan payment*[5] are found as the main reasons that put farmers into selling their crops during the respective months in which producer prices are low. For crop sales constitute the most important sources of family cash income in such smallholder farm households, farmers opt to crop sales when they are required to settle their land use tax and fertilizer debt obligations. Since this is well known by the Office of Finance and Economic Development (OFED) and by the Office of Agriculture Development (OAD), Ambo district, which collect land use tax and advance the fertilizer credit, the land use tax and fertilizer debt collection are intentionally scheduled from November to April, with more emphasis given to January and February in the case of the OAD for fertilizer debt collection (according to the survey results from the rapid appraisal). Such seasonality of the schedule for land use tax and fertilizer debt collection is rationalized on the crop calendar of farmers (see Table 2). Key informants from the OFED and from the OAD confirm that the schedule is not subject to any revision for it must necessarily coincide with the crop calendar of farmers in order to make the farmers settle such cash obligations from crop sales[6]. The crop calendar, in turn, depends on the biological nature of the agricultural production in which crop harvesting and threshing in Ambo and in most parts of Ethiopia are practiced from early November to late January, hence the scheduled land use tax and fertilizer debt payment from November to April.

Table 2. Crop calendar and schedule for land use tax and fertilizer debt payment around Ambo



Source: Author's survey results (2002); OPED (1998).
Note: Harvesting season. Threshing season.

In addition to stating their own reasons that put them into selling large quantities of crops in those months in which they perceive producer prices to be low, farmers were also asked to state other reasons which they believe make producer prices too low in December, January, and February. Their collective responses to these questions show poor market access and excess production (whenever there is favourable weather condition) as the third and fourth important factors, for both crops. Such factors supposed to be responsible for the low producer prices in December, January, and February are rated as shown in Table 3, based on farmers' perceptions.

Table 3. Factors responsible for low producer prices of white teff and white wheat in December, January, and February

Factors	Rate of importance and number of selectors									
	White teff					White wheat				
	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
Fertilizer debt	**122**	65	0	0	0	**120**	63	2	0	0
Tax payment	56	**111**	19	1	0	52	**106**	28	0	0
Poor market access	7	12	**79**	22	1	12	17	**68**	21	1
Excess production	2	0	27	**51**	0	2	0	26	**48**	0
Poor storage facility	0	0	2	0	***2***	0	0	3	0	**5**

Note: 1st = Highly important factor and 5th = Less important factor.
Cell entries refer to the number of scores marked for the particular factor under each rate.
Bold figures in each column indicate the factor that is perceived to be most important.

Though majority of the farmers sell a large proportion of their marketable teff and wheat products in December, January, and February, typically for settling land use tax and fertilizer debt, it is found that a considerable number of them sell their products also in July and August (see Figure 2). According to the survey results, the main reason of these farmers for delaying the sell of their products until July and August is the need to benefit from high prices for their commodities in these months. This shows that some farmers perform storage functions and are also aware of the benefits they could gain from postponing the sell of their products. For majority of the farmers, however, this is not easy as the immediate problem of settling land use tax and fertilizer debt obligations, in December, January, and February, is irrefutable.

