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Contact address

Journal of Agriculture and Environmental Sciences (JAES),
College of Agriculture and Environmental Sciences,
Bahir Dar University, Bahir Dar, Ethiopia
E-mail: caes.jaes@gmail.com
Tel: 25158 820 96 77
Fax: 25158 320 60 94
P.O. Box: 5501
Bahir Dar, Ethiopia

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Yield and Nutritional Quality of Oat (*Avena sativa*) Genotypes under Vertisols Conditions in the Central Highlands of Ethiopia

Gezahagn Kebede[1]*, Mulisa Faji[1], Fekede Feyissa[2], Kedir Mohammed[1], Getnet Assefa[3], Diriba Geleti[2], Muluneh Minta[1], Mesfin Dejene[1], Mengistu Alemayehu[4], Alemayehu Mengistu[5], Aschalew Tsegahun[1] and Solomon Mengistu[1]

[1]Holetta Agricultural Research Center, P.O Box, 31, Holetta, Ethiopia.

[2]Ethiopian Institute of Agricultural Research, P.O. Box, 2003, Addis Ababa, Ethiopia

[3]Livestock specialist, Addis Ababa, Ethiopia

[4]Ethiopian Agricultural Research Council Secretariat, Addis Ababa, Ethiopia

[5]Forage and Rangeland Scientist, Urael Branch, P.O. Box 62291, Addis Ababa, Ethiopia

***Corresponding author:** gezk2007@yahoo.co.uk

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Abstract: *Shortage of feed is a critical problem for livestock production in Ethiopia. However, the selection of oat genotypes that perform better under vertisol conditions is very important to mitigate the feed shortage problem in the central highlands of Ethiopia. So, the study was designed to evaluate the agro-morphological and nutritional performance of fifteen oat genotypes under vertisol conditions during the main cropping seasons of 2015 and 2016 at Kuyu and Ginchi sub-stations of Holetta Agricultural Research Center. Randomized complete block design replicated three times was used for evaluating the genotypes. The genotypes were sown with the recommended seeding rate of 100 kg ha^{-1} using an inter-row spacing of 20 cm. Diammonium phosphate (DAP) fertilizer at the rate of 100 kg ha^{-1} was uniformly applied at sowing for all genotypes at both locations and years. Data were collected on plant height, dry matter yield, leaf to stem ratio, straw yield, seed yield, thousand seed weight, harvest index, and nutritive values. All measured data were subjected to analysis of variance using procedures of SAS general linear model. The genotypes responded differently ($P<0.001$) for plant height, leaf to stem ratio, straw yield, seed yield, thousand seed weight, and harvest index. All measured agro-morphological traits of oat genotypes were significantly influenced by genotype by location by year interaction. In both cropping seasons, the genotypes produced relatively better dry matter yield at Kuyu than Ginchi indicating the performance of genotypes was highly hampered by heavy vertisol characteristics of Ginchi location. In the over years and locations combined analysis, genotypes 1600, 1740, 2596, 79983, 1493, and 1742 produced more than 15 t ha^{-1} dry matter yield at the soft dough stage. Oat genotypes that had relatively higher plant height and better dry matter yield showed higher straw yield when compared with small plant height and lower dry matter-producing genotypes. The mean seed yield performance of oat genotypes in the combined analysis was 2250 kg ha^{-1} and the highest seed yield was recorded for genotype 2806 followed by 79983, 2291, 8251, and 1742. Moreover, the chemical and in-vitro dry matter digestibility analysis of oat genotypes was done and genotype 1486 produced the highest crude protein and in-vitro dry matter digestibility contents while the lowest was recorded from genotype SAIA. The highest crude protein yield was recorded for oat genotype 2291 followed by 2596, 2806, 1506, and 1742 and oat genotypes that produced the highest crude protein yield also gave the highest digestible yield. Generally, better dry matter yield, crude protein yield, digestible yield, and seed yield performances were recorded from genotypes 2291, 2596, 2806, 1506, 1742, 8251, and 79983. Therefore, these oat genotypes were recommended for vertisol conditions of the study areas and similar agro-ecologies.*

Keywords: Forage yield, Harvest index, Herbage quality, Leaf to stem ratio, Seed yield, Straw yield

1. Introduction

Feed shortage in terms of both quantity and quality is the leading problem affecting the livestock productivity in Ethiopia (Aduga, 2007; Fekede et al., 2015a). Traditional livestock production system mainly depends upon poor pasturelands and crop residues which are usually inadequate to support reasonable livestock production (Tsige, 2000). During the latter part of the dry season, livestock feed is normally in short supply and is also of poor quality. Residues from cereals are the main source of forage but these are low in protein and have poor digestibility. The production of adequate quantities of good quality dry season forages to supplement crop residues and pasture roughages is the only way to economically overcome the dry season constraints affecting livestock production in Ethiopia. Much of the available feed resources are utilized to support the maintenance requirement of the animals with little surplus left for production. Poor animal nutrition and productivity arising from the inadequate supply and low-quality feed are among the major constraints facing livestock production in developing countries (Fekede et al., 2015b).

Screening of different forage crops was made both at accessions and species level and promising materials were promoted for production (Getnet and Gezahagn, 2012). A wide range of annual and perennial forage species were evaluated in areas ranging in altitude from 600-3000 meters above sea level, and many promising species have been selected for high, medium, and low altitudes. The selected forage crops are generally well adapted to the different agro-ecologies and high-yielding and have better quality compared to natural pasture (Getnet et al., 2012). Among the different forage crops recommended for various agro-ecological zones of Ethiopia, common oat (*Avena sativa*) is abundantly grown in the central highlands of Ethiopia. Oat is a potential fodder crop for livestock feed and has been growing in the central highlands of Ethiopia for about five decades. It has been well accepted by the farming community because of its hardy nature which performs better under stressful conditions with very minimal managerial inputs. It is used as livestock feed in the form of hay, silage, and grazing or green feed and provides an abundance of excellent forage at a time when other succulent, high-protein feeds are scarce. Its grain also makes part of the staple diet of human beings in some parts of the country (Lulseged, 1981).

In Ethiopia, vertisol covers 10.2% or 12.5 million ha of which 7.6 million ha occur in the Ethiopian highlands and are the fourth most important soil. Despite this soil is very fertile, its productivity is constrained by unique soil physical properties. Due to the high water holding capacity of this soil, aeration becomes a limiting factor for root growth and activity. Soil type was found to be the most important factor affecting forage biomass yield and seed production. Different varieties respond differently to different soil types, climatic, and management conditions. Thousands of oat lines have been collected and tested for environmental adaptation and forage yield in the highlands (Astatke, 1976). Several reports have indicated that there is a considerable variation in agronomic and quality traits between oats genotypes under a given environmental condition. Until recently, the focus of research works on oat has been limited to evaluation and selection varieties in terms of adaptation to edaphic and agro-ecological conditions as well as herbage yield potential. However, the number of oat genotypes tested and recommended for vertisol conditions is highly limited. So, evaluation of promising oat genotypes under vertisol conditions is vital to improving oat production and productivity. Therefore, the study was designed to evaluate the performance of different oat genotypes under vertisol conditions and to select promising genotypes of oat for utilization in the study areas and similar agro-ecologies of the country.

2. Materials and Methods

2.1. Description of the study areas

The experiment was conducted under field conditions at the Kuyu and Ginchi sub-station of Holetta Agricultural Research Center during the main cropping seasons of 2015 and 2016. The test locations represent the highland areas ranging in altitude from 2200 to 2400 masl. The farming system of the study areas is a mixed crop-livestock production system. The long-term (30 years) average annual rainfall and minimum and maximum air temperatures and the descriptions of the study sites are indicated in Table 1.

Table 1: Descriptions of the test environments

Parameter	Kuyu[a]	Ginchi[b]	References
Latitude	9° 00'N	9° 02'N	
Longitude	38° 30'E	38° 12'E	
Altitude (masl)	2400	2200	
Distance from Addis Ababa (km)	29	75	
Annual rainfall (mm)	1044	1095	EIAR, 2005
Daily minimum temperature (°C)	6.2	8.4	EIAR, 2005
Daily maximum temperature (°C)	21.2	24.6	EIAR, 2005
Soil type	Vertisol	Vertisol	EIAR, 2005
Textural class	Clay	Clay	EIAR, 2005
pH (1:1 H2o)	5.63	6.50	Desta, 1982; Getachew *et al*., 2007
Total organic matter (%)	5.63	1.30	Desta, 1982; Getachew *et al*., 2007
Total nitrogen (%)	0.16	0.13	Desta, 1982; Getachew *et al*., 2007
Available phosphorous (ppm)	6.95	16.50	Desta, 1982; Getachew *et al*., 2007

2.2. Experimental treatments and design

The fifteen genotypes of oat considered for this experiment were 633, 1486, 1488, 1493, 1506, 1589, 1600, 1740, 1742, 2291, 8251, 2806, 2596, 79983 and SAIA. The genotypes were planted at the beginning of the main rainy season at the two locations. The genotypes were sown in rows of 20 cm with seed rate of 100 kg ha^{-1} on a plot size of 1.8 m x 3 m= 5.4 m^2 consisting of nine rows. However, the seven rows with a net plot size of 1.4 m x 3 m = 4.2 m^2 were used for data collection. The experiment was conducted on randomized complete block design (RCBD) with three replications and the genotypes assigned randomly to plots within the block. At sowing, 100 kg ha^{-1} Diammonium phosphate (DAP) fertilizer was uniformly applied using the broadcast method for all treatments at both locations and years. Generally, all crop management was uniformly applied for all genotypes and maximum care was taken in the experimental plots to reduce the possible yield-limiting factors which could affect the yield performance of the genotypes.

2.3. Data collection and measurements

For plant height determination, the mean height of five randomly selected plants from net plot area was recorded for each plot. At the forage harvesting stage (soft dough), four interior rows were clipped at 5cm above the ground level to determine the biomass yield. The weight of the total fresh biomass yield was recorded from each plot in the field and the estimated 500 g sample was taken from each plot to the laboratory. The sample taken from each plot was weighed to know the total sample fresh weight and oven-dried for 24 hours at a temperature of 105°C for herbage dry matter yield determination. The herbage sample taken from each plot was weighed to know the total sample fresh weight and manually fractionated into leaf, stem, and panicle. The morphological parts were separately weighed to know their sample fresh weight, oven-dried for 24 hours at a temperature of 105°C, and separately weighed to estimate the proportions of these morphological parts. Accordingly, leaves were separated from stems, and the leaf to stem ratio (LSR) was estimated based on the dry matter basis of each component.

The remaining inner three rows of each plot were harvested at grain maturity to assess the grain and straw yield performances of the genotypes. To isolate the seed from the total biomass, the panicle portion of the plant was first cut apart and separately collected. The remaining aftermath was harvested from ground level and its fresh biomass was measured and recorded in the field. About 300 g samples of the aftermath were taken and oven-dried at 65°C for 72 hours to determine the straw dry matter yield. The residue remaining after grain threshing (chaff) was oven-dried at 100°C overnight and added to the aftermath dry matter for estimation of straw dry matter yield. Seed samples were taken and oven-dried at 100°C for 48 hours to adjust the moisture content of 12.5%, a recommended percentage level for cereals (Biru, 1979). Seed yield and thousand seed weight were then calculated at 12.5% moisture content. Harvest index was calculated as the ratio of grain yield to total above-ground biomass yield per unit area multiplied by 100.

2.4. Nutritional quality analysis

Harvesting for chemical analysis was undertaken as the genotypes reached the soft dough stage, as recommended for forage harvesting for oat genotypes (Astatke, 1976; Lulseged, 1981; Fekede, 2004). The fresh weights of the samples were recorded, and they were then oven-dried at a temperature of 65^{o}C for 72 hours for laboratory analysis to determine the chemical composition and *in-vitro* organic matter digestibility of the genotypes. The oven-dried samples were then ground to pass a one mm sieve and used for laboratory analysis. The chemical analysis and *in-vitro* dry matter digestibility of oat genotypes were done following the standard laboratory procedures as indicated in Table 2.

Table 2: Laboratory procedures for chemical and *in-vitro* organic matter digestibility analysis

Parameters	Procedures
Total ash	By combusting the samples at 550°C for 6 hours (AOAC, 1990)
CP	N determination (AOAC, 1995) and the CP content estimated by N * 6.25.
NDF, ADF, ADL	Van Soest and Robertson (1985)
IVDMD	Tilley and Terry (1963)
Hemicellulose	NDF - ADF
Cellulose	ADF - ADL
CP yield	(CP% * DM yield)/100
Digestible yield	(IVDMD% * DM yield)/100

2.5. Statistical analysis

Analysis of variance (ANOVA) procedures of SAS general linear model (GLM) was used to compare treatment means (SAS, 2002). For the combined analysis of variance, the homogeneity of error variance was tested (Gomez and Gomez, 1984). The least significant difference (LSD) at a 5% significance level was used for comparison of means. For each year and location analysis, the model below [1] was used.

$$Y_{ij} = \mu + G_i + B_j + e_{ij} \quad [1]$$

Where:
- Yij = Dependent variable;
- μ = overall mean;
- Gi = effect of genotype i;
- Bl = effect of block l
- eij is a random error

For the combined analysis, the model below was used [2].

$$Y_{ijkl} = \mu + G_i + Y_j + L_k + (GY)_{ij} + (GL)_{ik} + (YL)_{jk} + (GYL)_{ijk} + B_l + e_{ijkl} \quad [2]$$

Where
- Yijkl = Dependent variable;
- μ = overall mean;
- Gi = effect of genotypei;
- Yj = effect of year j;
- Lk = effect of location k;
- (GY)ij = the interaction effect of genotype i and year j;
- (GL)ik = the interaction effect of genotype i and location k;
- (YL)jk = interaction effect of year j and location k;
- (GYL)ijk = interaction effect of genotype i, year j and location k;
- Bl = the effect of the block I
- eijkl = random error

3. Results and Discussion

3.1. Analysis of variance

The combined analysis of variance for plant height, dry matter yield, leaf to stem ratio, straw yield, seed yield, thousand seed weight, and harvest index of oat genotypes tested over locations and years are indicated in Table 3. The genotypes showed a non-significant (P>0.05) difference for only dry matter yield. The location didn't significantly (P>0.05) affect the seed yield and thousand seed weight of oat genotypes. Harvest index and dry matter yield were not affected significantly by the interaction effects of genotype by location and genotype by year, respectively.

On the other hand, the tested genotypes responded differently (P<0.001) for plant height, leaf to stem ratio, straw yield, seed yield, thousand seed weight, and harvest index. Similarly, all the measured agro-morphological traits of oat genotypes were significantly influenced (P<0.001) by cropping season. Moreover, plant height, dry matter yield, leaf to stem ratio, straw yield, and harvest index were significantly affected (P<0.001) by location, indicating the two locations varied in edaphic and climatic conditions. Some genotypes exhibit a highly specific response to a particular environment (soil, rainfall, and temperature), others are uniform in performance over a range of environments (Gezahagn *et al*., 2017a). Generally, all measured agro-morphological traits of oat genotypes were significantly influenced by genotype by location by year interaction. The selection of better performing genotypes in one environment may not enable the identification of genotypes that can repeat nearly the same performances in other environments (Gemechu, 2012; Gezahagn *et al*., 2017a).

Table 3: Combined analysis of variance for measured agro-morphological traits of oat genotypes

Parameters	G	L	Y	G*L	G*Y	L*Y	G*L*Y
PH	***	***	***	***	***	NS	*
DMY	NS	***	***	**	NS	**	**
LSR	***	***	***	**	**	NS	*
StY	***	***	***	***	***	***	***
SY	***	NS	***	**	***	***	*
TSW	***	NS	***	***	***	***	***
HI	***	***	***	NS	**	***	*

PH= plant height; DMY= dry matter yield; LSR= leaf to stem ratio; StY= straw yield; SY= seed yield; TSW= thousand seed weight; HI= harvest index; G= genotype; L= location; Y= year; G*L= genotype by location interaction; G*Y= genotype by year interaction; L*Y= location by year interaction; G*L*Y= genotypeby location by year interaction; NS = non-significant; * = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001

3.2. Forage Yield and Yield Components

The plant height of oat genotypes tested over years and across locations is indicated in Table 4. The result indicated that the genotypes respond differently (P<0.05) in terms of plant height for both cropping seasons and locations at the forage harvesting stage. Moreover, the plant height in the combined analysis showed significant variation (P<0.05) for tested genotypes. The genotypes produced relatively higher plant height at Kuyu than the Ginchi location in both cropping seasons. The combined analysis indicated that the SAIA genotype produced the highest plant height followed by 2596, 2291, 1486, and 8251. On the other hand genotypes 1506, 1740, 633, 2806, and 1488 had the lowest plant height while the remaining genotypes had intermediate plant height. Variation in plant height was observed among the tested oat genotype in the present study agrees with previous findings (Fekede 2004; Getnet *et al*., 2004; Gezahagn *et al*., 2016). In addition to genetic variability, soil fertility and environmental conditions could also contribute to the difference in plant height (Gezahagn *et al*., 2017a). Plant height may differ in varieties due to environmental conditions which in turn cause variation in hormonal balance and cell division rate (Zaman *et al*., 2006). Generally, the presence of genetic variation among the tested genotypes, response of genotypes to environmental factors, and their interactions are the major reason for plant height differences in oat genotypes.

The response of oat genotypes for herbage dry matter yield performance at the forage harvesting stage across locations and over years is indicated in Table 5. The result revealed that the dry matter yield of oat genotypes varied significantly (P<0.05) only at Ginchi in both cropping seasons. In 2015, the oat genotypes produced better dry matter yield at both locations when compared with the 2016 growing season. The dry matter yield ranged from 20.0 – 31.1 with a mean of 24.4 t ha^{-1} and from 9.6 – 18.6 with a mean of 14.6 t ha^{-1} at Kuyu and Ginchi, respectively, in 2015 cropping season. Similarly, in the 2016 growing season, the dry matter yield ranged from 3.9 – 17.0 with a mean of 13.3 t ha^{-1} at Kuyu and from 4.8 – 7.7 with a mean of 6.1 t ha^{-1} at Ginchi. In the combined analysis, the genotypes responded non-significantly (P>0.05) for dry matter yield. In both cropping seasons, the genotypes produced relatively better dry matter yield at Kuyu than Ginchi. The overall mean dry matter yield of oat genotypes at Kuyu had a 67% yield advantage over Ginchi in the 2015 cropping season. Similarly, the dry matter yield of oat genotypes at Kuyu had a 118% yield advantage over Ginchi in the 2016 cropping season. Among the tested oat genotypes, 1600, 1740, 2596, 79983, 1493, and 1742 were produced better dry matter yield. The yielding ability of the genotype is the result of its interaction with the environment and environmental factors such as soil characteristics, moisture, and temperature (Gezahagn *et al*., 2017b). Yield is a complex quantitative character and is greatly influenced by environmental fluctuations; hence, the selection for superior genotypes based on yield *perse* at a single location in a year may not be very effective (Shrestha *et al*., 2012). Generally, considerable variation in terms of dry matter yield was observed among the tested oat genotypes and this result is in close conformity with the findings of Fekede (2004) and Getnet *et al*. (2004).

Table 4: Mean plant height (cm) of oat genotypes tested over years and locations

SN	Genotypes	2015		2016		Combined
		Kuyu	Ginchi	Kuyu	Ginchi	
1	2806	162.5^{c}	136.7^{abcd}	161.7^{a}	90.6f	137.9^{cde}
2	79983	177.8^{abc}	127.6^{de}	155.5^{ab}	119.4^{bc}	144.9^{abcd}
3	8251	176.7^{abc}	130.6^{cde}	165.5^{a}	111.7^{bcd}	146.1^{abcd}
4	1493	175.0^{abc}	147.8^{ab}	147.2^{abc}	100.0^{def}	142.5^{bcde}
5	2291	169.6^{bc}	152.2^{a}	146.7^{abc}	120.0^{bc}	147.1^{abc}
6	1742	187.2^{a}	130.0^{cde}	151.7^{ab}	109.4^{bcde}	144.6^{abcd}
7	1488	185.6^{ab}	121.7^{de}	154.4^{ab}	100.0^{def}	140.4^{bcde}
8	1740	177.8^{abc}	119.4^{e}	135.5^{bc}	108.9^{bcdef}	135.4^{de}
9	633	167.2^{c}	137.3^{abcd}	123.9^{c}	122.2^{ab}	137.7^{cde}
10	1486	186.7^{ab}	145.0^{abc}	152.2^{ab}	102.2^{cdef}	146.5^{abcd}
11	2596	187.2^{a}	131.1^{bcde}	170.0^{a}	117.2^{bcd}	151.4^{ab}
12	SAIA	161.7^{c}	144.4^{abc}	170.6^{a}	140.6^{a}	154.3^{a}
13	1506	166.1^{c}	131.7^{bcde}	136.7^{bc}	91.1^{ef}	131.4^{e}
14	1600	178.3^{abc}	136.7^{abcd}	146.7^{abc}	101.7^{cdef}	140.8^{bcde}
15	1589	173.3^{abc}	121.1^{de}	155.5^{ab}	115.0^{bcd}	141.3^{bcde}
	Mean	175.5	134.2	151.6	110.0	142.8
	P-value	0.0378	0.0072	0.0242	0.0006	0.0102

Means followed by a common superscript letter within a column are not significantly different from each other at P<0.05

Table 5: Mean dry matter yield (t ha^{-1}) of oat genotypes tested over years and locations

SN	Genotypes	2015		2016		Combined
		Kuyu	Ginchi	Kuyu	Ginchi	
1	2806	20.0	17.5[ab]	15.2	5.0[cd]	14.4
2	79983	24.7	14.5[abcd]	15.1	7.3[abc]	15.4
3	8251	24.2	13.0[bcde]	13.8	7.5[ab]	14.6
4	1493	23.3	14.7[abcd]	17.0	5.2[cd]	15.0
5	2291	21.8	18.6[a]	10.3	6.3[abcd]	14.3
6	1742	23.3	16.9[abc]	14.4	5.2[bcd]	15.0
7	1488	23.6	14.6[abcd]	15.1	4.8[d]	14.5
8	1740	31.1	9.6[e]	13.6	7.6[a]	15.5
9	633	22.7	14.7[abcd]	3.9	4.9[d]	11.5
10	1486	25.7	14.8[abcd]	13.9	5.1[cd]	14.9
11	2596	25.0	17.2[abc]	13.3	6.0[abcd]	15.4
12	SAIA	21.9	12.4[cde]	13.5	6.5[abcd]	13.6
13	1506	26.5	14.8[abcd]	10.7	7.7[a]	14.9
14	1600	25.5	14.5[abcd]	15.8	6.4[abcd]	15.6
15	1589	26.8	11.8[ed]	13.1	5.2[bcd]	14.2
	Mean	24.4	14.6	13.3	6.1	14.6
	P-value	0.1077	0.0496	0.1224	0.0673	0.4768

Means followed by a common superscript letter within a column are not significantly different from each other at P<0.05

The leaf to stem ratio of oat genotypes varied significantly (P<0.05) in both locations during the 2016 cropping seasons and in the combined analysis (Table 6). The result showed that the highest leaf to stem ratio at the forage harvesting stage was recorded at Ginchi than Kuyu in both cropping seasons. The mean leaf to stem ratio of oat genotypes in the 2015 cropping season was 0.76 and it increased to 1.06 in 2016 at Kuyu. Similarly, the mean leaf to stem ratio of oat genotypes increased from 1.11 in 2015 to 1.20 in the 2016 cropping season at Ginchi. The combined analysis indicated that genotype 1600 produced the highest leaf to stem ratio followed by 1506 1486, 2596, and 633. On the other hand genotypes SIAI, 79983, 1740, 2291, and 2806 had the lowest leaf to stem ratio while the remaining genotypes had intermediate leaf to stem ratio. The mean leaf to stem ratio of oat genotypes at Ginchi had 46% higher than Kuyu in the 2015 cropping season. Though it decreased in 2016, the tested genotypes had a 13% higher mean leaf to stem ratio at Ginchi than Kuyu. The leaf to stem ratio was directly proportional to the proportion of leaf and inversely proportional to the proportion of stem. Due to the presence of genetic variations, the tested oat genotypes respond differently for the leaf to stem ratio. Growth characteristics and management such as tillering performance, plant height, and age of harvesting also affect the proportion of leaf and stem of the plant. The leaf to stem ratio also varied among tested oat varieties (Fekede, 2004). The leaf to stem ratio has significant implications on the chemical composition of any forage crop as leaves contain higher levels of nutrients and less fiber than stems. The result indicated that the leaf to stem ratio is an important factor affecting diet selection, quality, and intake of forage (Smart *et al.*, 2004). The leaf to stem ratio is associated with the high nutritive value of the forage because the leaf is generally of higher nutritive value (Tudsri *et al*., 2002) and the performance of animals is closely related to the amount of leaf in the diet.

The straw yield of oat genotypes tested across locations and over years is indicated in Table 7. The result indicated that the genotypes responded differently (P<0.05) for straw yield at Kuyu in both cropping seasons and Ginchi only in the 2016 growing season. The combined analysis also showed that the straw yield at the grain harvesting stage varied significantly (P<0.05) among the tested oat genotypes. The straw yield was higher in the 2015 cropping season than in 2016 in both locations indicating the climatic conditions of the first year were conducive for the tested genotypes. The mean straw yield of oat genotypes had 100 and 94% yield advantages at Kuyu than Ginchi in 2015 and 2016 cropping season, respectively. Among the tested genotypes, 1742, 1493, 1506, 1600, and 2806 genotypes which had relatively higher plant height and better dry matter yield showed higher straw yield. On the other hand, genotypes 2291, 1488, 633, 1589 and SAIA produced lower straw yield while the remaining oat genotypes were intermediate in straw yield performance.

In general, all the oats varieties included in this study gave higher straw yield than the values reported for different cultivars of barley in the highlands of Ethiopia (Seyoum *et al*., 1995) and maize in mid-altitude areas of southern Ethiopia (Adugna and Sundstol, 1999). Oat straw is used as animal feed because it is softer and has more digestible organic matter and metabolic energy to livestock than other cereal crops. It is a preferred feed of all animals and its straw is soft and superior to wheat and barley. Moreover, the straw is used as a bedding material (Fekede, 2004) due to its softness and better absorbent nature.

Table 6: Mean leaf to stem ratio of oat genotypes tested over years and locations

SN	Genotypes	2015		2016		Combined
		Kuyu	Ginchi	Kuyu	Ginchi	
1	2806	0.74	1.25	1.01^{bcd}	0.63^{b}	0.91^{bcde}
2	79983	0.72	0.91	0.78^{d}	0.85^{b}	0.82^{de}
3	8251	0.79	1.06	0.99^{bcd}	0.94^{b}	0.95^{bcde}
4	1493	0.74	1.03	1.20^{bc}	1.00^{b}	0.99^{bcde}
5	2291	0.65	0.91	0.84^{cd}	1.10^{b}	0.88^{cde}
6	1742	0.84	1.10	0.90^{bcd}	1.30b	1.04^{bcde}
7	1488	0.81	1.18	0.98^{bcd}	1.04^{b}	1.00^{bcde}
8	1740	0.65	0.94	0.92^{bcd}	0.89^{b}	0.84^{cde}
9	633	0.64	0.95	1.94^{a}	0.73^{b}	1.07^{bcd}
10	1486	0.74	1.56	0.98^{bcd}	1.62^{b}	1.23^{ab}
11	2596	0.79	1.22	1.25^{b}	1.42^{b}	1.17^{bc}
12	SAIA	0.64	0.78	0.66^{d}	0.72^{b}	0.70^{e}
13	1506	0.97	1.30	1.24^{b}	1.49^{b}	1.25^{b}
14	1600	0.90	1.27	1.22^{b}	3.13^{a}	1.63^{a}
15	1589	0.86	1.21	0.93^{bcd}	1.16^{b}	1.04^{bcde}
	Mean	0.76	1.11	1.06	1.20	1.03
	P-value	0.1844	0.4564	<.0001	0.0054	0.0001

Means followed by a common superscript letter within a column are not significantly different from each other at P<0.05

Table 7: Mean straw yield (t ha^{-1}) of oat genotypes tested over years and locations

SN	Genotypes	2015		2016		Combined
		Kuyu	Ginchi	Kuyu	Ginchi	
1	2806	19.5^{bc}	11.5	11.1^{bcd}	4.8^{ab}	11.7^{abcd}
2	79983	18.5^{cd}	10.1	9.0^{cde}	5.8^{ab}	10.8^{abcdef}
3	8251	17.7^{cd}	8.2	8.5^{de}	5.9^{a}	10.1^{bcdef}
4	1493	24.1^{a}	10.5	9.0^{cde}	6.0^{a}	12.4^{ab}
5	2291	11.0^{f}	9.7	5.8^{ef}	4.1^{b}	7.7^{g}
6	1742	22.5^{ab}	11.1	13.1^{abc}	4.6^{ab}	12.8^{a}
7	1488	13.5^{ef}	8.3	8.6^{de}	4.3^{ab}	8.7^{fg}
8	1740	19.6^{bc}	9.8	9.8^{bcde}	5.3^{ab}	11.1^{abcde}
9	633	18.5^{cd}	9.4	3.3^{f}	5.0^{ab}	9.1^{efg}
10	1486	16.6^{cde}	7.0	17.0^{a}	5.4^{ab}	11.5^{abcd}
11	2596	17.2^{cde}	9.7	8.5^{de}	5.8^{ab}	10.3^{bcdef}
12	SAIA	15.0^{de}	7.7	11.7^{bcd}	4.9^{ab}	9.8^{cdefg}
13	1506	24.3^{a}	8.7	10.1^{bcde}	5.2^{ab}	12.1^{abc}
14	1600	19.5^{bc}	9.4	14.1^{ab}	4.3^{ab}	11.8^{abcd}
15	1589	17.6^{cd}	7.5	8.5^{de}	4.8^{ab}	9.6^{defg}
	Mean	18.36	9.2	9.9	5.1	10.6
	P-value	<.0001	0.3178	0.0002	0.4834	0.0005

Means followed by a common superscript letter within a column are not significantly different from each other at P<0.05

3.3. Seed yield and yield components

The seed yield of oat genotypes harvested at the seed harvesting stage differed significantly (P<0.05) across locations and over years as shown in Table 8. The genotypes produced better seed yield in the 2015 cropping season when compared to 2016 indicating favorable climatic conditions in the first year assisted the genotypes to express the genetic potential. The genotypes gave the highest seed yield at Kuyu than Ginchi in the 2015 cropping season. However, the seed yield obtained in 2016 was highest at Ginchi than at Kuyu. The combined analysis also showed that the seed yield performance of oat genotypes varied significantly (P<0.05). The seed yield performance of oat genotypes in the combined analysis ranged from 1460 – 3210 with a mean of 2250 kg ha^{-1}. Oat genotype 2806 produced the highest seed yield followed by 79983, 2291, 8251, and 1742. On the other hand genotypes 1589, SAIA, 1600, 1740, and 1486 gave the lowest seed yield while the remaining oat genotypes had intermediate seed yield performance. The variability among the oat genotypes in seed yield performance was mainly due to their genetic difference and their differential response to the growing environments. The seed yield difference among oat genotypes is also reported in different research studies (Fekede, 2004; Getnet et al., 2004). The significant effect of oat genotypes on seed yield performance in the present study is also in agreement with the previous findings in other countries (Singh and Singh, 1992; Lupingan et al., 1999; Naeem et al., 2002).

Thousand seed weight of oat genotypes tested across locations and over years is indicated in Table 9. The result showed that the genotypes responded differently (P<0.05) for thousand seed weights at each location and over years. The genotypes gave relatively higher mean thousand seed weight in the 2015 cropping season than in 2016. This indicates that in the 2015 cropping season, the climatic conditions such as amount and distribution of rainfall and minimum and maximum temperatures were favorable for oat production. In the combined analysis, significant (P<0.05) variation was also observed among oat genotypes for thousand seed weight. Thousand seed weights of oat genotypes in the combined analysis ranged from 22.6 – 34.7 with a mean of 30.2 g. The highest thousand seed weight was recorded for oat genotype 633 followed by 2806, 1742, 8251, and 1493. On the other hand, the lowest thousand seed weight was recorded for oat genotypes SAIA, 1589, 1600, 1740, and 1506 while the remaining genotypes produced intermediate thousand seed weight. Oat genotypes with high grain yield showed higher 1000 kernel weight (Fekede, 2004; Getnet et al., 2004). The difference could be due to the inherent variation in seed size complemented with the environmental and soil conditions. Thousand seed weight has got practical significance in estimating the seeding rate for each oat genotype to ensure that an equal number of seeds could be sown per unit area (Fekede, 2004).

Table 8: Mean seed yield (kg ha^{-1}) of oat genotypes tested over years and locations

SN	Genotypes	2015		2016		Combined
		Kuyu	Ginchi	Kuyu	Ginchi	
1	2806	6280^{a}	5040^{a}	250^{ab}	1240^{a}	3210^{a}
2	79983	5480^{ab}	4390^{ab}	190^{abcd}	1100^{ab}	2790^{ab}
3	8251	5480^{ab}	4180^{abc}	110^{cdef}	880^{bcd}	2660^{abcd}
4	1493	4210^{cdef}	3890^{abcd}	130^{cdef}	860^{bcd}	2270^{bcdef}
5	2291	5910^{ab}	3880^{abcd}	190^{abcd}	1080^{ab}	2760^{abc}
6	1742	5390^{abc}	3800^{bcd}	230^{bcd}	890^{bcd}	2580^{abcde}
7	1488	3920^{ef}	3530^{bcde}	80^{def}	830^{bcd}	2090^{cdefg}
8	1740	3160^{fg}	3460^{bcde}	130^{cdef}	950^{abc}	1920^{efg}
9	633	4900^{bcde}	3450^{bcde}	70^{ef}	910^{abcd}	2330^{bcde}
10	1486	4040^{edf}	3110^{cdef}	150^{bcdef}	870^{bcd}	2040^{defg}
11	2596	5260^{abcd}	3070^{cdef}	180^{abcde}	1090^{ab}	2400^{bcde}
12	SAIA	2240^{g}	2900^{cdef}	170^{bcde}	950^{abc}	1590^{g}
13	1506	4820^{bcde}	2680^{edf}	300^{a}	590^{d}	2100^{cdefg}
14	1600	3130^{fg}	2350^{ef}	150^{bcdef}	790^{bcd}	1610^{fg}
15	1589	3040^{fg}	2090^{f}	50^{f}	660^{cd}	1460^{g}
	Mean	4480	3460	160	910	2250
	P-value	<.0001	0.0025	0.0075	0.0398	<.0001

Means followed by a common superscript letter within a column are not significantly different from each other at P<0.05

Table 9: Mean thousand seed weight (g) of oat genotypes tested over years and locations

SN	Genotypes	2015		2016		Combined
		Kuyu	Ginchi	Kuyu	Ginchi	
1	2806	30.3^{ef}	36.3^{a}	34.0^{a}	36.3^{a}	34.3^{ab}
2	79983	35.3^{c}	31.3^{cde}	29.7^{c}	31.3^{c}	31.9^{cd}
3	8251	35.7^{bc}	30.3^{def}	30.0^{bc}	32.3^{bc}	32.1^{bcd}
4	1493	32.0^{de}	33.3^{b}	30.3^{bc}	32.7^{bc}	32.1^{bcd}
5	2291	25.3^{h}	33.7^{b}	30.7^{bc}	32.7^{bc}	30.0^{cde}
6	1742	32.0^{de}	32.0^{bcd}	31.7^{abc}	33.7^{abc}	32.3^{bc}
7	1488	32.3^{d}	33.0^{bc}	29.7^{c}	31.3^{c}	31.6^{cd}
8	1740	29.0^{fg}	28.0^{hi}	25.7^{d}	27.7^{d}	27.6^{fg}
9	633	34.7^{c}	36.3^{a}	32.7^{ab}	35.0^{ab}	34.7^{a}
10	1486	38.0^{a}	29.0^{fgh}	25.7^{d}	27.0^{de}	29.9^{de}
11	2596	37.3^{ab}	30.0^{efg}	29.0^{c}	31.3^{c}	31.9^{cd}
12	SAIA	25.7^{h}	23.0^{k}	20.3^{e}	21.3^{f}	22.6^{h}
13	1506	38.0^{a}	25.3^{j}	25.0^{d}	26.7^{de}	28.8^{ef}
14	1600	28.0^{g}	28.3^{gh}	25.3^{d}	27.0^{de}	27.2^{fg}
15	1589	31.0^{de}	26.3^{ij}	23.0^{de}	24.7^{e}	26.3^{g}
	Mean	32.3	30.4	28.2	30.1	30.2
	P-value	<.0001	<.0001	<.0001	<.0001	<.0001

Means followed by a common superscript letter within a column are not significantly different from each other at P<0.05

The harvest index of oat genotypes tested across locations and over years is indicated in Table 10. The result showed that the genotypes responded differently (P<0.05) for harvest index at both locations in the 2016 cropping season. Moreover, the harvest index of oat genotypes was varied significantly (P<0.05) at Kuyu in the 2015 cropping season. The highest harvest index was recorded in the 2015 cropping season than in 2016. The combined analysis also showed that the tested oat genotypes varied significantly (P<0.05) for harvest index. The mean harvest index of oat genotypes in the combined analysis ranged from 12.4 – 22.0 with a mean of 16.1%. The highest harvest index was recorded for oat genotype 2291 followed by 2806, 8251, 79983, and 1488. On the contrary, oat genotypes 1589, 1600, 1506, 1740, and 1493 produced the lowest harvest index while an intermediate harvest index was obtained by the remaining oat genotypes. The harvest index obtained in the current study is lower when compared to the harvest index reported by another study (Fekede, 2004). Variation in genotypes, climate, and soil conditions could be the major reasons for harvest index differences in tested oat genotypes. Varietal differences in harvest index were also reported in maize (Adugna *et al*., 1999), in tef (Seyoum *et al*., 1996), and barley (Seyoum and Zinash, 1995). The general trend in this study indicated that high grain-producing oat genotypes had a higher harvest index than low grain-producing genotypes.