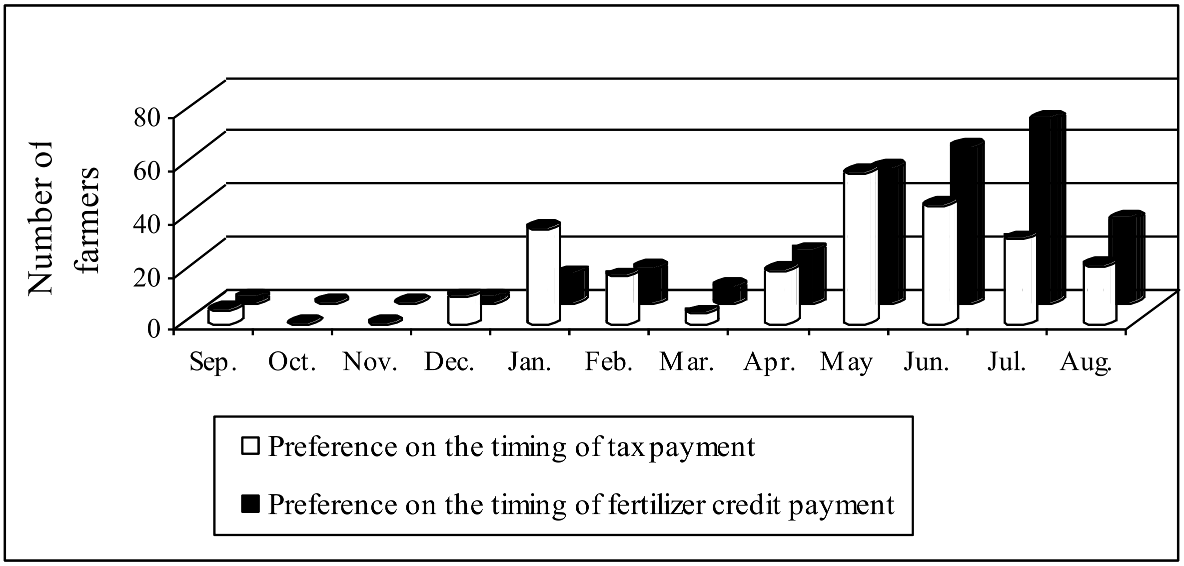


Figure 3. Farmers' preferences on the timing of land use tax and fertilizer debt payment

If given the chance to postpone the payment of their land use tax and fertilizer debt obligations, therefore, it can be assumed that farmers are rational and tend to exploit the advantage of high crop prices in the late months (May, June, July, August, September, and October) by delaying their crop sell until then. Their response to a question on their preference for the timing of land use tax and fertilizer debt payment shows months from May to August as the first four months of preference (see Figure 3). These months coincide with those months of high producer prices of the two crops, as revealed both from the descriptive study results and from the farmers' perceptions about price movements. Unless it has negative implications on the tax collection and revenue schemes of the government and technical and budgetary influences on the creditors of fertilizer debt, therefore, rescheduling land use tax and fertilizer debt payment according to farmers' preferences would benefit farm households in terms of better prices to their crops. However, the results from the rapid appraisal survey concerning this issue show that the OFED and OAD do not seem flexible to reschedule the collection of fertilizer loan and land use tax, indicating that policy makers need to reconsider it if possible.

4. Conclusions

Rooted in the biological nature of agricultural production, the harvest and supply of agricultural products are generally seasonal. In the absence of a well developed marketing system to perform processing, storage, and transportation functions, the seasonal supply of agricultural products affects product prices negatively during the harvest and immediate post-harvest seasons. In addition to the seasonal supply of products due to the biological nature of their production, seasonality of farmers' cash demand contributes to further decline of product prices if it overlaps with the harvest and immediate post-harvest seasons.

The case of white teff and white wheat investigated in this study reveals overlapping seasonality between the harvest and immediate post-harvest seasons (December, January, February, March, and April), on the one hand, and the seasons of high cash demand by farmers, on the other. Obviously, the overlap is expected to further reduce the price of products received by the farmers, since price is already low as a result of excess supply during such seasons. From policy making point of view, raising and stabilizing farmers' income from such crop sales would possibly be approached through shifting the seasons of high cash demand by the farmers. This, in turn, requires knowledge about those factors that raise the cash demand of farmers during the harvest and immediate post-harvest seasons, for possible intervention of manipulation. In the study area, the survey results show that land use tax payment and fertilizer debt payment (scheduled from November to April) are the first two most important factors that raise the cash demand of farmers during the harvest and immediate post-harvest seasons of the two crops. Scheduling land use tax payment and fertilizer debt payment during the harvest and immediate post-harvest seasons ends in adding benzene to fire, in which the already low prices of the crops due to their high seasonal supply tend to further decline.

Provided that it has no or only a very limited impact on the government tax administration and revenue and on the default rate of fertilizer debt payment, it is advisable to reschedule the time of land use tax collection and fertilizer debt payment from the harvest and immediate post-harvest seasons to the lean seasons (June, July, August, September, and October). An alternative would be also to create a mechanism of cash earning to the farmers that do not put them in a position of selling their crops during the harvest and immediate post-harvest seasons. In this regard, the recent initiative of the Ethiopian government to issue a certificate to a farmer upon his delivery of grains to a stocking centre, for the certificate to be used as a guarantee to borrow money to satisfy his immediate cash demand, is a commendable strategy. Moreover, establishing and promoting agricultural marketing cooperatives would be helpful to member farmers in terms of providing better marketing opportunities for their products by allowing them to generate immediate cash during the harvest and immediate post-harvest seasons and by enabling them to get dividends from the profits generated as a result of delayed sell of the grains stored by the cooperatives during the harvest and immediate post-harvest seasons. To the extent that their economic incentives from the production and marketing of such crops are promoted using the different mechanisms mentioned above, the farmers will increase their agricultural production and productivity, with positive contribution to the welfare of the farm households, in particular, and to the food self-sufficiency and food security objectives of the country, in general.

5. References

Alderman, H. and Shively, G. 1996. Economic reform and food prices: Evidence from markets in Ghana. *World Development* 24(3): 521-534.

Badiane, O., 2000. The Effect of Liberalization on Food Markets in Africa. *In*: van Tilburg, A., Moll, H.A. and Kuyvenhoven, A. (eds.), Agricultural Market Beyond Liberalization. Kluwer Academic Publishers, USA.pp. 19-56.

Getnet, K. 2005. Behaviour of farmers towards price changes beyond liberalization of grain markets in Ethiopia. Ph.D dissertation, Ghent University, Belgium.

Getnet, K., Verbeke, W. and Viaene, J. 2005. Feasibility of on-farm commercial grain storage in the smallholder agriculture of Ethiopia. *Outlook on Agriculture* 34: 41-47.

Kherallah, M., Delgado, C., Gabre-Madhin, E., Minot, N. and Johnson, M.2000. Agricultural Market Reforms in Sub-Saharan Africa: A Synthesis of Research Findings. Revised Draft, IFPRI, Washington, D.C.

Sahn, D.E., Dorosh, P. and Younger, C. 1996. Exchange Rate, Fiscal and Agricultural Policies in Africa: Does Adjustment Hurt the Poor? *World Development* 24(4):719-747.

Seppala, P. 1997. Food Marketing Reconsidered: An Assessment of the Liberalization of Food Marketing in Sub-Saharan Africa.UNU World Institute for DevelopmentEconomics Research, Research for Action 34, Helsinki, Finland.

Thorbecke, E. 2000. Agricultural Markets Beyond Liberalization: The Role of the State.*In*: van Tilburg, A., Moll, H.A. and Kuyvenhoven, A. (eds.), Agricultural Markets Beyond Liberalization. Kluwer Academic Publishers, USA. pp. 19-56.

Valdes, A. 1996. Surveillance of Agricultural Price and Trade Policy in Latin America during Major Policy Reforms. World Bank Discussion Paper No. 349, World Bank, Washington, D.C.