Table 10: Mean harvest index (%) of oat genotypes tested over years and locations

SN	Genotypes	2015		2016		Combined
		Kuyu	Ginchi	Kuyu	Ginchi	
1	2806	24.4^{b}	30.6	2.3^{abc}	20.8^{a}	19.5^{ab}
2	79983	22.8^{b}	30.7	2.1^{bcd}	16.1^{ab}	17.9^{bc}
3	8251	23.7^{b}	33.6	1.4^{cd}	12.9^{bc}	17.9^{bcd}
4	1493	14.7^{de}	27.6	1.5^{cd}	12.8^{bc}	14.2^{defgh}
5	2291	34.8^{a}	29.1	3.5^{a}	20.6^{a}	22.0^{a}
6	1742	19.4^{bcd}	26.6	1.7^{bcd}	16.7^{ab}	16.1^{bcdefgh}
7	1488	22.9^{b}	30.0	0.98^{cd}	16.2^{ab}	17.5^{bcde}
8	1740	13.9^{de}	26.2	1.3^{cd}	15.1^{bc}	14.2^{efgh}
9	633	21.0^{bc}	27.3	2.0^{bcd}	15.9^{ab}	16.6^{bcdef}
10	1486	19.5^{bcd}	30.5	0.98^{cd}	13.9^{bc}	16.2^{bcdefg}
11	2596	23.8^{b}	24.4	2.2^{abcd}	16.2^{ab}	16.6^{bcdef}
12	SAIA	12.9^{e}	27.9	1.8^{bcd}	16.4^{ab}	14.7^{cdefgh}
13	1506	16.7^{cde}	23.6	2.9^{ab}	10.3^{c}	13.4^{fgh}
14	1600	14.0^{de}	20.4	1.1^{cd}	15.6^{abc}	12.8^{gh}
15	1589	14.7^{de}	22.1	0.76^{d}	12.2^{bc}	12.4^{h}
	Mean	19.9	27.4	1.8	15.5	16.1
	P-value	<.0001	0.4830	0.0192	0.0310	<.0001

Means followed by a common superscript letter within a column are not significantly different from each other at P<0.05

3.4. Nutritional Characteristic of Oat Genotypes

The mean ash, crude protein (CP), *in-vitro* dry matter digestibility (IVDMD) contents, and CP yield and digestible yield of oat genotypes harvested at the soft dough stage are indicated in Table 11. The result revealed that ash, crude protein yield, and digestible yield varied significantly (P<0.05) among oat genotypes. On the other hand, the CP and IVDMD contents didn't vary (P>0.05) among the tested oat genotypes. The ash content of oat genotypes ranged from 9.4 – 12.5 with a mean of 10.8%. The amount of ash in forage is an indication of mineral concentrations in the feed. The mineral content is affected by the stage of maturity and the leaf to stem ratio of the forage plant. The plant developmental stage, morphological fractions, climatic conditions, soil characteristics, and fertilization regime are some of the potential factors causing variation in mineral concentration in forage plants (McDowell and Valle, 2000; Jukenvicius and Sabiene, 2007). Among the tested genotypes, genotype 1486 produced the highest CP and IVDMD contents while the lowest was recorded from genotype SAIA. When the plants matured, the proportion of leaves to stems declines, which reduces the CP and IVDMD contents (Mannetje, 1983; Humphreys, 1991). The highest CP yield was recorded for the oat genotype 2291followed by 2596, 2806, 1506, and 1742. On the other hand, oat genotypes 1589, SAIA, 1740, 1488, and 633 gave the lowest CP yield while the remaining genotypes produced an intermediate CP yield. Similarly, oat genotypes that produced the highest CP yield also gave the highest digestible yield. The nutritive value of forages is mainly determined by voluntary intake, crude protein, and structural carbohydrates. Forage intake is influenced by digestible dry matter and CP content and the extent of degradation (Minson, 1990).

Table 11: Mean ash (%), CP (%), IVDMD (%), CP yield (t/ha) and digestible yield (t/ha) of oat genotypes

SN	Genotypes	Ash	CP	IVDMD	CPY	DY
1	2806	10.9^{abcde}	7.9	53.7	0.89^{ab}	6.0^{abc}
2	79983	11.0^{abcde}	7.6	53.6	0.84^{abc}	5.9^{abcd}
3	8251	9.4^{e}	7.3	53.2	0.74^{bc}	5.4^{bcde}
4	1493	9.8^{de}	7.5	53.4	0.75^{bc}	5.3^{bcde}
5	2291	10.7^{abcde}	7.9	54.1	0.98^{a}	6.7^{a}
6	1742	10.8^{abcde}	7.9	53.4	0.87^{ab}	5.9^{abc}
7	1488	10.3^{bcde}	7.5	53.5	0.73^{bc}	5.2^{bcde}
8	1740	10.9^{abcde}	7.7	53.7	0.67^{c}	4.7^{de}
9	633	12.5^{a}	7.6	53.6	0.74^{bc}	5.2^{bcde}
10	1486	11.0^{abcde}	8.1	54.3	0.81^{abc}	5.4^{bcde}
11	2596	9.8^{de}	7.8	53.8	0.90^{ab}	6.3^{ab}
12	SAIA	10.2^{cde}	6.9	52.4	0.65^{c}	5.0^{cde}
13	1506	11.9^{abc}	7.8	53.8	0.88^{ab}	6.0^{abc}
14	1600	11.5^{abcd}	7.8	53.8	0.81^{abc}	5.6^{abcde}
15	1589	12.1^{ab}	7.7	53.7	0.65^{c}	4.6^{e}
	Mean	10.8	7.7	53.6	0.79	5.5
	P-value	0.0455	0.2154	0.2184	0.0333	0.0478

Means followed by a common superscript letter within a column are not significantly different from each other at P<0.05. CP = crude protein; IVDMD = in-vitro dry matter digestibility; CPY = crude protein yield; DY = digestible yield

The mean neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), cellulose, and hemicellulose contents of oat genotypes harvested at the soft dough stage are indicated in Table 12. The result indicated that except for the ADL content, the fiber contents didn't vary significantly (P>0.05) among the tested oat genotypes. The ADL content of oat genotypes ranged from 9.1 – 11.7 with a mean of 10.5%. The general trend showed that the NDF>ADF> Cellulose > Hemicellulose >ADL content and the trend conform with other studies done on oat varieties (Fekede, 2004). The mean NDF content of oat genotypes in the current study is higher than the mean NDF content (63.5%) reported on oat varieties (Fekede, 2004). Variations on genetic materials, harvesting stage, climatic conditions, and soil factors are the major causes of difference for NDF content in oat genotypes. The NDF content of all the oat genotypes in this study lies within the range (55 to 76%) reported for high-quality roughages (Nsahlai *et al*., 1996). The ADF content of the oat genotypes in this study falls in the range of 33.30 to 59.40% reported for high-quality roughages (Nsahlai *et al*., 1996). The comparatively lower ADF content in oats could be indicative of its better digestibility than the other roughages (Fekede, 2004). ADL content value above 60 g/kg DM can negatively affect the digestibility of forage (Van Soest, 1982). Generally, the presence of insoluble fiber, particularly lignin, lowers the overall digestibility of the feed by limiting nutrient availability (Van Soest, 1994; Mustafa *et al*., 2000). The higher cellulose and hemicelluloses contents in the feed limit forage intake and digestibility (Wolf *et al*., 1993; Lundvall *et al*., 1994) and its content in the feed varies among morphological fractions (Seyoum *et al*., 1996; Fekede, 2004) and increased with harvesting stage (Adane, 2003).

Table 12: Mean NDF (%), ADF (%), ADL (%), cellulose (%) and hemicellulose (%) contents of oat genotypes

SN	Genotypes	NDF	ADF	ADL	Cellulose	Hemicellulose
1	2806	73.3	52.0	10.5[abc]	41.5	21.2
2	79983	72.7	46.5	10.2[abc]	36.4	26.1
3	8251	70.1	45.4	11.7[a]	33.8	24.7
4	1493	71.6	45.7	11.5[a]	34.2	25.9
5	2291	72.7	50.9	11.2[a]	39.8	21.8
6	1742	73.1	49.1	10.3[abc]	38.8	24.0
7	1488	71.1	45.8	9.6[bc]	36.2	25.3
8	1740	74.0	50.7	11.0[ab]	39.7	23.3
9	633	73.4	48.7	9.4[c]	39.3	24.6
10	1486	73.0	48.1	10.6[abc]	37.6	24.9
11	2596	71.3	48.3	11.5[a]	36.8	23.0
12	SAIA	74.1	49.4	10.2[abc]	39.2	24.6
13	1506	74.8	48.5	10.5[abc]	38.0	26.2
14	1600	74.2	50.2	10.3[abc]	39.9	24.0
15	1589	72.5	47.8	9.1[c]	38.8	24.7
	Mean	72.8	48.5	10.5	38.0	24.3
	P-value	0.5778	0.4892	0.0361	0.6087	0.4936

Means followed by a common superscript letter within a column are not significantly different from each other at P<0.05. NDF = neutral detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin

4. Conclusions and Recommendation

Oat genotypes respond differently for agro-morphological performance and nutritive values on vertisol conditions at Kuyu and Ginchi during the main cropping seasons of 2015 and 2016. Plant height, dry matter yield, leaf to stem ratio, straw yield, seed yield, thousand seed weight, harvest index, chemical composition, and in-vitro dry matter digestibility showed variations among the tested oat genotypes on vertisol conditions. The result revealed that genotypes such as 1600, 1740, 2596, 79983, 1493, and 1742gave better forage dry matter yield on vertisol conditions. On the other hand, 2806, 79983, 2291, 8251, and 1742 produced better seed yields. The highest crude protein yield was recorded for oat genotype 2291 followed by 2596, 2806, 1506, and 1742 and oat genotypes that produced the highest crude protein yield also gave the highest digestible yield. Generally, better dry matter yield, crude protein yield, digestible yield, and seed yield performances were recorded from genotypes 2291, 2596, 2806, 1506, 1742, 8251, and 79983. Therefore, these oat genotypes can be recommended for vertisol conditions of the study areas and similar agro-ecologies.

Conflict of Interest

The authors declared that there is no conflict of interest.

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Reproductive Biology of Nile Tilapia (*Oreochromis niloticus)* in Lake Chamo, Ethiopia

***Buchale Shishitu*[1], *Gashaw Tesfaye*[2] *and Atnafu W/yohans*[3]**

[1]Arba Minch Agricultural Research Center, Arba Minch, Ethiopia
[2]National Fisheries and Aquatic Life Research Center, Addis Ababa, Ethiopia
[3]Arba Minch Agricultural Research Center, Arba Minch, Ethiopia
***Corresponding author:** buchale.shishitu@yahoo.com

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Abstract: *The objectives of the study were to determine the breeding season, fecundity rate, size at first maturity and sex ratio of O. niloticus in Lake Chamo. Data (total length (TL), total weight (TW), sex, maturity stages and number of eggs) were collected. A total of 1,245 samples (968 females and 277 males) were collected during the sampling period (December 2019 to November 2020). The collected data were summarized using descriptive statistics (percentage, graphs, tables) and analyzed with the application of Microsoft Excel 2010 and Sigma plot 13.0 Software. There was significant deviation in sex ratio (Females: Males) from hypothetical 1:1 ratio (χ^2 = 393.0; $p<0.05$). The mean fecundity was 1,138 eggs/ fish and it was positively correlated with TL and TW. The size at first sexual maturity (TL_{50}) was 23.4 and 22.0 cm for females and males respectively. The O. niloticus in Lake Chamo breeds throughout the year. The peak breeding season was observed from March to May and August to November. It is recommendable to reduce commercial fishing of O. niloticus during the peak breeding seasons in order to minimize the capture of breeding fish. The size at first maturity in the present study for both sexes was 23.6 cm which is too smaller than the earlier study (39.6 cm). This might be due to heavy fishing together with illegal fishing activities, fishing during the breeding season, breeding ground destruction by buffer zone agricultural practices around the lake. Therefore, appropriate fishery management tools such as closing season during peak breeding, buffer zone conservation and mesh size regulation should be implemented for sustainable fishery utilization in Lake Chamo.*

Keywords: Breeding season, fecundity, length at first maturity, sex ratio, total length, total weight

1. Introduction

Tilapia (Family Cichlidae) is mainly indigenous to Africa, but various species in the group are now found in most tropical and sub-tropical areas of the world. They are naturally distributed throughout Africa, Central America and parts of Asia (Philipart and Ruwet, 1982). Among Tilapia, *Oreochromis niloticus* is more widely distributed in Africa than in any other tropical region (Balarin and Hatton, 1979). The distribution of this species in Ethiopia is quite similar to that of other African countries. It is one of the most important species in the ecology and fisheries of almost all Ethiopian inland waters (Ted1a, 1973).

The study of reproduction is one of the major aspects in the study of fish biology (Khallaf and Authman, 1991). Description of reproductive strategies and the assessment of fecundity are fundamental topics in the study of biology and population dynamics of fish species and also for evaluation of the reproductive potential of individual fish species (Shalloof and Salama, 2008; Costache *et al*., 2011). Of course, this will increase our knowledge about the state of a stock and improves standard assessments of many commercially valuable fish species (Hunter *et al*., 1992; Murua *et al*., 2003). Moreover, the availability of data based on reproductive parameters and environmental variations could lead to a better understanding of observed fluctuations in reproductive output and enhances our ability to estimate recruitment (Kraus *et al*., 2002). Information on the breeding and fecundity of *O. niloticus* can provide basic knowledge for the proper management of the resource (Nikolskii, 1980).

Reproductive biology of *O. niloticus* in Lake Chamo appears to have higher growth and better condition than the same species in the other Ethiopian rift valley lakes. In Lake Chamo, the smallest size of mature fish for both sexes was 39 cm TL and TL_{50} was 42 cm. The fecundity of *O. niloticus* in Lake Chamo is high and enables the fish to produce in the lake rapidly (Teferi, 1997).

According to Shishitu *et al*., (2019), a large numbers of *O. niloticus* were being removed before they grow and replace their populations. Out of the total estimated annual catch, over 95% of *O. niloticus* catch ranged in length between 19 to 41 cm and more importantly, the length groups' 25 to 37 cm total length composed about 63% of the total catch.

When fish is under heavy fishing pressure, the length at first maturity (TL_{50}) becomes smaller and also the reproductive biology may vary based on the situation. So, in order to manage the fish resource properly, study on reproductive biology is crucial. The present study was aimed to provide information on sex ratio, maturity stages, fecundity and breeding season of *O. niloticus* in Lake Chamo. These details are needed for the establishment of *O. niloticus* production potential and recruitment which will enhance better rational exploitation, planning and management procedures.

2. Materials and Methods

2.1 Description of the study area

Lake Chamo is geographically located at 5°42′– 5°58′ N Latitude and 37°27′– 37°38′ E Longitude and it is one of Ethiopian Rift Valley lakes with an area of 551 km^2 and a maximum depth of 16 m (Belay and Wood, 1982). The lake is located at an altitude of 1108 m and about 515 km south of the capital city Addis Ababa (Dadebo *et al*., 2005).

Lake Chamo is part of the Ethiopian Rift Valley Lakes Basin (ERVLB) in the Abaya–Chamo drainage sub-basin (ACB). The ERVLB comprises eight natural lakes and their tributaries. The ACB comprises Lake Chamo and Lake Abaya, and rivers and streams entering the lakes. The two lakes are connected via surface hydrology. Outflow from Lake Abaya enter Lake Chamo through River Kulfo, and an overflow from Lake Chamo through Metenafesha joins Sermale River in Amaro Woreda (Bekele, 2006). Earlier studies stated that, Lake Chamo has a surface area of 551 km^2 and a maximum depth of 16m (Belay and Wood, 1982). However, according to Bekele (2006), the surface area of the lake declined to about 335 km^2. The high rate of evaporation of water and the diversion of the feeder river, Kulfo, for agricultural activities are the reasons for the decline in the surface area of the lake (Kebede, 1996).

The fishery on Lake Chamo is almost exclusively conducted with a surface gillnet, although long–lines are also used to some extent to African catfish (*Clarias gariepinus*) and *Bagrus docmak*. The nets are prepared locally by fishers themselves or by some other people involved in fishing gear making activity. Also a monofilament gillnet is obtained commercially from abroad illegally which is dangerous and causes recruitment overfishing. The gill nets are the most important fishing gears and are typically set in the afternoon and hauled early in the morning. They are removed only to change the fishing ground or when maintenance is necessary.

2.2 Methods of sampling and data collection

Samples from the commercial catch at Lake Chamo were taken from two randomly selected landing sites at monthly periods from December 2018 to November 2019. The fish were caught by gillnetting. Immediately after capture, total length (TL) and total weight (TW) of each specimen were measured to the nearest 0.1 cm and 0.1 g, respectively. Each fish specimen was opened ventrally from the anus to the pectoral fin and its sex and stage of gonadal maturation determined visually (Roberts, 1989). All gonads were removed, weighed and gonadal stages noted (Hyndes *et al.,* 1992). The ovaries collected from each fish specimen were preserved separately in modified Gilson's fluid (Simpson, 1951; Barbieri, 1989). The preserved ovaries were periodically shaken to ensure the separation of eggs from ovarian tissues and all the eggs in each pair of ovaries were determined by direct counting. Then, the average number of eggs g^{-1} of the preserved wet weight of the ovary was calculated and multiplied by the total weight of each ovary giving the total number of eggs $ovary^{-1}$ (Snyder, 1983). A chi square test was employed to determine if the sex ratio varies between male and female *O. niloticus*.

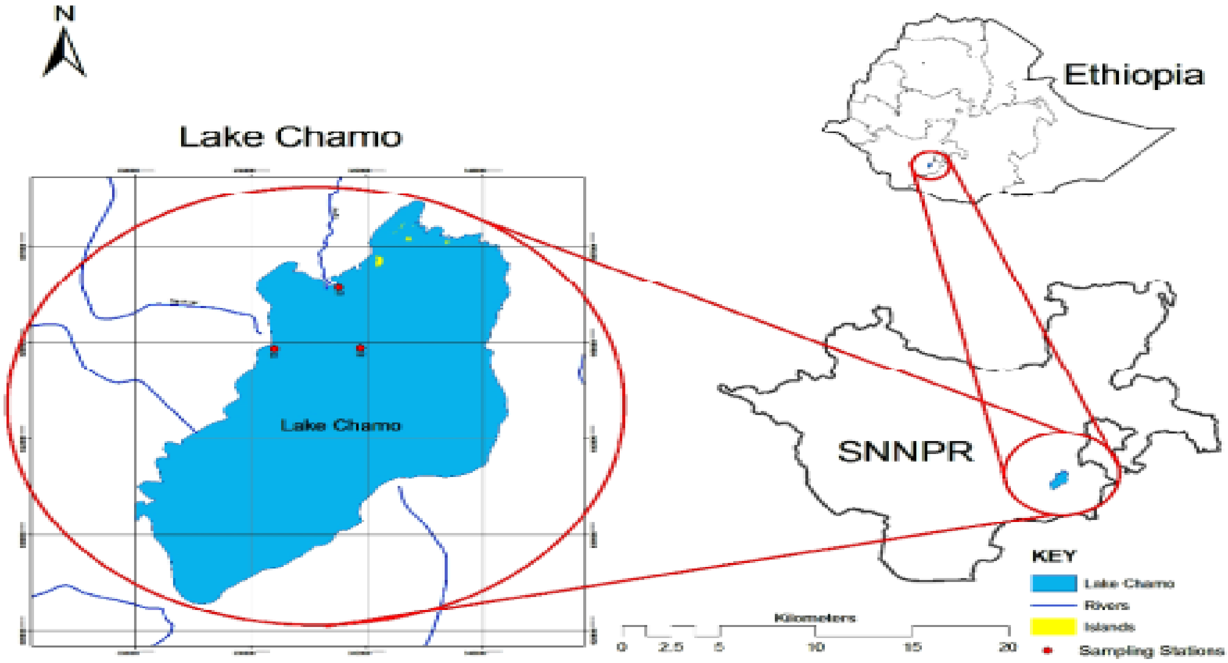

Figure 1: Location of Lake Chamo, Southern Ethiopia (Utaile and Sulaiman, 2016)

3. Results and Discussion

3.1 Sex ratio and length at first maturity

3.1.1 Sex ratio

Totally 1,245 *O. niloticus* fish samples, ranged from 20 to 38.5 cm in total length, and 132 to 1,056 g in body weight were collected. Among these sampled fishes, 968 were females (77.75 %) and 277 (22.25%) were males. Females were more numerous throughout the year (Table 1). The sex ratio was 1:3.49 (Males: Females) and it significantly differs from the hypothetical 1:1 sex ratio ($\chi^2 = 393.0$; $p < 0.05$).

Contrarily of this result, it was pointed out that water bodies in African, are commonly dominated by male populations because they generally present more growth than females without this representing a risk situation for fishery (Fryer and Iles, 1972; Offem *et al.*, 2007, 2009). The sex disparity could be a result of the differential survival to certain environmental conditions and is described as a mechanism for regulation in fishes. Females could possibly emigrate from spawning areas towards feeding grounds located where they are caught. The males build and guard spawning grounds where they court several females. The females move to this area for fertilization, and then move with their brood to the brooding sites (Lowe - McConnell, 1958). Therefore, males stay longer in the bottom while females are mostly active and stay near the water surface. Hence, during the spawning seasons, females are more likely to be caught in passive gears such as gill nets than males. A similar phenomenon has been suggested by Admassu (1994) in Lake Hawassa and by Teferi (1997) in Lake Chamo for the same species.