Appendix I. Isolation of seasonal indices (GSI) using the classical multiplicative model of time series decomposition

In a classical multiplicative model of time series decomposition, price series P_i could be decomposed into four component parts as follows:

$$P_i = T_i \times C_i \times S_i \times E_i \qquad (1)$$

where P = price, T = trend component, C = cyclical component, S = seasonal component, E = irregular component, i = time period (i = 1, 2, …, n)

Calculating the centred moving average values (CMA) of a series over a certain time period, for example, CMA^n (n = 12) with monthly data, completely eliminates the seasonal price movements (S_i and E_i components) observed in the P_i series over the twelve months. Hence, if CMA removes the irregular components and seasonal movements of a price time series, it follows that CMA^{12} figures are without S_i and E_i components. That is, CMA_i^{12} reflects only the trend and cyclical components ($P_i = T_i \times C_i$). Therefore, dividing (1) to CMA^{12} helps to obtain the ratio-to-moving average values for each month, which is referred to as the seasonal index $\widetilde{S}_i$.

$$P_i / CMA^{12} = \widetilde{S}_i = (TCSE/TC)_i = S_i E_i \qquad (2)$$

Since the seasonal index (S_i) under (2) constitutes both the seasonal component (S) and the irregular component (E) of the series, it is important to calculate the Grand Seasonal Index (GSI) to obtain the pure seasonal component. The GSI, which is an average of each month's seasonal indices, removes all random movement or irregular component of the time series data and filters out the pure seasonal component. Accordingly, there are twelve GSI (one for each month, calculated as average) and these twelve figure series are adjusted in such a way that they add up to 1200, when each month's value is expressed in percentage.

$$GSI_i = \widetilde{S}_i \times \left[1200 / \sum_{i=1}^{12} \widetilde{S}_i \right] \qquad (3)$$

where $\widetilde{S}_i$ is the average seasonal index for month i.

End Note

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[1] *January is considered as the reference month with the lowest producer prices for white teff and white wheat since it is the month in which these crops are harvested and threshed.*

[2] *In case the reference month is with the highest possible monthly price, the rest of the months are expected to depart from it negatively with different magnitude of departure depending on their distance from it.*

[3] *See Appendix I on how the classical multiplicative model of decomposition is used to isolate the seasonal components (GSI).*

[4] *"Too high" and "too low" prices, as used here, are not quantified objectively, rather they are used subjectively as relative concepts to refer to price levels that deviate too much from the levels acceptable as normal.*

[5] *Because farmers can not pay the full price to acquire inorganic fertilizers (such as DAP and UREA) during the production seasons (mainly June and July), the widely used practice is for the government to pay fertilizer prices to the suppliers on the farmers' behalf and for the farmers to take the fertilizers on credit basis with the agreement that they repay the loan from crop sales ahead during the harvest and immediate post-harvest seasons.*

[6] *As an alternative to escape low seasonal prices, experts from the OFED, Ambo district, suggest that farmers better store their crops during such months of land use tax and fertilizer debt payment and settle their obligations from other income sources such as livestock sales. However, this will not be an easy option for all farmers since the livestock base of farm families may not be necessarily dependable.*

Registration of *Ilani* and *Oda* Durum Wheat Varieties for Highlands of Bale

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Abstract: Two durum wheat (*Triticum durum* desf.) varieties: *Ilani* (DZ 2234) and *Oda* (DZ 2227) developed by Sinana Agricultural Research Centers were released for production in highlands of Bale similar agro ecologies. These varieties were selected and evaluated at Sinana on-station and three on-farms in highlands of Bale for three consecutive years and they were proved to have stable, high yield and superior industrial qualities. They were also proved to have resistance to stem, yellow and leaf rusts. Multilocation testing in the regional variety trial confirmed their productivity with above-average yield performance in all environments and demonstrated their yield stability compared to the commercial durum wheat cultivars Foka, Cocorit-71 and Ingiliz.

1. Agronomic and Morphological Characteristics

The agronomic and morphological characteristics of Ilani and Oda varieties, and the checks are given in appendices I and II.

2. Yield Performance

Multilocation testing was conducted within the regional variety trial, which consisted 20 durum wheat genotypes including two standard checks (Foka and Cocorit-71) and one local check (Ingiliz). The trial was grown at four sites for three consecutive years covering the durum wheat growing environments in the highlands of Bale. The results of the trial provided useful information on variety adaptation and yield stability. Yield performance of the multilocation testing for promising genotypes among the twenty genotypes is summarized in Table 1.