Table 1: The number of males, females, the total number and sex ratio in monthly samples of *O. niloticus* caught from Lake Chamo. The last column shows chi-square values, significant at 95% CI, (p<0.05)

Months	Male	Female	Total No. fish	Sex ratio (M: F)	chi-square (x^2)
December	15	38	53	1:2.53	10.0
January	18	54	72	1:3	18.0
February	28	99	127	1:3.53	39.7
March	12	85	97	1:7	54.9
April	16	83	99	1:5.19	45.3
May	21	93	114	1:4.43	45.5
June	22	85	107	1:3.86	37.1
July	22	72	94	1:3.27	26.6
August	26	68	94	1:2.62	18.8
September	37	109	146	1:2.95	35.5
October	31	90	121	1:2.9	28.8
November	29	92	121	1:3.17	32.8
Total	277	968	121	1:3.49	393.0

3.1.2 Length at first maturity

The relation between body length and gonadal development was examined in 620 fish samples randomly selected from the commercial catches. The smallest mature female and male fish was 14.5 cm and 17.0 cm long in TL, respectively. While, the smallest ripe female and male was 14.5 cm and 17.5 cm long in total length, respectively. Using logistic curve fitted values (Fig. 2), the estimated mean lengths at sexual maturity (TL_{50}) were 23.6 cm, 23.4 cm and 22.0 cm for combined sex (A), females (B) and males (C), respectively. It appears that males attain maturity earlier in life with a size of around 1.4 cm smaller than females.

The size of maturation of many fish species depends on demographic conditions and is determined both by genes and the environment (Fryer and Iles, 1972; Lowe-McConnell, 1987). The smallest size of mature fish for both sexes was 39 cm TL and the length at first maturity (TL_{50}) was found to be 41.5 cm TL for females and 42.5 cm TL for males of *O. niloticus* in Lake Chamo (Teferi, 1997).

The length at first maturity (TL_{50}) in the present study was higher than that of Lake Hayq 12.8 for females and 12.9 for males (Tessema *et al*., 2019), Tekeze Reservoir 15 for females and 14 cm for males (Teame *et al*. (2018), Lake Langano 16.4 for females and 15.8 for males (Temesgen *et al*., 2018) and Lake Hawassa 20.8 for females and 20.3 for males (Muluye *et al*., 2016). The length at first maturity (TL_{50}) in this finding was lower than the estimated value of the previous study in Lake Chamo (42 cm for both sexes) as indicated by Teferi and Admasu, (2002).

Overfishing can alter population structure, impair growth and earlier maturation depended on the selectivity of the fishery, (Jorgensen *et al*., 2007). Illegal fishing activities, utilization of a greater number of narrow mesh sizes gillnets lower TL_{50} values in lakes as reported for Lake Victoria in Kenya, (Yongo *et al*., 2018). Fishing pressure or fishing intensity is one of the major factors for early maturation and stunt growth in *O. niloticus*. Because, they allocate more resources for reproduction than somatic bodybuilding in water bodies where there is fishing pressure (Bandara and Amarasinghe, 2018). According to Shishitu *et al*., (2019), *O. niloticus* of Lake Chamo is experiencing growth overfishing due to the application of reduced mesh size gillnets (<11 cm, below the recommended). The lower TL_{50} values reported in the present study in Lake Chamo might be associated mainly with illegal fishing activities, fishing during breeding season, and buffer zone agricultural activities that have been practiced around the lake.

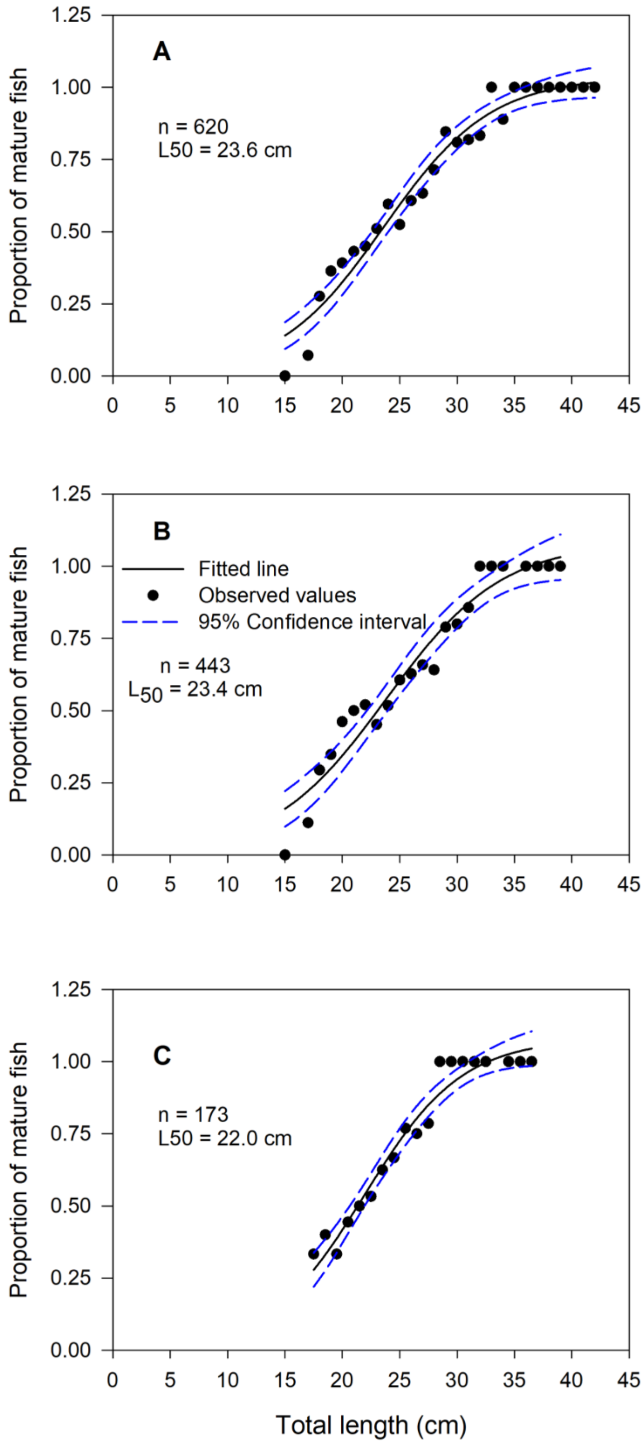

Figure 2: The proportion of size at first maturity (TL_{50}) of combined sex (A), females (B) and males (C) of *O. niloticus* in Lake Chamo

3.2 Breeding Season and Fecundity Estimation

3.2.1 Maturity stages

Samples of *O. niloticlis* were caught at various stages of gonad development and reproduces in almost all months. However, their frequency varied with the month fish were caught. The percentage of each gonadal development stage is illustrated in Fig. 3. According to the female's gonadic maturation stages, 12.3% of the total fish were immature (stage I), 15.91% were maturing (stage II), 20.87% were mature (stage III), 31.82% were ripe (stage IV) and 19.11% were spent (stage V). Therefore, 52.69% of the female fish were in the reproductive process. In the case of males, 17.22% of the total fishes were immature (stage I), 20.51% were maturing (stage II), 21.98% were mature (stage III), 28.94% were ripe (stage IV) and 12.45% were spent (stage V). Therefore, 50.92% of the male fishes were in the reproductive process. In general, 50.92-52.69% of *O. niloticus* in Lake Chamo were in the reproductive process.

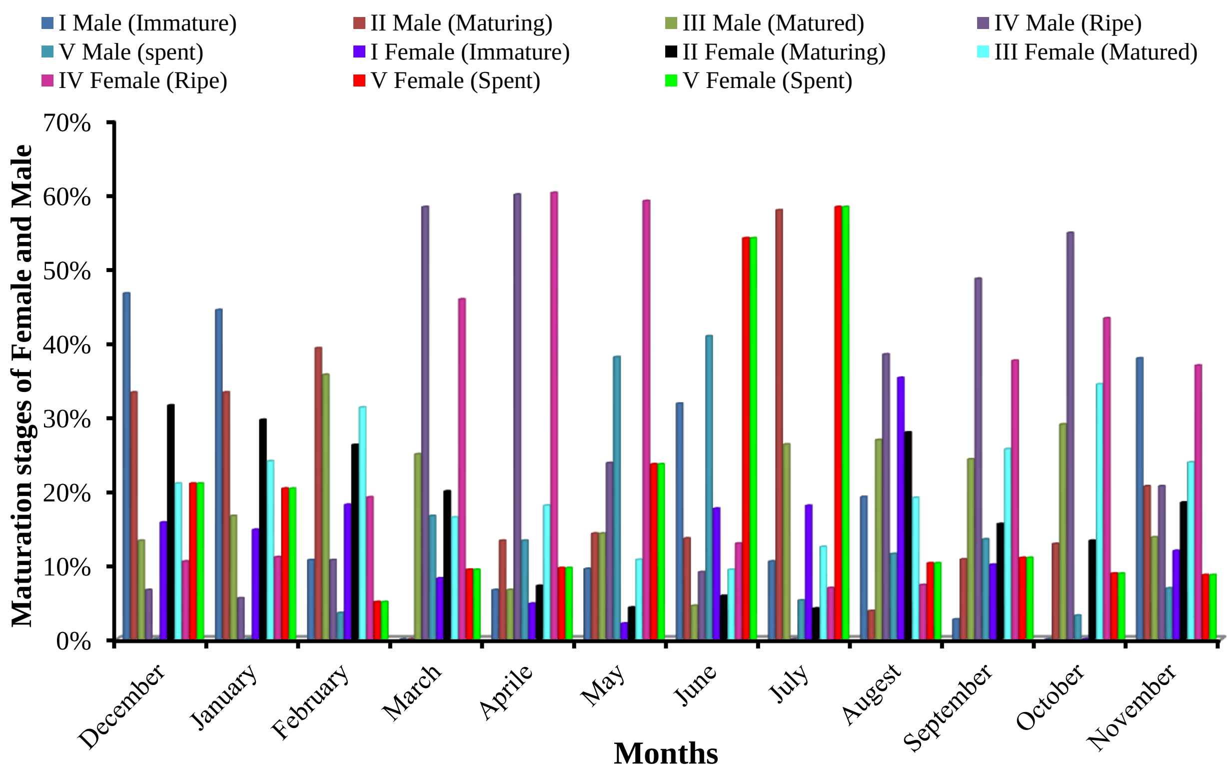

Figure 3: Seasonal variation of maturity stages for male and female *O. niloticus* in Lake Chamo

3.2.2 Breeding season

The frequency of temporal variation between ripe males and females and the pattern of gonad development for both sexes was almost similar (Fig. 4). The frequency was found high from March to May and from August to November. Ripe males occurred at high frequencies ranged 20.69 - 60% during March, April, May, August, September, October and November whereas females occurred in March, April, May, September, October and November which ranged from 36.96 - 60%. The low frequency of ripe fish of both sexes was recorded in December to February and June to July. Mature ovaries were available all year round and this is an indication that the fish breeds throughout the year. Based on the result of this study, it is evident that *O. niloticus* in Lake Chamo breeds throughout the year with peak breeding activity in March to May and August to November.

In Lake Ziway, *O. niloticus* was found to breed throughout the year, but more intensively between

December and March (Tadesse, 1988), whereas in Lake Hawassa it breeds twice a year, i.e., January to March and August to October (Admassu, 1994). *O. niloticus* in Lake Turkana breeds continuously but has an increased breeding activity from March to July (Stewart, 1988). The principal breeding season for most species of tilapia in Lake Victoria is at high water levels from January to March (Lowe-McConnell, 1987). The *O. niloticus* in Lake Chamo breeds intensively from March to June with some breeding activity occurring in other months (Teferi, 1997). But, the present study showed two intensives (peak) breeding seasons which includes March to May and August to November. The peak breeding season variation with the earlier study might be due to climate change and other factors.

Periodicity in fish breeding is believed to result from adaptation to fluctuation in the environmental factors so that offspring are produced during periods of maximum growth and survival (Welcomme, 1972). Temperature and photoperiod are the most important factors associated with the timing of fish breeding in waters at higher latitudes (Billard and Breton, 1978). In tropical waters, the major breeding activity of most species has been variously associated with light intensity, temperature, rainfall, and water level or seasonal flooding (Fryer and Iles, 1972; Lowe-McConnell, 1982). The abundance of food has also been considered as an important clue for the timing of breeding in some fish at low latitudes (McKaye, 1977).

Although environmental factors such as photoperiod and temperature do not vary much in Ethiopian lakes, there are annual peaks of reproduction activity for *O. niloticus* in most lakes (Teferra, 1987; Tadesse, 1988; Admassu, 1989; 1994). The main breeding time in most cases corresponds with the onset of the rainy season. In the current investigation, the occurrence of intensive breeding activity during March to May indicated the relation with the increase of solar radiation and sunshine that activates phytoplankton production while August to November was linked to heavy rainfall. Thus, in Lake Chamo, the reproduction of *O. niloticus* is higher during the rainy and sunny season than the rest of the year.

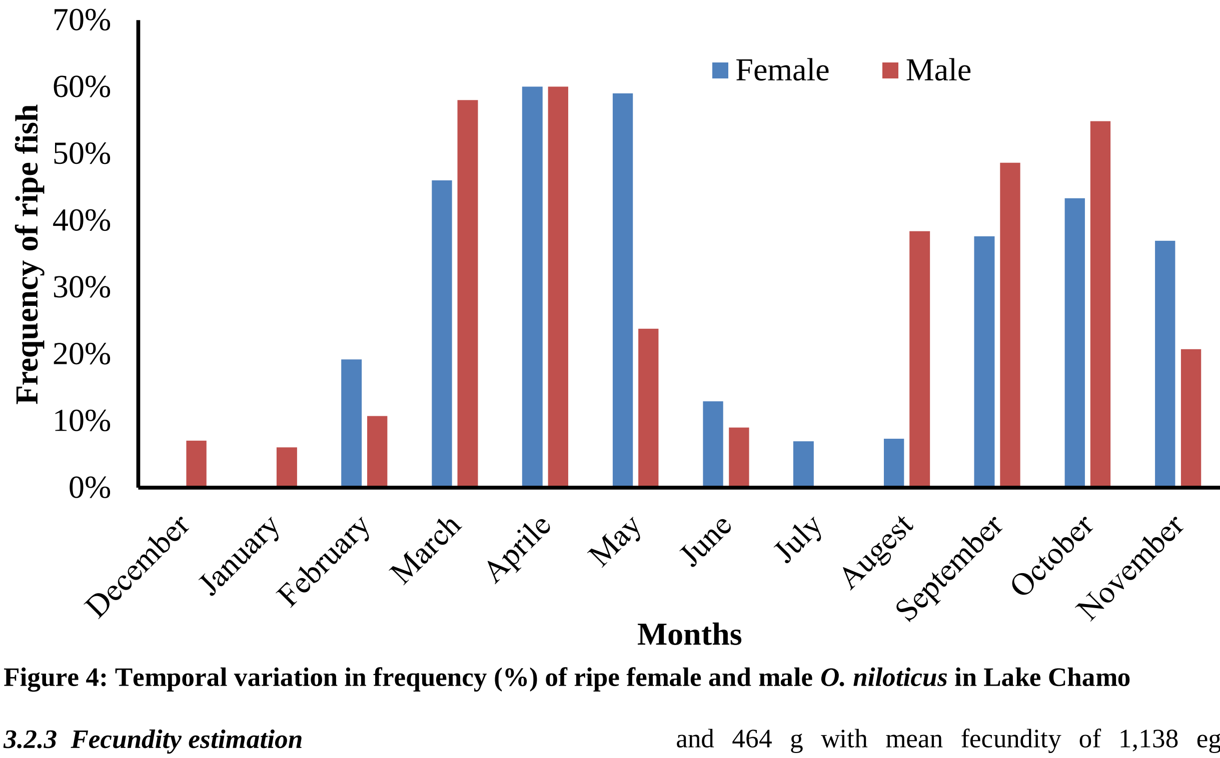

Figure 4: Temporal variation in frequency (%) of ripe female and male *O. niloticus* in Lake Chamo

3.2.3 Fecundity estimation

Fecundity of *O. niloticus* in Lake Chamo varied from 325 to 1,764 eggs for females whose length was between 20 and 30 cm and weight was between 132 and 464 g with mean fecundity of 1,138 eggs. Fecundity was curvilinearly related to total length (Fig. 5) and linearly related to the total weight (Fig. 6). The correlation between fecundity and body length was smaller ($r = 0.83$, $p < 0.05$) than the fecundity-body weight correlation ($r = 0.94$, $p < 0.05$).

In the earlier study, the fecundity of *O. niloticus* in Lake Chamo was ranged from 1,047 to 4,590 eggs (Teferi, 1997). For the same species from Lakes Ziway (Tadesse, 1988) and Hawassa, (Admassu, 1994) estimated values ranging from 198 to 934 and from 304 to 967 eggs, respectively. The fecundity of *O. niloticus* in the present study is smaller than the earlier study in Lake Chamo but is more fecund than in Lakes Hawassa and Ziway. Because *O. niloticus* in Lake Chamo matures at bigger sizes than in Lakes Hawassa and Ziway, they produce a larger number of eggs and broods. The highest number recorded in the ripe ovaries of mouth brooding *Tilapia aurea* from Lake Tiberias is 4,300 (Fryer and Iles, 1972). In *Tilapia galilaea*, females have been found to contain as many as 5,010 eggs (Ben - Tuvia, 1960). As was indicated in the result of this study, *O. niloticus* showed high fecundity and may enable the fish to reproduce in the lake rapidly than Lakes Hawassa and Ziway.

Fecundity of *O. niloticus* in Lake Chamo was related to the cube ($b = 3.01$) of their length (Fig. 5). This is a similar relationship with substrate spawners where fecundity is related to the cubic of their length (Simpson, 1951; Lowe-McConnell, 1959). It was mentioned that in mouth brooding cichlids, the fecundity is considerably low because the parents assure the survival of the offspring and in consequence less mortality (Moyle and Cech, 2000). Within a given species, fecundity may vary as a result of different adaptations to environmental habitats (Witthames *et al*., 1995). Even within a stock, fecundity is known to vary annually, undergo long-term changes and has been shown to be proportional to fish size and condition (Kjesbu *et al*., 1989). In addition, the variation in fecundity may be attributed to the differential abundance of food within the members of the population. Also, Siddiqui *et al*. (1997) pointed out that fecundity increased with increased feeding levels. Lake Chamo is characterized by a relatively high phytoplankton biomass and production rate which may indicate the abundance of food for fish in the lake (Tefera, 1993). High productivity of the water that results in high food availability and high temperature of the area could be the main reasons for the larger size of the fish and thus higher fecundity.

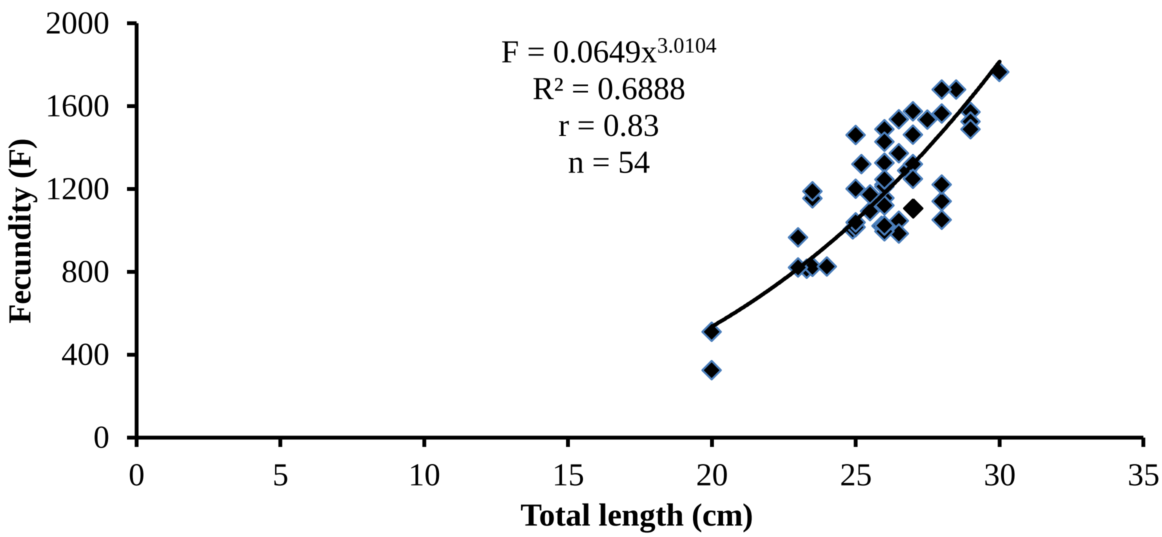

Figure 5: Relationship between fecundity and total length of *O. niloticus* in Lake Chamo

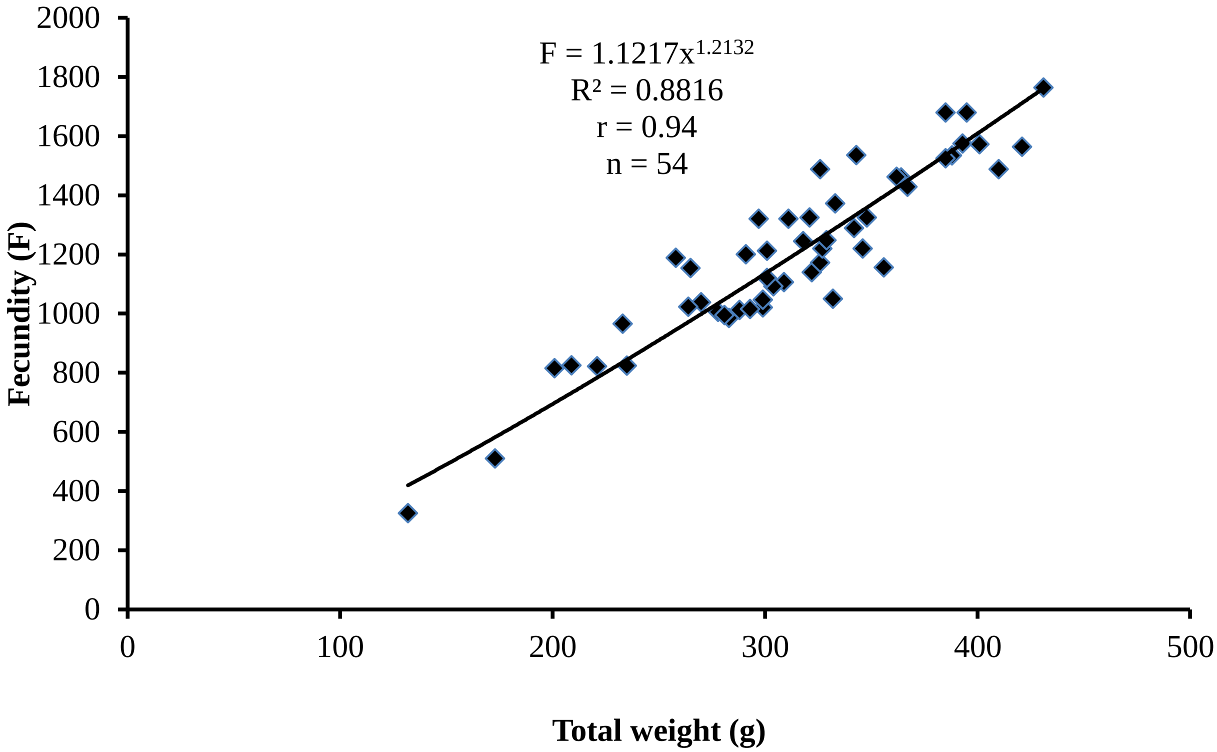

Figure 6: Relationship between fecundity and the total weight of *O. niloticus* in Lake Chamo

4. Conclusion and Recommendations

Female *O. niloticus* was dominated over the male throughout the year. This may possibly be due to females emigrate from spawning areas towards feeding grounds where they are caught. Fecundity of *O. niloticus* in Lake Chamo varied from 325 to 1,764 eggs with mean fecundity of 1,138 eggs. *O. niloticus* in Lake Chamo breeds throughout the year with peak breeding season of March to May and August to November. It is recommendable to reduce commercial fishing of *O. niloticus* during the peak breeding seasons in order to minimize the capture of breeding fish. The size at which 50% of the fish sexually mature was about 23.6 cm total lengths for both sexes. The size at first maturity (TL_{50}) in the present study for both sexes was too small than the earlier study (39.6 cm) in Lake Chamo for the same species. The smallness of TL_{50} might be due to heavy fishing together with illegal fishing activities, fishing during the breeding season, breeding ground destruction by buffer zone agricultural practices around the lake. Therefore, appropriate fishery management tools such as closing season during peak breeding, buffer zone conservation and mesh size regulation should be implemented for sustainable fishery utilization in Lake Chamo.

Conflicts of interest

The authors declare that there is no conflict of interest in publishing the manuscript in this journal.

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Lessons from Small-Scale Fish Farming in South West and West Shewa Zone, Oromia Region, Ethiopia. A Review

Yared Mesfin[1], Mesay Yami[1] and Gashaw Tesfaye[1]*

[1]*Ethiopian Institute of Agricultural Research (EIAR), National Fishery and Aquatic Life Research Center*
***Corresponding author:** yaredmesfin44@gmail.com

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Abstract: *For the past 13 years, the National Fisheries and Aquatic Life Research Center (NFALRC) have intervened with small-scale fish farming trials in South West and West Shewa zones of Oromia Region, Ethiopia. Opportunities and challenges of the trial, farmers' awareness, and attitude towards small-scale fish farming and its economics have already been studied and documented. However, the studies were not comprehensively reviewed, synthesized, and presented to inform further intervention. This paper is meant to fill this gap. Desk review of those studies and others supported by prior experience of the author to intervention areas is the core approach followed. As a result, seven key lessons were learned: the need for redefining core challenges of small-scale fish farming, gender inclusion in small-scale fish farming, need for a revision of public sector-led formal extension service delivery linked to the change in the conventional extension approach followed by NFALRC, emphasis on awareness creation on fish farming, the importance of participatory approaches and the need for repeating research trials in the economics of small-scale fish farming. Among these, awareness creation, the use of participatory approaches, and changes in conventional extension service delivery by NFALRC should be given priority.*

Keywords: Aquaculture, By-product, Fish farming, NFALRC, Oromia Region

1. Introduction

The fish farming system in Ethiopia is mostly extensive with some small-scale and semi-intensive systems of production among a few practicing farmers (Rothius *et al*., 2012). An extensive farming system is a case where fingerlings are literally stocked in ponds with virtually no feed supply, pond management, or other packages necessary for fish farming (Rothius *et al*., 2012). In this case, the ecosystem inside the pond provides food for the fish (Lekang, 2013). However, in a Semi-intensive system, there is some sort of supplementary feed and pond fertilization support in addition to the natural feed obtained from the pond ecosystem (Edwards and Demaine, 1998). Semi-intensive fish farming is currently being practiced by very few subsistence farmers as observed from field experience. Estimated size of more than 1,300 fish farmers in Ethiopia is subsistence types with a pond size of about 100-300m^2 (Rothius *et al*., 2012).

Fish species being cultured in many fish farming sites of Ethiopia are mainly Tilapia (Nile Tilapia and Redbelly Tilapia) followed by African Catfish and Common Carp (Chalacheww, 2010; Daba, 2010; Yared *et al*., 2011; Alayu *et al*., 2015; Hiwot *et al*., 2016). These are commercially important fish species available in Ethiopia. In addition to those mentioned above, the species, being cultured at NFALRC also includes Crussian carp and goldfish (NFALRC, 2010).

Evidence from some studies in Ethiopia shows that in areas where there was no prior experience of fish farming, the first challenge those who intervene face is a lack of awareness about the activity. Thus, improving community awareness is necessary to start out the same and improve its adoption (Hiwot *et al*., 2016; Tena, 2021). The second challenge is the lack of inputs for fish farming, basically fish feed (Hiwot *et al*., 2016; Tena Alemu, 2021).

Fish farming is a management-intensive business. The need for intensive and skilled management comes from a high level of capital invested in the facilities and a high level of operating capital required for a competitive and profitable business (Yemi and Deji, 2012). The importance of studying the economic viability of fish farming is that it is one of the components of sustainability in the sector (Yemi and Deji, 2012). Hence it is termed as "economic sustainability". If fish farming is to be sustainable without any incentive, it has to be economically viable (Hishamunda *et al*., 2007).

From 2008 onwards NFALRC commenced small-scale fish farming trials using six farmers from South West and five farmers from West Shewa zones of the Oromia region, observing the availability of year-round river and farmers' willingness to participate in the trials. Land allocated for constructing fish ponds was bush land or land used to prepare livestock fodder and grassland. Then, ponds of an average size of about 100-200 m^2 area were constructed with the cost first covered by the farmers themselves and refunded by the center. After the ponds are filled up with water they were stocked with tilapia fingerlings only (mono-culture) and other fish species such as common carp and African catfish mixed (polyculture). Fish farming inputs and associated training were then provided to experts and farmers. Finally, having seen the home consumption benefits reaped and promoted by the adopters, other farmers also joined the trials and showed more demand from time to time.

At the beginning, what to feed the fish was the basic challenge faced by farmers who commenced the trials. Hence, they provided potato leaves, bread scrambles, and other homemade food leftovers, wheat bran, or noug cakes in dried forms (Yared *et al*., 2018).This feeding habit then became common when Sebeta I fish feed, prepared from a mix of industrial by-products: noug cake, brewery waste, and wheat bran was not supplied timely by the center (Yared *et al*., 2018). Based on personal observation and field experience on the sites, commercial-grade fish feed was not accessible and affordable to fish farmers. Alema Koudijs Feed PLC is currently the only animal feed processing factory producing fish feed, both for Nile Tilapia and African Catfish on a limited scale (Koudijs, 2019).

During the intervention, three successive studies were conducted by researchers from the center on fish farming challenges and opportunities, the economics of small-scale fish farming as well as awareness and attitude of farmers towards the activities (Hiwot et al., 2016, Yared *et al*., 2018, Abebe and Mesay, 2018). All the studies were conducted in the intervention areas. However, they were not synthesized to clarify the gaps and inform all possible local intervention options in an organized manner. The current review is done to fill this gap.

2. Research Methodology

This paper follows a conceptual analysis of studies made by Hiwot *et al*. (2016), Yared *et al*. (2018), and Abebe and Mesay (2018) through a desk review, supported by practical evidence. Though these studies are focal areas of the current review, other studies conducted on similar topics with implications to the current intervention areas were also revisited. Basic data points are then extracted from the three studies and categorized into themes, narrating the challenges to small-scale fish farming and partly lessons learned from their findings. The lessons are then backed up by personal experiences and further discussed accordingly.

3. Results and Discussion

3.1 Lessons from the surveyed intervention areas

3.1.1 *Lessons from farmers' awareness and attitude towards fish farming*

A survey conducted by Yared *et al*., 2018 on farmers' awareness and attitude towards fish farming has shown that more information is necessary on the nutrition benefits of fish. As observed from the survey output, the nutrition and health benefit of fish compared to other livestock species was not properly understood among farmers. Detailed awareness of pond dynamics is also lacking. Meanwhile, the survey output indicated that farmers could be more motivated to start fish farming if they are aware of the unique benefits of fish consumption such as for their health and mental development of their young children. The study also depicted awareness and attitude differences among fish farmers themselves, calling for change. Such a gap may partly be attributed to limitations in information coverage by the formal extension system. It is because formal extension in Ethiopia cannot address all farmers and at once. Thus, the farmer-to-farmer linkage is a more important and cost-effective way of disseminating information; creating better awareness and improving attitude towards fish farming (Kumar, 1999).

3.1.2 Lessons from economic analysis of small-scale fish farming

Several studies conducted on the economic viability of small-scale fish farming have shown that the activity is profitable provided the market and all relevant inputs are available at a given price. Among major factors limiting the profitability of small-scale fish farming, the fish feed was mentioned as one of the three: labor for pond construction and management, fish feed, and fingerlings (Hyuha *et al*., 2011). The same was found to be true in the respective order of importance for the study conducted by Abebe and Mesay (2018). Although some information is already available on the production cost of semi-intensive fish farming and profitability (Rothius, 2012; Abebe and Sileshi, 2015; FAO, 2017), these information cannot be recommended directly for NFALRC intervention areas. Thus, economic analysis on small-scale fish farming had to be conducted in those areas.

For the study, eight progressive fish farmers residing in two fish farming pilot project sites namely: Wonchi and Illugelan districts of South West and West Shewa zones were selected (Abebe and Mesay, 2018). For the purpose of analysis, fish farming activities were grouped into four major production stages namely: Pre-stocking, stocking, feeding together with pond management and harvesting. Based on the finding, the cost of labor for pond preparation and maintenance at pre-stocking stage was found to be the highest covering about 78% of the total production cost (Abebe and Mesay, 2018). The second and third highest production cost components of small-scale fish farming were found to be fish feed (Sebeta I), which is developed from industrial by-products, currently used by NFALRC and fish fingerlings. They covered part of the remaining 22% of the cost. Among others, fish feed alone covered around 14% of the total production cost (Abebe and Mesay, 2018). The low percentage contribution of the feed to the overall production cost was because of its relative cost-effectiveness to commercial fish feed (Alema Feed) and recommended for small-scale fish culture systems (Abelneh and Zenebe, 2017).

From the study, it was understood that labor, especially at the initial stage, is a crucial cost factor for small-scale fish farming. It is demanded at all levels of the production process (Abebe and Mesay, 2018).This reality is contradictory with the expected assumption cited in the strategic document prepared for small-scale fish farming and included in the National Aquaculture Development Strategy of Ethiopia (MoARD and FAO, 2009). In the document, it is stated that labor cost for small-scale fish farming is low as it would be organized locally for free. In reality, farmers don't necessarily organize family labor as the majority of them have small children who have not yet reached a working age (Abebe and Mesay, 2018). Fish fingerlings and Sebeta I fish feed are normally given to farmers from the National Fishery and Aquatic Life Research Center only for subsistence production and free of charge.

Thus, the analysis of production cost for small-scale fish farming was done assuming if farmers were to prepare Sebeta I fish feed taking industrial by-products from nearby factories and unit price of fish fingerlings currently set by the center and sold to flower farms from the center (Abebe and Mesay, 2018). During the whole project period, all costs associated with fish farming starting from land clearing, pond preparation, provision of fish fingerlings, filling water and lime application were fully supported or compensated by the center.

Compared with the results of other similar studies, the benefit to cost ratio of the current intervention is higher than smallholder fish farming in the case of Nigeria (Yemi and Deji, 2012) Zambia (Kapembua and Samboko, 2017) and China (Phiri and Yuan, 2018) but lower than that of a study conducted in Oyo State, Nigeria (Tunde *et al*., 2015; Ashley *et al*., 2017) and Iran (Maaruf and Akbay, 2020) to mention some. From the study result, it is understood that cost-reducing technologies are important to ensure economic success out of fish farming. This should primarily focus on the reduction of labor costs for pond construction and maintenance by maximizing the use of locally existing natural water bodies, which could be used as ponds. Fish feed should be the next issue that demands more attention. The output of the economic analysis, conducted in the study area, leads us to recommend farmers either to develop their own feed from locally available resources or apply an integrated fish farming system to get relatively better off.

Regarding the overall profitability of small-scale fish farming, the benefit to cost ratio of all respondents engaged in the activity was positive and above one. As indicated in the paper by Abebe and Mesay (2018), the overall mean value of the benefit to cost ratio was 1.49, indicating that a one-Birr investment in small-scale fish farming would result in a profit of 0.49 Birr, provided there is a consistent market, existing technologies and inputs are used. The authors of this study finally concluded that fish farming in the project areas is still economically viable on a small scale but not satisfactory as a business of choice to most other farm business enterprises selected and used for comparison (Table 1).

Table 1: Profitability comparison of different livestock, and crop enterprises in Ethiopia

S/No	Type of farm business	Benefit to cost ratio
1	Smallholder dairy farming	1.20
2	Aquaculture	1.49
3	Highland maize production	1.59
4	Durum wheat production	1.60
5	Chickpea	1.60
6	Mid-altitude maize	1.70
7	Tef	1.79
8	Commercial dairy farms	2.00
9	Lentil	2.26

Source: Author's compilation from Abebe and Mesay (2018)

3.1.3 Lessons from the potentials and challenges of smallholder fish farming

The study by Hiwot *et al*. (2016) tried to assess overall potentials and challenges for smallholder fish farming in the intervention areas. As a result of the study, cost of commercial fish feed and its inaccessibility, lack of awareness on fish farming, poor extension, and advisory service delivery, lack of adequate expertise on fish farming, absence of private sector investment in the subsector, and embedded food culture of the local community were identified as primary challenges. However, the potentials for smallholder fish farming, operating in small-scale, are also identified such as availability of sufficient land, water and, some technical staff with fishery background. Three key lessons learned from the survey output were:

- Availability of water and land should not be the sole criteria in selecting sites for small-scale fish farming trials. I.e. also use other suitability mappings and species compatibility using multi-criteria analysis
- Participatory problem identification and joint planning, as well as promotion of fish as part of farm household's recipe, should be done before introducing fish farming trials
- The challenges to fish farming have to be redefined in a participatory manner and synthesized in a way to provide optimal solutions unlike the formal method used to gather information related to those challenges from farmers.

3.2 Overall lessons from small-Scale fish farming in the intervention areas

3.2.1 Challenges to be clearly defined for small-scale fish farmers

The challenges faced by farmers in promoting fish farming practices are so diverse and complex. Hence, they need to be clearly defined. Moreover, it needs a systemic understanding of their origin, root cause, and effect relationships. Multi-dimensionality of the challenges leads us not to forward a single faceted solution to the overall problem (Hiwot et al., 2016). Hence, a closer look at these challenges shows that they are interrelated. It is thus important to synthesize similar cases into a comprehensive framework. Experiences drawn from the project sites show that challenges related to smallholder fish farming could generally be grouped as: Social, Economic, Technological and Institutional (Figure1).