Location by year mean yields of each of varieties *Ilani* and *Oda* were higher than all entry mean yields for the tested seasons. They were also higher than the mean yields of the two standard checks, Foci and Cocotit-71, and a local check (Ingiliz). Based on the grand mean, *Oda* out yielded the standard check, Foka by 17.5% and Local check by 12.8% and *Ilani* out yielded Foka by 11.4% and the local check by 7%. These two varieties also proved to have higher average yield ranges (Table 1). In addition, *Oda* was the top yielder at six environments and *Ilani* at four environments. In conclusion, the yield performance of the varieties was above average in many environments, and both varieties were superior to Foka and Ingiliz in their grand mean.

3. Stability Performance

Regression coefficients (b) and deviation from regression (S^2d) were calculated as stability parameters for three years. Eberhart and Russell (1966) defined a stable variety as one with unity regression coefficient and small deviations from regression. Accordingly, *Ilani* was stable for two seasons (1999/2000, and 2000/2001), and *Oda* for one season (2000/2001), Foka for two season (1999/2000, and 2000/2001), and Kilinto for one season (1999/2000). It can thus be concluded that *Ilani* is the best in yield stability and superior to the check varieties, and the genotype *Oda* is comparable in stability to Foka.

4. Reaction to Stem, Yellow and Leaf Rusts

Reactions to stem, yellow and leaf rusts were recorded for all genotypes at all sites (Table 1). The scores of the two varieties were less than 20Ms; therefore, the varieties may be considered to have adequate resistance to all the three rust diseases. However, all checks were found to be susceptible to ether of the three rusts relative to the newly released varieties. Therefore, the varieties are more resistant to the three rusts.

5. Quality Analysis

The quality analysis of both physical grain analysis and chemical wheat flour analysis were presented in Tables 2 and 3, respectively. The result showed that both *Ilani* and *Oda* varieties have the best hectoliter weight and vitreousness qualities from physical quality parameters, and best wet gluten and falling number from chemical quality parameters. These released varieties were highly appreciated and accepted by food factories as their quality met required standards.

6. Conclusions

The durum wheat varieties Ilani and Oda had above average yield performance in most test environments, out yielded the Foka and Ingiliz. They have also better yield stability than checks. They are more resistant to stem, yellow and leaf rust diseases, have good agronomic characteristics, and are superior in quality. They are, therefore, released for production in all wheat growing environments in the highlands of Bale and other locations with similar agro ecologies.

7. Reference

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

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Table 1. Mean agronomic traits and disease measured on two released durum wheat varieties and checks in multi location testing, 1999-2001

Genotypes	DH	DM	PH (cm)	LR (%)	SR (%)	YR (%)	SP (00-99)	BM (t/ha)	TKW (g)	Mean yield (over years And locations) (t/ha)
DZ 2227 (Oda)	72	137	110	20Ms	10Ms	20Ms	73	7.76	47.46	3.76
DZ 2234 (Ilani)	64	135	96	20Ms	15Ms	20Ms	73	6.42	51.12	3.56
Foka	70	137	120	20S	40S	25Ms	73	7.71	44.43	3.20
Cocorit-71	67	135	84	20S	15Ms	30Ms	83	6.36	43.18	3.47
Ingliz	71	137	113	40S	20Ms	25Ms	73	6.02	41.75	3.33

DH= days to heading, DM= days to maturity, PHT=plant height, LR= leaf rust= stem rust, YR= yellow rust, SP= septoria, BM= biomass,and TKW= thousand kernels weight

Table 2. Durum wheat varieties physical quality parameters as analysed by Kality Share company, Ethiopia.