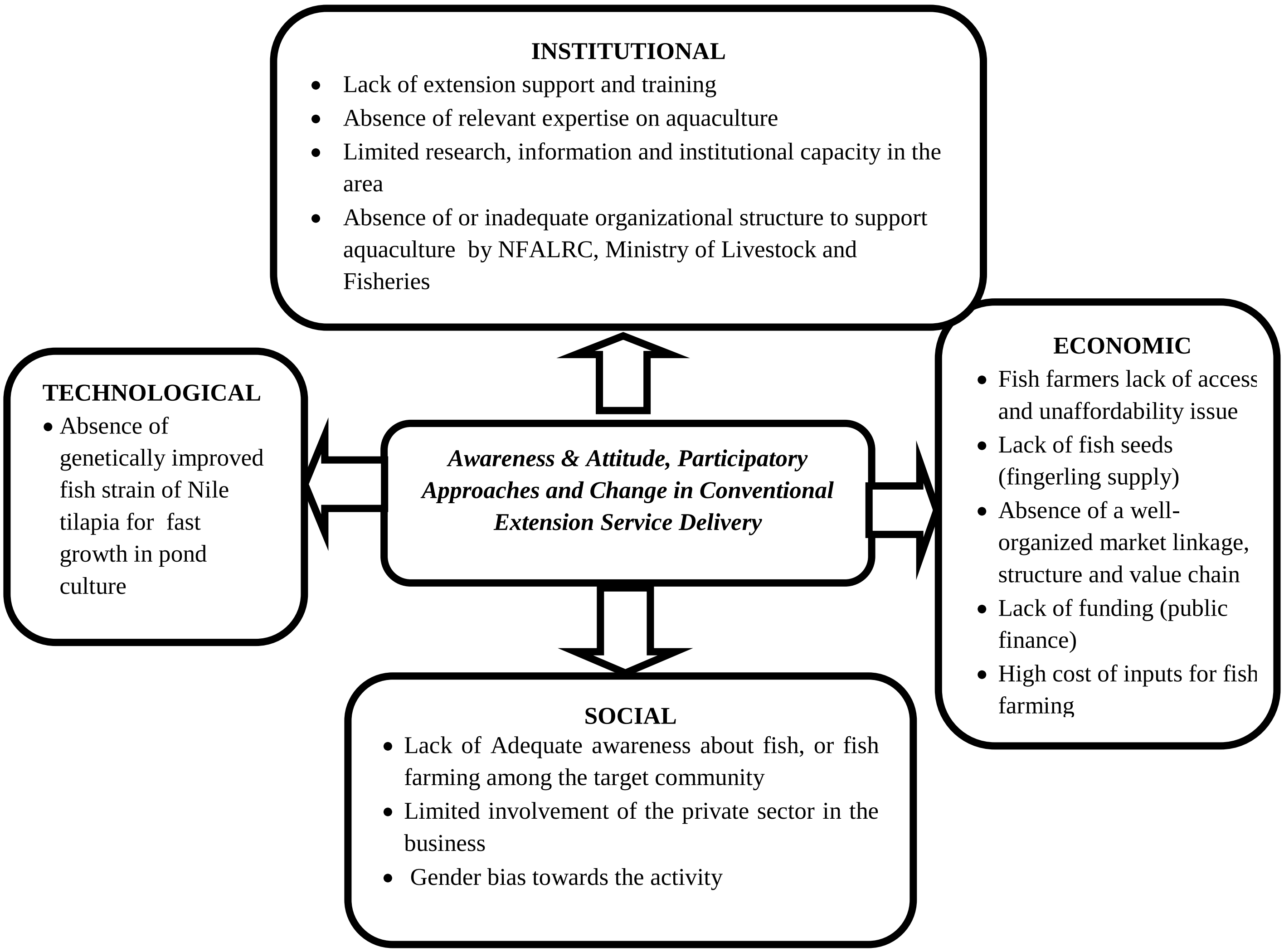

Figure 1: Framework of challenges to smallholder fish farming in the study areas

3.2.2 Consideration of Gender in small-scale fish farming

Gender plays a central role in small-scale fish farming, which is expressed by the sharing of roles and responsibilities for mutual benefit. However, the gender literature on fish farming is often scattered. The dearth of literature indicates that both research and projects in fish farming value chains often fail to take the gender perspective into account (Kruijssen and McDougall, 2018). Failure to address gender issues is attributed to the fact that like the terminologies of "agriculture or farmer", smallholder fish farming is also perceived as a male-dominated activity. Men are normally and usually engaged in creating the foundation for activities such as allocating capital and doing physically demanding responsibilities.

Women have a significant contribution and impact on fish farming (Atdhe *et al*., 2009). For instance, they are sometimes involved in pond construction, fish feeding, liming regular supervision, medication, pond drying, cleaning, stocking, fish harvesting, sorting fingerlings, marketing, and seed supply. There are also cases where women are involved in gillnet making, mending, and transportation activities. (Brugere and Williams, 2017; Luomba, 2013, Das and Khan, 2016; Quddus *et al*., 2017). Despite this, they are usually invisible in policy due to the lack of comprehensive and timely data on women in fish farming (Hapke, 2012; Brugere, 2015).

Regarding the intervention areas, gender roles in fish farming were mapped. As a result, the participation of women in small-scale fish farming is not significant, as for boys and girls. Based on the survey results of Hiwot *et al*., 2018 and Yared *et al*., 2018, women participate only in fish feeding, fish processing, sometimes pond management and cooking-related value addition activities. Despite their role, they are not actively engaged in formal trainings and workshops related to fish farming and processing as expected (Hiwot *et al*., 2018). This, in addition to several factors for their non-participation, shows a lack of gender consideration in fish farming. Enhancing women's participation, therefore, helps to increase labor productivity, reduce the cost of production associated with pond management and hence productivity of small-scale fish farming. As an implication, non-participation is indicative of an unused potential of fish feed preparation and feeding, which a very significant assignment in fish-farming.

3.2.3 Changing the conventional extension approach

Ethiopia is one of the African countries with a greater number of extension personnel to farmers. the ratio which is 1:475. This exceeds that of Kenya, Malawi, and Tanzania having ratios of 1:1,000, 1:1,613, 1:2,500 respectively (Pablo *et al*., 2008; Davis *et al*., 2010). Despite these concentrations of extension personnel to farmers, the performance of the extension effort was not as satisfactory as expected. The previous studies conducted in the NFALRC intervention areas also evidenced that there is poor public extension support for small-scale fish farming trials.

The poor performance of the public extension system in fish farming of Ethiopia is partly attributed to the biased nature of extension service against the Livestock Sub-sector (Belay, 2003). Weak budget, human resources and equipment allocated to fish farming also contributed their part (Erkie *et al*., 2020). But, most of all it is due to the extension of information dissemination in the country which applies top-down and inflexible approaches to service delivery (Befekadu and Berhanu, 2000). The current review recommends alternative means of information dissemination through individual farmers and farmer organizations for successful information dissemination and service delivery in relation to small-scale fish farming. Therefore, it is a necessary to shift from an expert-led transfer of information and service delivery, currently applied by NFALRC, to more participatory approaches and use of farmer networks for fish farming-related information dissemination (Kumar, 1999; Yared *et al*., 2018).

3.2.4 Contextualizing economic viability of small-scale fish farming

Private sectors' engagement in fish farming is nonexistent (Hiwot *et al*., 2018). Various studies conducted on the economic viability of small-scale fish farming claim that the venture is profitable provided market and all relevant inputs are sustainably available. Among major factors limiting the profitability of smallholder fish farming include labor for pond construction and management, fish feed and fingerlings (Hyuha *et al*., 2011). In the context of NFALRC intervention areas studied, low-cost pond construction, feed, and access to fish fingerlings need more emphasis in the business of small-scale fish farming.

Comparing outputs from some other studies, the benefit to cost ratio economic analysis study from the intervention areas is higher than that of Zambia (Thelma and Indaba, 2017), China (Phiril and Yuan, 2018), and Nigeria (Yemi and Deji, 2012) but lower than that of a study conducted in Oyo State, Nigeria, which is 1.69 (Ashley *et al*., 2017) and 1.9 (Tunde *et al*., 2015). Despite this, the economic analysis of small-scale fish farming studied in our pilot project areas does not provide a holistic picture of profitability at all times and in all places. This is because of contextual differences among varied implementation areas. For resource endowed farmers reduced cost of production factors and growing experience in fish farming implies more profitability than the number shown above. Thus, alternatives should be suggested for a higher benefit to cost ratios. For the sake of the researcher's confidence in stating overall profitability, more replicable and confirmatory studies are still needed across space and time.

3.2.5 Emphasizing towards awareness and attitudes of small-scale fish farming

An assessment of the potentials and challenges of smallholder fish farming in the study areas shows that the awareness level of sample fish farmers on the practices was still low. This necessitated the identification of fish farming practices that need more clarity to the farmers. A subsequent study conducted by Yared Mesfin *et al*., (2018) in one of the project sites, has also shown the same result, recommending on the improvement of farmers' understanding of pond dynamics and contribution of fish for nutrition security in multi-faceted ways. Still, knowledge and experiences gained by fish farmers, their overall awareness and attitude towards fish farming need to be assessed and documented.

3.2.6 Participatory situation analysis before project start-up

Before implementing projects related to smallholder fish farming, it is always necessary to start from a small number of farmers with detailed baseline data about the community, their problems, opportunities, and challenges in a participatory manner. One important lesson learned regarding appropriate site selection for smallholder fish farming intervention is about participatory situation analysis. In the pilot project areas, criteria used for selecting project sites were only, availability of land, water, labor, and farmers' willingness to implement new projects (Hiwot *et al*., 2016). However, entry into fish farming not only demands farmers' willingness but also participation in the whole process of the activity i.e. from joint plans to implementation (Ejigu, 2004; Taha *et al*., 2004). But, unfortunately, this was not the approach used by NFALRC in the intervention areas. To circumvent upcoming challenges related to fish farming project implementation, it is, therefore, better to undertake detailed participatory situation analysis so that, project beneficiaries would have a sense of ownership and contribute to resolving day-to-day challenges on their own. Successful village-level fish farming interventions in many Asian countries followed a system of planning at grass root level which is part of a situation analysis and joint planning (Kumar, 1999).

3.2.7 Key lessons learned from NFARLC's intervention experiences

Summarizing all points mentioned in this review, key lessons learned were: Need for revisiting the conventional transfer of technology mode of extension followed by NFALRC and impacting the formal extension service delivery, gender consideration, economic viability of small-scale fish farming, awareness and attitude towards fish farming, redefining root challenges of small scale fish farming and application of participatory approaches to start small-scale fish farming. A framework showing the relationship between these lessons is illustrated below (Figure 2).

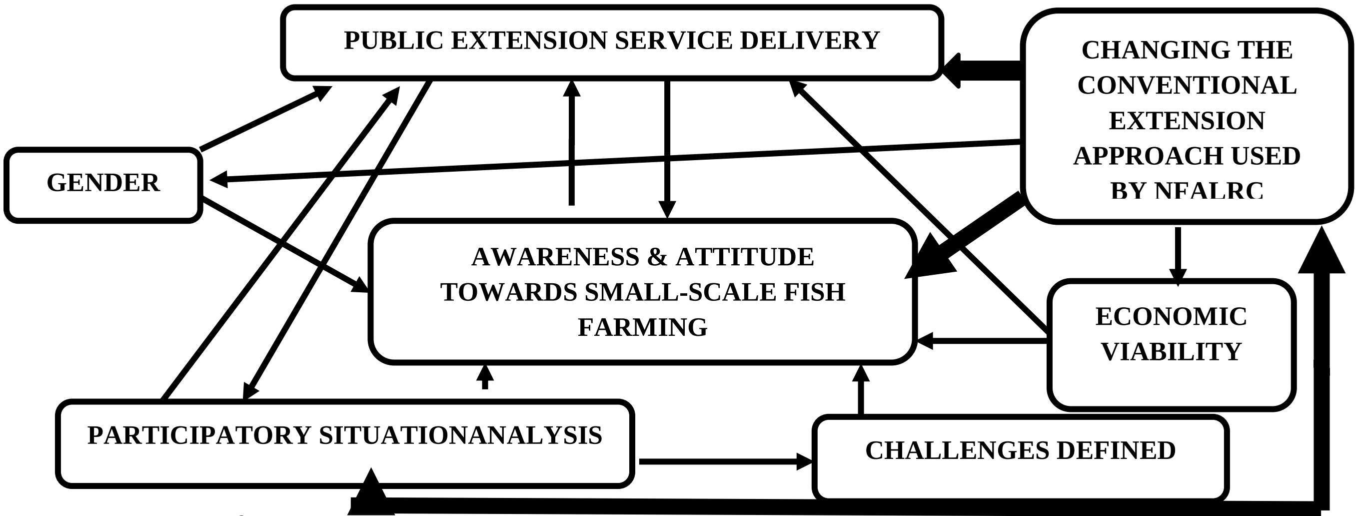

Figure 2: Association of key lessons learnt

4. Conclusion and Recommendations

The challenges of small-scale fish farming observed in the studied intervention areas are very complex and need a systemic intervention. A systemic intervention again needs redefinition of the challenges to identify their root cause. However, it is still possible to link some of the findings observed in the previous studies and design a framework to understand the lessons learned which might give a hint in finding solutions to those challenges. From the review, seven key lessons were learned and presented as a framework of concepts leading to a solution to those challenges as evaluated by the author. These lessons are entry points for future interventions in the study areas.

To come up with the challenges observed in the intervention areas, it is important to reconsider points cited in the framework of key lessons learned from small-scale fish farming in general and the three studies in particular. The framework of key lessons learned should be utilized as an input for a systemic intervention in small-scale fish farming of the study areas. For instance, points presented as a framework of key lessons learned and linked in bold line of Figure 2 could be used as entry points for systemic intervention. Among the key lessons, awareness creation on small-scale fish farming; use of participatory approaches, and a shift in the mode of extension service delivery by NFALRC should be given top priority for later interventions to the studied areas.

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Conflict of Interest

The authors declare that they have not sent this review article to any other journal for publication.

Ethical Approval

This Article does not contain any studies with animals performed by any of the authors.

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Phenotypic Characterization of Indigenous Goat Population Reared in Uba Debre-Tsehay and Zala Districts of Gofa Zone, South Ethiopia

***Dereje Dea*[*1], *Ermias Eramo*[1], *Otoro Olke*[2]**

[1]Arba Minch Agricultural Research Center, Arba Minch, Ethiopia
[2]South Agricultural Research Institute, AGP-II Program, Hawassa, Ethiopia
***Corresponding author:** deredea12@gmail.com

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Abstract: *The objective of this study was to describe the morphological features of indigenous goats in two lowland districts of Gofa zone in their home tract, Ethiopia. A total of 170 goats (50 males and 120 females) were used for the morphological characterization. Results confirmed that there were morphological variations in terms of coat color patterns. Accordingly, about 49.2% of goats showed plain followed by patchy (27.8); the dominant coat color was brown (44.7%) followed by white (32.7%). About 98.5% goats were characterized by possessing horn, 80.5% curved horn-shape, 54.5% with obliquely-upward horn orientation, 75.2% horizontal ear-orientation, 88.0% straight head-profile, 92.0% partially-sprit scrotum-type, 6% wattle presence, 38.0% beard and 2.5% ruff. There were no statistically significant morphological variations between males and females (p>0.05). These may be due to the high off-take rate of male goats at an early age. A significant difference (p<0.05) was observed between age and linear body measurements. There were significant correlations found among body weight with body length (r=0.81), wither height (r=0.67), chest girth (r=0.82), head length (r=0.64) and horn length (r=0.61). Morphological traits' variations suggest that this goat population has not yet been selected through structured selective breeding.*

Keywords: Goat, Gofa Zone, Phenotypic characterization

1. Introduction

Ethiopia has an estimated over 23 million heads of goats (CSA, 2020). Despite the wide distribution and large size of the Ethiopian goat population, the productivity per unit of animal and the contribution of this sector to the national economy is relatively low. This may be due to different factors such as poor nutrition, the prevalence of diseases, lack of appropriate breeding strategies, and poor understanding of the production system as a whole (Tesfaye *et al.*,, 2010).

Designing of goat improvement programs will only be successful when characterization of local genetic resources (based on morphological traits) based on size and shape in turn which can be to some extent reasonable economic indicator (Okpeku *et al.,* 2011).

Different research works (particularly phenotypic and genetic characterizations research activities) had been executed in different parts of the country by different organizations and individuals (FARM Africa, 1996; Tesfaye, 2004; Grum, 2010; Tesfaye, 2010; Halima *et al.,* 2012a; Halima *et al.,* 2012b). Despite the researches done, still, there are major gaps in the coverage of phenotypic characterization activities and information for monitoring populations' trends and hence unknown current risk status for many breeds. Gaps are particularly prominent in developing countries like Ethiopia (FAO, 2015).

Gofa Zone of South Region is a lowland part of the country. Characterizing goat populations around this area in the existing production environment was very essential to design management and utilization strategies. Therefore, this study was designed with the objective to characterize the physical characteristics of indigenous goat populations.

2. Materials and Methods

2.1. Description of the study areas

The study was conducted in Zala and Uba Debre-Tsehay districts of Gofa administrative zone, which is one of the 17 Zones in Southern Nations, Nationalities, and Peoplels` Region of Ethiopia. Sawla is the capital town of Gofa zone and located 514 km away from Addis Ababa, at an elevation of 1285 meters above sea level. Gofa zone is part of a region known for hilly and undulating midland and upper lowland terrain. Food crops include maize, enset. Sweet potatoes, taro, teff, and yams are grown in Gofa zone.

Zala district is bordered on the southwest by Uba Debretsehay, on the northwest by Demba Gofa, on the northeast by Kucha, on the east by Deramalo, and on the southeast by Kemba districts. Uba Debretsehay is bordered on the south and west by the Debub Omo Zone, on the north by Oyda and Demba Gofa, on the northeast by Zala, and on the east by Kemba districts.

The temperature, rainfall and altitude of Zala district is 18-25°C, 1401-1,600 mm, and 501-2,000 m, respectively, while the corresponding parameters in Uba Debre-Tsehay district are 10-27°C, 1200-1,600 mm and 5001-3.500 m

2.2. Sampling procedures

A rapid reconnaissance survey was carried out before the actual survey work with zonal and district livestock experts, development agents, local farmers, village leaders and socially respected individuals who had known to have better knowledge to locate the distribution of goat and production systems. Then, phenotypic characterization was conducted in both Zala and Uba Debre-Tsehay districts. The two districts were selected purposively based on goat population potential and accessibility.

For linear body measurements, a total of 50 males and 120 females from two districts were sampled, of which the majorities were adults following the phenotypic descriptor of FAO (2012). Measurements were taken early in the morning to avoid the effect of feeding and watering on the animal's size and conformation and when they are in a normal standing position during the same season (FAO, 2012).

The age of the animals was estimated by recall and dentition methods. Adult goats were classified in to five age groups based on pair of the permanent incisor 0PPI, 1PPI, 2PPI, 3PPI, and 4PPI, which represent the age 0-1 year, 1-2 years, 2-3 years, 3-4 years and 4-5 years, respectively as described by Gerald (1994) and FAO (2012) for tropical goat breeds.

2.3. Data collection

Quantitative data was collected by using measuring tapes and weighing scale (50 Kg spring balance) and for qualitative data coding sheets, Global Positioning System (GPS, Garmin 6.2) and Digital Camera.

Qualitative variables collected were sex, district, age, coat color pattern, coat color, horn type, horn shape, horn orientation, ear orientation, head profile, scrotum type, wattle, beard and ruff presence (Halima *et al*., 2012a).

Quantitative variables collected were: BW (bodyweight), body length (BL), Height at wither (HW), Chest Girth (CG), head length (HL), Horn Length (HL), Ear Length (EL), Scrotal circumference (SC) and Teat Length (TL) (FAO, 2012). Pregnant and highly emaciated animals were excluded from the measurement to avoid over and under-estimation, respectively.

2.4. Data analysis

All qualitative and quantitative data were analyzed by using SPSS Software version 20. The data emanating from the qualitative data (non-parametric data) were described using descriptive statistics and compared using the chi-square test

2.4.1. Models for quantitative data analysis

The model indicated below (Hulunim, 2014) was used for the analysis of adult body weight and linear body measurements (LBMs) except scrotum circumference and teat length.

$$yijk = \mu + Ai + Sj + \text{Dk} + \text{eijk} \quad [1]$$

Where

- yijk = the observation of body weight and LBMs in i^{th} age group, j^{th} sex and k^{th} district
- μ = overall mean

- Ai = the fixed effect of ith age group (I = 1PPI, 2PPI, 3PPI, 4PPI)
- Sj= the fixed effect of jth sex (j = female and male)
- Dk= the fixed effect of kth district (K = Uba Debre-Tsehay and Zala)
- eijk = random residual error

The multiple regression models indicated below were used for estimation of body weight from linear body measurements (Hulunim, 2014).

$$Yj = \propto + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \beta 6X6 + \beta 7X7 + \beta 8X8 + ej \quad [2]$$

Where:

- Y_j = Response variable (body weight)
- α = Intercept
- X_1…., X_8 = Explanatory variables (body length, Height at wither, Chest Girth, head length, Horn Length, Ear Length, Scrotal circumference and Teat Length
- β_1…, β_8 = Regression coefficients of the variables X_1…, X_8
- e_j = Random error

3. Results and Discussion

3.1. Phenotypic description of Gofa area goat population

3.1.1. Qualitative characteristics

The frequency and their percentage of qualitative traits of Gofa goat population are presented in Table 1. The observed overall coat color patterns were 49.2% plain, 27.8% patchy and 22.9% spotted. According to Tesfaye *et al*. (2006) report, a higher proportion (93%) of plain coat color patterns for central highland goats around South Wollo and North Shewa. The dominant coat color types in both study districts were brown (44.7%) followed by white (32.7%), which in agreement with the findings of Halima *et al*. (2012a) and Grum (2010) where a wide range of coat colors were reported. Goats observed in the present study across all study districts were about 98.5% (horned), 54.5% (obliquely up-ward horn orientation), 75.2% (horizontal ear orientation), 92.0% (split scrotum type), 94.0% (absent wattle), 62.0% (absent beard) and 97.7% (absent ruff) (Figure 1 and 2).

Figure 1: Typical Gofa area goat population (A: Breeding buck, B: Breeding doe)

Figure 2: Scrotum type observed in the study are (A: Partially split; B: single)

Table 1: Qualitative traits of Gofa area goat population (Uba Debre-Tsehay =74, Zala = 96 and Total=170)

Parameters		District		
		Uba-D/Tsehay (%)	Zala (%)	Total (%)
Coat color pattern	Plain	41.9	52.1	49.2
	Patchy	16.2	32.3	27.8
	Spot	41.9	15.6	22.9
Coat color	White	44.6	28.1	32.7
	Brown	36.5	47.9	44.7
	Spot	2.7	2.1	2.3
	Gray	8.1	7.3	7.5
	Black	8.1	14.6	12.8
Horn type	Horned	100.0	97.9	98.5
	Polled	0.0	2.1	1.5
Horn shape	Straight	51.4	7.3	19.5
	Curved	48.6	92.7	80.5*
Horn orientation	Erect	5.4	6.2	6.0
	Obliquely upward	47.3	57.3	54.5
	Obliquely backward	47.3	36.5	39.5
Ear orientation	Horizontal	86.5	70.8	75.2*
	Semi-pendulous	13.5	29.2	24.8
Head profile	Straight	67.6	95.8	88.0*
	Partially convex	32.4	4.2	12.0
Scrotum type	Partially split	4.0	8.0	6.7
	Split	92.0	92.0	92.0
Wattle	Present	10.8	4.2	6.0
	Absent	89.2	95.8	94.0*
Beard	Present	36.5	38.5	38.0
	Absent	63.5	61.5	62.0
Ruff	Present	2.7	2.1	2.3
	Absent	97.3	97.9	97.7

3.1.2. Live body weight and linear body measurement

Body weight and linear body measurements of the study goat by sex, district, and age are presented in Table 2. Males showed higher values than females on the head length and horn length (p<0.05). However, body weight, body length, height at wither, chest girth and ear length were not significantly affected by sex (p<0.05). This could be due to the high off-take rate of male goats at the young stage (Hulunim, 2014).

All linear measurements except teat were significantly affected across districts (p<0.05). Except for ear length, goats in Uba Debre-Tsehay district revealed higher values on body weight, body length, height at wither, chest girth, head length and horn length (p<0.05). This could be due to variation of the management practices in the study areas mainly in Uba Debre-Tsehay district.

Age had significant effect on linear body measurements except for ear length and scrotum circumference (p<0.05). Body weight, body length, height at withers, chest girth, head length, horn length, and teat length increased when the goats get older. Knowledge of quantitative characteristics is important to implement genetic improvement through selection so as to facilitate their sustainable use and estimate live body weight from simple and more easily measurable variable as well as market value in terms of the cost of the animals (Hulunim, 2014).

Table 1: Quantitative traits (mean ±SE) of indigenous goats in Zala and Uba Debre-Tsehay districts

Parameters	BW	BL	HW	CG	HL	HoL	EL	SC	TL
Overall means	29.55±0.45	61.96±0.53	65.16±0.32	72.46±0.41	19.38±0.14	12.17±0.29	13.65±0.10	25.14±0.38	3.49±0.07
CV	13.44	6.73	5.23	5.11	6.30	23.20	8.43	8.37	18.52
R^2	0.56	0.64	0.36	0.54	0.57	0.44	0.28	0.34	0.23
Sex	NS	NS	NS	NS	*	*	NS	NS	NS
Male	29.49±0.98	61.25±1.06	66.20±0.77	72.08±0.80	20.21±0.35[a]	14.08±0.63[a]	13.26±0.19		
Female	29.57±0.51	62.19±0.61	64.82±0.34	72.59±0.48	19.10±0.14[b]	11.51±0.30[b]	13.78±0.12		
District	*	*	*	*	*	*	*	*	NS
U.D-Tsehay	32.76±0.57[a]	66.79±0.73[a]	66.29±0.53[a]	74.79±0.55[a]	20.57±0.18[a]	13.04±0.40[a]	13.15±0.12[b]	26.17±0.63[a]	3.49±0.10
Zala	27.18±0.55[b]	58.38±0.47[b]	64.33±0.38[b]	70.74±0.52[b]	18.49±0.15[b]	11.51±0.39[b]	14.016±0.14[a]	24.26±.37[b]	3.49±0.09
Age	*	*	*	*	*	*	NS	NS	*
1PPI	24.43 ±1.15[c]	56.04±1.25[c]	63.09±0.87[b]	67.04±0.88[c]	18.46±0.44[b]	10.22±0.72[c]	13.28±0.26	24.60±0.68	2.56±0.24[c]
2PPI	28.83±1.14[b]	60.65±1.22[b]	64.31±0.70[ab]	71.73±1.08[b]	19.65±0.40[a]	12.38±0.80[ab]	13.54±0.22	25.54±0.61	3.36±0.18[ab]
3PPI	26.59±1.08[bc]	59.09±1.09[b]	64.26±0.92[ab]	69.70±0.79[b]	18.96±.33[ab]	10.91±0.69[bc]	13.52±0.27	25.33±0.67	3.09±0.17[b]
4PPI	31.88±0.49[a]	64.64±0.63[a]	66.19±0.41[a]	74.82±0.44[a]	19.65±0.17[a]	12.95±0.36[a]	13.81±0.14	25.50±1.56	3.67±0.07[a]

* Significant at P<0.05, NS = not significant at P<0.05, BW = body weight, BL = body length, HW = Height at wither, CG = Chest girth, HL = Head length, HoL = Horn length, EL = Ear length, SC = Scrotal circumference, TL = Teat length, SE = standard error of mean, means with the same letter within the column and factors are not significant

3.1.3. Relationships between body weight and other body measurements

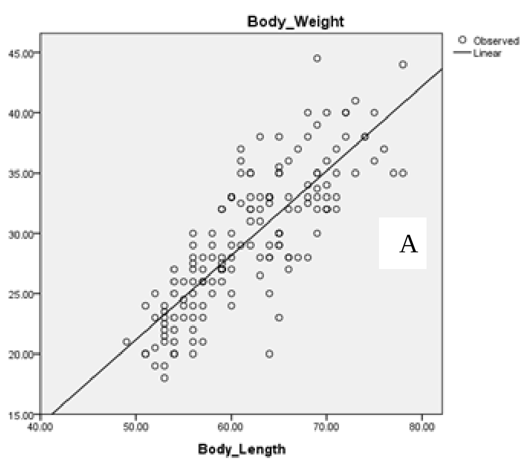
Correlation coefficient between body weight and studied traits varied from strong (0.81) to low (-0.11) at (p<0.05) (Table 3). Most measurements (BL, HW, CG, HL, HoL, and SC) depicted a positive and highly significant (p<0.05) correlation with live body weight. Therefore, the selection of one or more of these traits except horn length (biologically which is not acceptable), may increase the live body weight of these goat populations as indicated by Hulunim (2014).

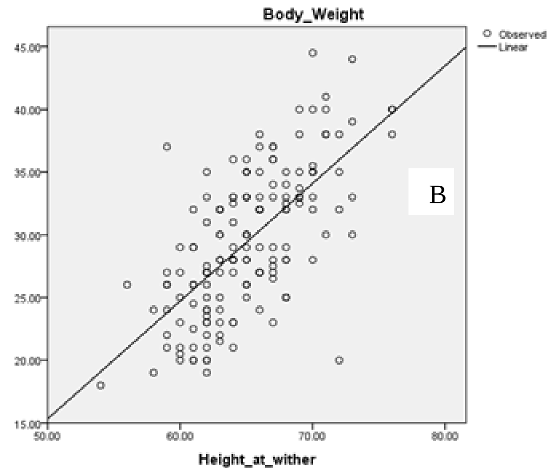
Due to the positive and highly significant correlation between body weight and other linear body measurements, traits in combination or individually could be measured to predict live body weight. Particularly, body length, height at wither, chest girth, and horn length would provide a good estimate for predicting live body weight as indicated with equation [3] and Figure 3.

$$Y = -38.97 + 0.36BL = 0.17HW + 0.46CG + 0.16HoL$$

Where:

- Y= Body weight
- BL= Body length
- HW= Body height at wither
- CG= Chest girth
- HoL = Horn length





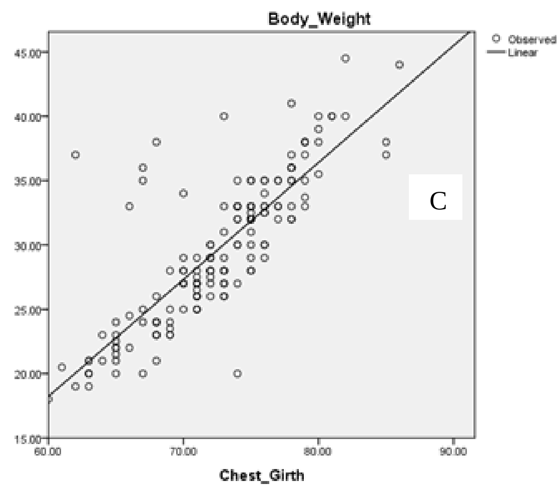


Figure 3: Regression of body weight with body length (A), height at wither (B) and chest-girth (C) of Gofa area indigenous goats

Table 3: Relationships between body weight and linear body measurements of Gofa area indigenous goats

Parameters	BW	BL	HW	CG	HL	HoL	EL	SC	TL
Body Weight		0.81*	0.67*	0.82*	0.64*	0.61*	-0.11^{NS}	0.71*	0.31*
Body Length	0.81*		0.59*	0.67*	0.65*	0.48*	-0.21*	0.57*	0.34
Height at wither	0.67*	0.59*		0.60*	0.48*	0.58	-0.05^{NS}	0.59*	0.24*
Chest Girth	0.82*	0.67*	0.60*		0.55*	0.58	-0.06^{NS}	0.57*	0.38*
Head Length	0.64*	0.65*	0.48*	0.55*		0.55*	-0.12^{NS}	0.50*	0.20*
Horn Length	0.61*	0.48*	0.58*	0.58*	0.55*		-0.02^{NS}	0.29^{NS}	0.35*
Ear Length	-0.11^{NS}	-0.21*	-0.05^{NS}	-0.06^{NS}	-0.12^{NS}	-0.02^{NS}		-0.08^{NS}	0.27*
Scrotum Circumference	0.71*	0.57*	0.59*	0.57*	0.50*	0.29^{NS}	-0.08^{NS}		-
Teat Length	0.31*	0.34*	0.24	0.38*	0.19^{NS}	0.35*	0.27*	-	

4. Conclusion

All linear body measurements and body weight were significantly affected by districts ($p<0.05$). This could be due to variation of the management practices in the study areas mainly in Uba Debre-Tsehay district. As age increases, most of the linear measurements were also increased to certain age limits ($p<0.05$). The higher correlation was observed among body length, height at wither and chest girth, and body weight in Gofa area goat types, which could be used as selection criteria.

Conflict of Interest

The authors declared that there is no conflict of interest.

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Optimizing the Plant Population and Time of White Lupine Intercropping with Food Barley in Northwest Ethiopian Highlands

***Sewnet Getahun*[1], *Getachew Alemayehu*[2*] *and Kassaye Mulatu*[1]**

[1]Department of Plant Science, College of Agriculture and Natural Resource, Debre Markos University, Debre Markos, Ethiopia

[2]Department of Plant Science, College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia

***Corresponding author:** getachew.64@gmail.com

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Abstract: *Lupine has traditionally been intercropped with food barley in northwest Ethiopian highlands. But, there is no any documented information about the optimum plant population and time of white lupine intercropping with food barley in these areas. Hence, a field experiment was conducted on plant population and time of lupine intercropping with food barley in 2017 and 2018 main cropping season in Gozamin highland, northwest Ethiopia, to determine the optimum plant population and time of lupine intercropping for maximum productivity of food barley fields. Factorial combinations of three plant population (500000, 250000 and 166667 plants/ha) and four time of lupine additive series intercropping (simultaneously, two weeks, four weeks and six weeks after barley sowing) with food barley were laid out in randomized compete block design with three replications. Sole food barely and sole lupine were included as a comparison purpose. The results indicated that there was no significant difference among treatment combinations for biomass and grain yields of food barley. However, highly significant differences among treatment combinations were observed for biomass and grain yields of lupine. The highest land equivalent ratio (1.48), relative economic efficiency (42.61%), and net economic return (Birr 38,160/ha) with acceptable higher marginal rate of return (598.68%) were recorded in the combination of 166667 plants/ha plant population and simultaneous time of lupine additive intercropping with food barley.*

Keywords: Additive intercropping, economic efficiency, *Hordeum vulgare*, land equivalent ratio, *Lupinus albus*, productivity efficiency

1. Introduction

Ethiopia is the second populous country in Africa after Nigeria and agriculture is the main stay of its economy (MoFED, 2016). Its highlands are especially important for human trafficking and crop production, while about 90% of the total human population and crop production of the country are found in these highlands (Hurni *et al*., 2010) that account only about 46% of the national surface area (Teklu, 2005). Subsistent smallholder crop-livestock mixed farming is the main agricultural system of Ethiopian highlands (Likawnt *et al*., 2010) and food barley (*Hordeum vulgare* L.) is one of the major food cereal crops grown in these highlands (Alemayehu *et al*., 2011; CSA, 2018). Since time immemorial, white lupine (*Lupinus albus* L.) has also been grown specially in northwest Ethiopian highlands as multipurpose legume crop used for reclaiming the crop soils especially after cereals, as well as for supplementing the household food security (as a good protein source) and incomes of farmers from its market sales (Hibstu *et al*., 2016; Akale *et al*., 2019). Lupine in most towns and cities of Ethiopia has also been used widely as a preferred snack food in both local and modern bear houses (Likawnt *et al*., 2011). On top of its high protein and fiber contents, lupine does have nutraceutical potential (combination of nutrition and pharmaceutical use) and have some health-protecting effects through preventing and controlling metabolic syndrome risk factors including abdominal obesity, increased triglyceride level, decreased HDL cholesterol concentration, hypertension, and hyperglycaemia (Hodgson and Lee, 2008; Sedláková *et al*., 2016; Villarino *et al*., 2016). This is due to causing the feeling of satiety (appetite suppression) and affecting the energy balance, affecting favorably glycaemia, improving the defecation and the levels of blood lipids, and having positive effect on hypertension (Hodgson and Lee, 2008; Tizazu and Emire, 2010).

Both food barley and white lupine productions in northwest Ethiopian highlands have however been facing big challenges of low productivity (CSA, 2018) and diminishing the cultivation area (Hibstu *et al*., 2016), respectively. On the one hand, productivity of barley fields in Ethiopia is low below the world average and beyond meeting the ever increasing food demand of rapidly growing highland population (CSA, 2018). As the result of high population growth, on the other hand, cultivated land in Ethiopian highlands has been becoming the scarcest resource for crop production and farmers have been forced to abandon crop rotation (Getachew *et al*., 2020) and give more priority to produce major cereals including food barley than white lupine, and thereby production of white lupine in northwest Ethiopian highlands has been declining steadily (Hibstu *et al*., 2016).

Hence, there is a need for enhancing the productivity of barley fields, as well as for expanding the production of white lupine in Ethiopian highlands, while beyond its food and economic contributions to poor smallholder farmers, white lupine plays a special role in raising the fertility of acidic crop soils of Ethiopian highlands effectively through its high symbiotic nitrogen fixation and soil phosphorous mobilization ability (Beneberu *et al*, 2019). Under the current circumstances of cultivated land and crop production in northwest Ethiopian highlands, increasing the productivity of barley fields and expanding the production of lupine in these areas can be possible through intercropping or mixed cropping of white lupine with food barley (Akale *et al*., 2019). Inter cropping/mixed cropping is the practice of cultivating two or more crops in the same piece of land at the same time or relayed (Yayeh *et al*., 2019), and it is commonly practiced by smallholder farmers mainly in the tropics (Panda, 2010; Seran and Brintha, 2010). Intercropping (in row planted crop fields) or mixed cropping (in broadcast planted fields) is among the most efficient land used systems adopted in tropical regions, where farmers have only limited access to agricultural inputs (Laurent *et al*., 2015).

Several authors described intercropping as an ecological intensification practice which has been widely used to boost crop productivity, increase crop diversity (Yayeh *et al*., 2014), enhance the land utilization ratio (Laurent *et al*., 2015), minimize crop failure due to adverse effects of biotic and abiotic factors (Dai *et al*., 2017), improve the use of limited resources (Tsubo *et al*., 2005), protect soil against erosion, improve soil fertility, increase stability of yield (Yayeh *et al*., 2020), reduce labor peaks, provide higher returns (Yayeh *et al*., 2019) and supply a balanced diet compared to sole cropping. This is mainly because of that intercropping is important to optimize the use of time, space and physical resources compared to sole cropping (Zhang and Li, 2003). Cereal-legume is the common combination used in most intercropping systems (Seran and Brintha, 2010), while legumes fix atmospheric nitrogen gas and make it available to plants on top of their other additional intercropping advantages.

Some low input farmers in northwest Ethiopian highlands have traditionally intercropped lupine with cereals mainly with food barley in additive design (ANRS Bureau of Agriculture, 2020), where the sole recommended plant density of the major crop barley is constant with varying the density of the minor crop lupine (Yayeh *et al*., 2020). Since farmers don't compromise the yields of major crops, proper additive intercropping can make the interest of farmers possible. Optimal additive intercropping enables farmers to get satisfactory additional yield from a secondary crop on top of a major crop yield obtained from its sole cropping. This is indeed possible when a secondary (minor) crop doesn't negatively affect the growth and yield of a major crop significantly apart from its economically sound additional yield gain (Yayeh *et al*., 2019, 2020). Hence, it is very essential to investigate the optimal plant density and time of intercropping of a secondary crop with a major crop in additive design for maximizing the productivity and profitability of the crop land (Akale *et al*., 2019). However, there is meager information on optimal plant density and time of lupine additive intercropping with food barley in the country. Therefore, the present study was devised to determine the optimum plant population and time of lupine additive intercropping with food barley in northwest Ethiopian highlands.

2. Materials and Methods

2.1 Description of the study site

A rain-fed field experiment was conducted during the main cropping season of 2017 and 2018 at trial-demonstration site of Debre Markos University in the main campus, in Gozamin District, Northwestern Ethiopia. Geographically, the study site is located at 10°21` N latitude and 37° 43`E longitude with an altitude of 2446 meter above sea level. It is found 300 kilometer northwest of Addis Ababa and 265 kilometer southeast of Bahir Dar. According to 36 years (1981-2016) recorded weather data (Debre Markos Meteorology Station, 2017), the mean annual rainfall of the experimental site is 1380 mm with average minimum and maximum temperatures of 15^{O}C and 22^{O}C, respectively (Figure 1).