Variety	Impurity (%)	Moisture content (%)	Hecto liter weight (kg/hl)	Odour	Vitreousness (%)
DZ 2227 *(Oda)*	3.8	7.6	83.75	Normal	98
DZ 2234 *(Ilani)*	5.5	8.5	83.95	Normal	99
Foka	5.4	8.2	80.80	Normal	94
Kilinto	6.0	8.3	83.30	Normal	75
Ingliz	5.0	8.1	82.15	Normal	89

Table 3. Durum wheat varieties chemical quality parameters as analysed by Kaliti food Share Company,Ethiopia

Variety	Moisture content (%)	Wet gluten content (%)	Ash (%)	Falling number (Second)
DZ 2227 (*Oda*)	14.4	37.6	1.95	308
DZ 2234 (*Ilani)*	14.5	44.6	1.25	322
Foka	13.7	46.5	1.55	284
Kilinto	14.2	29.6	1.96	250
Ingliz	12.9	39.4	1.46	291
specification	14.5 max.	33.0 min.	2.0 max	250 min.

Appendix I (Variety Oda (DZ 2227))
Variety: DZ 2227 (Oda)
Pedigree: DZ046881/imlo//cit 71/3/RCHI/LD 357//imlo/4/Yemen/Cit's'//Plc's'/3/Taganroy

1. Agronomic and Morphological Characteristics:
   - 1.1 Adaptation area: Highlands of Bale
     Altitude (m.a.s.l.): 2300-2600
     Rainfall (mm): 750-1000
   - 1.2 seed rate: 150 kg/ha
   - 1.3 planting date: End July-Late August
   - 1.4 Fertilizer rate: 41/46 N_2PO_5 kg/ha
   - 1.5 Days to heading: 72 days
   - 1.6 Days to maturity: 137 days
   - 1.7 Plant height (cm): 110
   - 1.8 Growth habit: Erect
   - 1.9 Test Weight: 82.8
   - 1.10 1000 seed weight (g): 47.46
   - 1.11 Seed color: Brown
   - 1.12 Plant stature: tall
   - 1.13 Spike: red color, awned
   - 1.14 Kernel: Ovate, mid long in shape, and hard
   - 1.15. Crop pest reaction:Yellow rust 20Ms, Leaf rust 20Ms, and Stem rust 10Ms
   - 1.16 Yield (t/ha):
     Research field: 3.8-5.3
     Farmer field: 3.8
2. Year of release: 2004/05
3. Breeder/maintainer: SARC (Sinana Agricultural Research Center)

Appendix II (Variety Ilani (DZ 2234))
Variety: DZ 2234 (Ilani)
Pedigree: Imilo/Rahum//A4#72/3/Gerardo

1. Agronomic and Morphological Characteristics:
   - 1.1 Adaptation area: Highlands of Bale
     Altitude (m.a.s.l.): 2300-2600
     Rainfall (mm): 750-1000
   - 1.2 seed rate: 150 kg/ha
   - 1.3 planting date: End July-Late August
   - 1.4 Fertilizer rate: 41/46 N_2PO_5 kg/ha
   - 1.5 Days to heading: 64 days
   - 1.6 Days to maturity: 135 days
   - 1.7 Plant height (cm): 96
   - 1.8 Growth habit: Erect
   - 1.9 Test Weight: 80.4
   - 1.10 Thousand seed weight (g): 51.12
   - 1.11 Seed color: Brown
   - 1.12 Plant stature: medium height
   - 1.13 Spike: Oblong to tapering, mid long, fusiform, and white in color
   - 1.14 Kernel: Elliptical in shape, and hard
   - 1.15 Crop pest reaction: Yellow rust 15Ms, Leaf rust 20Ms, and Stem rust 10Ms
   - 1.16 Yield (t/ha):
     Research field: 3.5-5.5
     Farmer field: 3.6
2. Year of release: 2004/05
3. Breeder/maintainer: SARC (Sinana Agricultural Research Center)