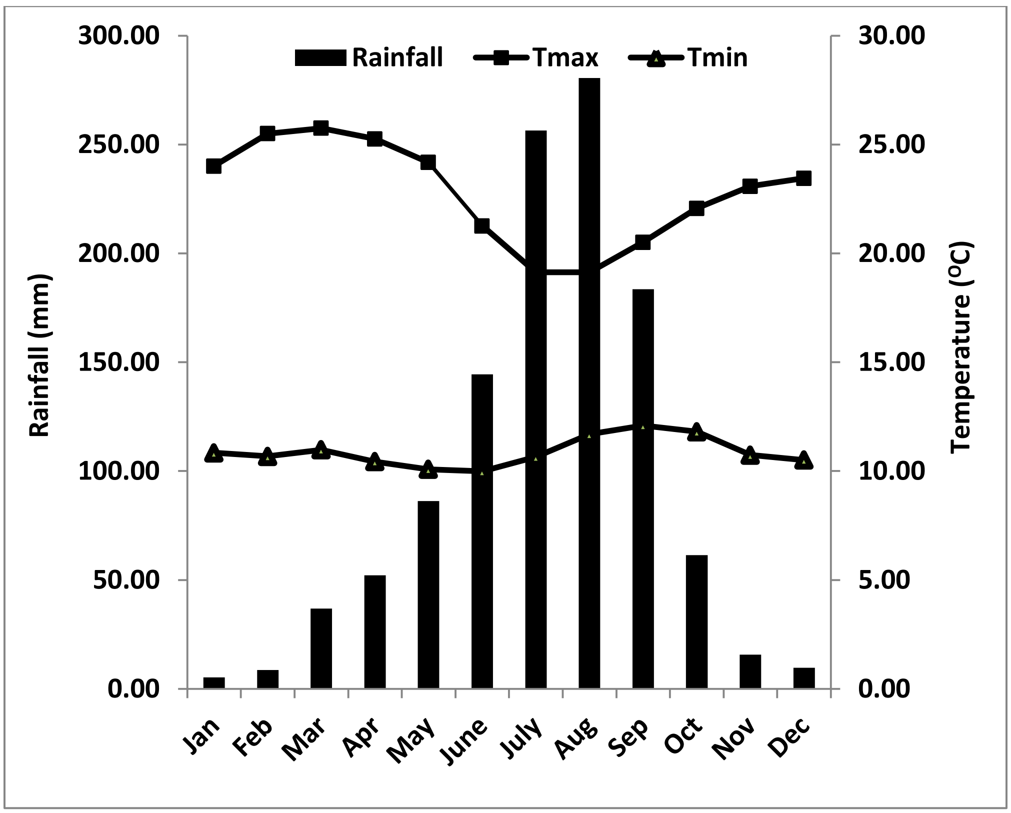

Figure 1: Average monthly rainfall, and minimum and maximum temperatures of the experimental site for 36 years from 1981 to 2016 (*Tmax = maximum temperature; Tmin = minimum temperature*)

To characterize the soil of the experimental site, a composite soil sample was taken before sowing and analyzed for important physicochemical properties. The composite soil sample was prepared by thorough mixing of seven soil samples collected randomly in a crisscross fashion of the whole experimental plot at a plow depth of 0-20 cm using an augur. It was then air dried up to attaining the constant weight and crushed with motorized grinder and sieved with a 2 mm diameter screen for further laboratory analysis that was done at Debre Markos Soil Laboratory. Particle size distribution (soil texture) was determined by hydrometer method (Bouyoucos, 1962; Gee and Bauder, 1986), while soil pH was measured using a digital pH meter in a 1:2.5 soil-water suspension as described by Panda (2010). Organic carbon (OC) was determined by wet digestion Walkley and Black method (Heanes, 1984). Determination of total nitrogen (TN) was carried out through micro-Kjeldahl digestion method (Bremner and Mulvaney, 1982). Available phosphorus (AP) was determined by calorimetrically using Olsen's method (Olsen *et al*., 1954), while cation exchange capacity (CEC) was determined using titration method (FAO, 2008). Lab analysis results of pH, CEC, OC, TN and AP status of the experimental soil before starting the experiment were rated according to Panda (2010), Landon (1991), Charman and Roper (2007), Havlin *et al*. (1999) and Tekalign *et al*. (1991) respectively, while texture of the soil was classified according to Brady and Weil (2017).

Laboratory analysis results of the experimental soil just before starting the study are presented in Table 1. The soil laboratory results showed that texture of the experimental soil was clay as per the soil texture triangle matrix of Brady and Weil (2017). According to Panda (2010), the experimental soil was moderately acidic. Cation exchange capacity (CEC) of the soil was also moderate (Landon, 1991). Organic carbon (OC), total nitrogen (TN) and available phosphorous (AP) contents of the experimental soil were low as per rating made by Charman and Roper (2007), Havlin *et al*. (1999), and Tekalign *et al*. (1991), respectively (Table 1).

Table 1: Physicochemical properties of the experimental soil before starting the study

Soil properties	Value	Rating category	Rating reference
pH (H_2O)	5.67	Moderately acidic	Panda (2010)
CEC (cmol(+)/kg)	26.80	Moderate	Landon (1991)
Organic carbon (%)	1.56	Low	Charman and Roper (2007)
Total nitrogen (%)	0.16	Low	Havlin *et al*. (1999)
Available P (ppm)	30. 29	Low	Tekalign *et al*. (1991)
Particle distribution			Bouyoucos (1962)
Sand (%)	18.00		
Silt (%)	20.00		
Clay (%)	62.00		
Textural class	*Clay*		Brady and Weil (2017)

CEC = cation exchange capacity, P = phosphorus, pH = potential of hydrogen

2.2 Experimental planting materials

A six-row food barley variety of HB-1307 and local variety of white lupine were used as a test crops. The six-row food barley variety HB-1307 was developed and released by Holetta Agricultural Research Center in 2006. This variety has been released for mid and high altitude barley growing areas due to its superiority in grain yield performance, stability and wide adaptation. It has also good physical grain quality, resistance to leaf rust and scald, moderate resistance to net and spot blotch, lodging tolerance and good biomass yield. Local variety of white lupine is well adapted in mid and high altitude areas and currently grown in the study area, as well as its seed is also easily available in the local markets.

2.3 Experimental treatments, design and procedures

Factorial combinations of three plant population (500000, 250000 and 166667 plants/ha) and four time of lupine additive intercropping (simultaneously, two weeks, four weeks and six weeks after barley sowing) with food barley, as well as two sole cropping as comparison were laid out in randomized compete block design with three replications. Detail treatment combinations and sole crops used for the experiment are presented in Table 2. The gross plot size was 4.0 m x 3.2 m (12.8 m^2) with the net plot area of barley was 3.8 m x 2.8 m (10.64 m^2) both in the intercropping and sole cropping. The net plot size of lupine in the sole cropping was 3.8 m x 2.4 m (9.12 m^2), but in the intercropping it was variable depending on the plant population. Adjacent plots and blocks were separated with 0.5 m and 1.0 m wide paths, respectively.

Table 2: Intercropping treatment combinations and sole crops used for the experiment

Lupine plant population (plants/ha)	Time of lupine intercropping with food barley			
	Simultaneously (P1)	2WABS (P2)	4WABS (P3)	6WABS (P4)
500000 (R1)	R1P1 (T1)	R1P2 (T4)	R1P3 (T7)	R1P4 (T10)
250000 (R2	R2P1 (T2)	R2P2 (T5)	R2P3 (T8)	R2P4 (T11)
166667 (R3)	R3P1 (T3)	R3P2 (T6)	R3P3 (T9)	R3P4 (T12)
Barley sole cropping (T13)				
Lupine sole cropping (T14)				

WABS = weeks after barley sowing, T = treatment

In both experimental years of 2017 and 2018, the selected experimental plots were plowed repeatedly by oxen using local plowing tool "Maresha" as conventionally practiced by the surrounding farmers. Experimental plots were then prepared manually as per the design and treatments using necessary farm tools. After starting the reliable rainfall, seeds of food barley were drilled in 20 cm spaced rows at the recommended plant population of 100 kg/ha on 22 and 14 June 2017 and 2018, respectively. Lupine seeds in sole cropping were planted at 40 cm inter-row and 10 cm intra-row spacing on the same date of barley sowing, while lupine seeds in the intercropping were planted after every two rows of barley (equivalent to the recommended 40 cm inter-row spacing of sole lupine) at intra-row spacing of 5, 10 and 15 cm (equivalent to 500000, 250000 and 166667 plants/ha, respectively) on different dates as per the treatments. All experimental plots including sole lupine plots were received a basal application of NPS (19% N, 38% P_2O_5, 7% S) at the rate of 100 kg/ha during planting of barley. Urea (46% N) at the rate of 100 kg/ha was also applied in split into barley plots in such a way that one third of it was applied as basal during planting and the remaining two third as side-dressing at tillering growth stage. Beyond fertilizers applied to food barley, any additional fertilizers were not specifically applied to white lupine in the intercropping treatments. Other all remaining agronomic practices were also carried out as per their recommendations used for food barley and lupine productions in the study area (ARARI, 2003).

2.4 Crop yield data collection

After physiological maturity, both barley and lupine plants were allowed to dry as stand up and harvested manually with sickle at the ground level. The harvested pieces of bunches were further subjected to sun drying till their weight attained constant and the above-ground biomass of the component crops per net plot area was measured with sensitive weighing balance. Grains of the component crops were further recovered and weighed after threshing, winnowing and cleaning. The grain yields of barley and lupine were adjusted to 12% and 10% contents, respectively. Above ground biomass and grain yields obtained from the net plot areas were finally converted to hectare basis.

2.5 Crop yield data analysis

Data of biomass and grain yields of the component crops collected in 2017 and 2019 were separately subjected to analysis of variance (ANOVA) using general linear model (GLM) procedures of SAS version 9.4 (SAS, 2013). Since values for the error mean square of the two years were homogeneous, the data were combined over years (Gomez and Gomez, 1984). Year was considered as a random variable in the combined analysis. Whenever the combined ANOVA result showed significant difference between treatments for a parameter, further mean separation was done using Tukey test using the same statistical software.

2.6 Production efficiency assessments

Land equivalent ratio (LER), area time equivalent ratio (ATER), crop equivalent yield (CEY), relative production efficiency (RPE) and relative economic efficiency (REE) are some of the common methods used for assessing the production efficiency of cropping systems (Samant, 2015; Yayeh *et al*., 2020). LER is a measure of the efficiency of land use in an intercropping system. It indicates the efficiency of intercropping for using the resources of the environment compared with sole cropping (Yayeh *et al*., 2020; Zhang *et al*., 2014). The LER was calculated using the formula outlined by Yayeh *et al*. (2020):

$$LER = \sum_{i=1}^{n}\left(\frac{Yi}{Ym}\right) \quad [1]$$

Where, Yi and Ym were yields of component crops in intercrop and sole cropping, respectively, and n was the number of the crops involved.

The critical value of LER was one. When LER was one, there was complementarity between component crops. When the LER was greater than one, the intercropping favored the growth and yield of the component crops. In contrast, when LER was lower than one, the intercropping negatively affected the growth and yield of the component species.

ATER was also calculated using the formula sketched by Yayeh et al. (2020) as:

$$ATER = \frac{(PLERb*Tb)+(PLERl*Tl)}{T} \quad [2]$$

Where, PLERb and PLERl were partial land equivalent ratios of barley and lupine, respectively; Tb, Tl and T were the durations of barley and lupine maturity, as well as the total duration of the intercropping system, respectively.

Like that of LER, the critical value of ATER was one. When ATER was equal to one, there was complementarity between the component crops. When the ATER was greater than one, intercropping favored the growth and yield of the component crops. In contrast, when ATER was lower than one, intercropping negatively affected the growth and yield of the component crops.

To estimate CEY, the average yield of the component crops was primarily converted into the main crop barley equivalent yield (BEY) on a price basis following Samant (2015) and Yayeh *et al*. (2020).

$$\text{BEY (kg ha}^{-1}) = \text{LY (kg ha}^{-1}) * \left(\frac{Pl(ETB\ kg-1)}{Pb\ (ETB\ kg-1)}\right) \quad [3]$$

Where, LY was the lupine yield; Pl and Pb were prices of lupine and barley, respectively, in Ethiopian Birr per kg (ETB kg^{-1}).

The CEY was then the summation of barely yield and barley equivalent yield (BEY). RPE and REE were further estimated on the basis of CEY using the formulae sketched by Yayeh *et al*. (2020) as the followings:

$$RPE\% = \left(\frac{CEYi-CEYs}{CEYs}\right) \text{ x } 100 \quad [4]$$

$$REE\% = \left(\frac{NRi-NRs}{NRs}\right) x100 \quad [5]$$

Where, CEYi and CEYs were crop equivalent yields of intercropping and sole cropping systems, respectively; NRi and NRs were net returns of intercropping and sole cropping systems, respectively.

Positive results of RPE indicated the superiority of the new intercropping system of white lupine with food barley over the existing system of sole cropping. Whereas, negative results of RPE indicated inferiority of the new intercropping system under the existing sole cropping. Higher REE was inferred as the better cropping system.

2.7 Partial budget analysis

Partial budget analysis was used to assess the economic advantage of the cropping systems by estimating total variable cost, gross return, net return and marginal rate of return on hectare basis following the procedures described by CIMMYT (1988). Seeds of the component crops, soil fertilizers and labor (for land preparation, sowing, fertilize application, harvesting, threshing and cleaning) were the main variable costs of the experiment. Costs of barley and lupine seeds were estimated at the local market prices of Ethiopian Birr 20 and 15 per kg, while costs of labor and fertilizers (Urea and DAP) were estimated at Ethiopian Birr 100 per manday and 13 and 15 per kg, respectively. Barley and lupine grain yields were adjusted by reduction of 10% to reflect the actual productivity of farmers as described by CIMMYT (1988). Gross return was hence estimated as the multiple of the adjusted grain yields of the component crops (barley and lupine) and their farm gate prices of Ethiopian Birr 15 and 10 per kg, respectively. Net return was estimated by subtracting the total variable cost from the gross benefit, while marginal rate of return (MRR%) was estimated as the percentile ratio of the net return and variable cost differences of the intercropping treatments and the control (barley sole cropping). Mathematically, MRR was calculated as follow:

$$\text{MRR}(\%) = \left(\frac{(\text{NRs}-\text{NRp})}{(\text{TVCs}-\text{TVCp})}\right)\text{x}100 \quad [6]$$

Where, NRs and NRp were the immediate succeeding and preceding net returns of the treatment combinations, while TVCs and TVCp were the immediate succeeding and preceding total variable costs of the treatment combinations, respectively, after putting the TVC in ascending orders.

Acceptability of intercropping by farmers is best judged by the marginal rates of return (MRR), which is considered as an appropriate indicator for maximum profit of the cropping systems (Kiwia *et al*., 2019) and it was used for ranking the intercropping treatments of the experiment. According to Kiwia *et al*. (2019), MRR less than 50% is considered low and unacceptable to farmers, while MRR > 100% is a higher cut-off value that has been recommended for the technology, which involves significant change from current farmer practices.

3. Results and Discussion

3.1 Grain and biomass yields

The results of analysis of variance showed that both grain and above ground biomass yields of food barley were not significantly ($P \geq 0.05$) influenced by both main and interaction of plant population and time of lupine additive intercropping. However, main and interaction of plant population and time of lupine additive intercropping with food barley highly significantly ($P<0.01$) affected both grain and above ground biomass yields of lupine (Table 3). In the intercropping treatments, the highest grain and biomass yields of lupine were recorded in the combination of 166667 plants/ha plant population (15cm intra-row spacing) and simultaneous planting of lupine on the same date of barley sowing. Simultaneous planting of lupine on the same date of barley sowing at its plant population of 250000 and 500000 plants/ha (10cm and 5cm intra-row spacing, respectively) gave the second and third highest grain and biomass yields of lupine in food barley-lupine intercropping systems (Table 3). Lupine grain and biomass yields were reduced consistently as its intercropping time after barley sowing prolonged and its plant population increased (Table 3).

Table 3: Average grain and biomass yields of the component crops as influenced by plant population and time of lupine additive intercropping with barley in 2017 and 18 in Gozamin highland

Lupine intercropping with barley		Food barley		Lupine	
SR (plants/ha)	Intercropping time	GY (ton/ha)	BY (ton/ha)	GY (ton/ha)	BY (ton/ha)
500000	SMPwB	1.78	7.49	1.46[d]	1.95[d]
	2WABS	1.87	7.53	0.64[g]	1.12[f]
	4WABS	2.02	7.70	0.53[gh]	0.95[fg]
	6WABS	2.10	7.84	0.27[i]	0.88[g]
250000	SMPwB	1.91	8.04	1.75[c]	2.12[c]
	2WABS	2.03	8.19	0.84[f]	0.98[fg]
	4WABS	2.17	8.26	0.80[f]	0.91[g]
	6WABS	2.21	8.32	0.44[h]	0.87[g]
166667	SMPwB	1.94	8.17	2.33[b]	2.74[b]
	2WABS	2.10	8.31	1.01[e]	1.35[e]
	4WABS	2.24	8.54	0.90[ef]	1.18[ef]
	6WABS	2.29	8.63	0.56g[h]	0.86[g]
Barley sole cropping		2.51	9.88	-	-
Lupine sole cropping		-	-	3.29[a]	4.65[a]
Sig. difference		NS	NS	**	**
SE±		0.09	0.88	0.03	0.05
CV (%)		7.82	10.64	5.02	5.89

SR = plant population; SMPwB = simultaneous planting with barley; 2WABS = two weeks after barley sowing; 4WABS = 4 weeks after barley sowing; 6WABS = six weeks after barley sowing; GY = grain yield; BY = above ground biomass yield; **highly significant at $P<0.01$; NS = not significant at $P\geq0.05$; means followed with the same letter are not significant at $P\geq0.05$.

The non-significant difference between the barley-lupine intercropping for the yield related parameters of barley indicated that the associated lupine did not cause severe competition for the limited growth resources on the main crop. On the contrary, both biomass and grain yield of lupine in the intercropping treatments were lessen below that of sole lupine cropping, indicating the growth dominance of barley over lupine in their intercropping systems. Similar results were also reported by Yeyeh *et al*. (2014), who showed that seed proportions in the lupine-barley intercropping did not affect all yield related parameters of barley. This is further supported by Adipala *et al*. (2002), who reported that maize yields were not significantly affected by the inclusion of cowpea in different time of planting in maize-cowpea intercropping experiment.

Consistent reduction of lupine grain and biomass yields with the prolong of lupine intercropping time after barley sowing would be associated to the increase of barley over shading effect, as well as to the progress of soil moisture stress as the advancement of drying season after August. Declining of lupine grain and biomass yields with the increase of lupine plant population in barley-lupine intercropping might related to the increase of intra-specific competition among lupine plants for light and moisture. These results are supported by other cereal-legume intercropping works (Tilahun, 2002; Egbe, 2010; Addo-Quaye *et al*., 2011). The present results clearly showed that delay intercropping of lupine after barley sowing was less advantageous than simultaneous intercropping with barley sowing, while lupine grows slower than barley. Besides, plant population of lupine in barley-lupine intercropping would be lower than the recommended plant population of sole lupine cropping.

3.2 Production efficiency

Influences of plant population and time of lupine additive intercropping with barley on various production efficiency measures including land equivalent ration (LER), area time equivalent ratio (ATER), crop equivalent yield (CEY), relative production efficiency (RPE) and relative economic efficiency (REE) are presented in Table 4. LER of intercropping treatment combinations was ranging from 0.84 to 1.48 (Table 4). Those intercropping treatments having <1 LER are disadvantageous than sole cropping, while those intercropping treatments having >1 LER are more advantageous than sole cropping. As shown in Table 4, several intercropping treatments resulted in the LER values of .05 to 1.48, indicating their yield advantages from 5% to 48%, respectively, over sole cropping. Compared the sole cropping, the treatment combination of 16667 plants/ha plant population and simultaneous intercropping of lupine with barley sowing (SMPwB) gave the highest yield advantage (48%), followed by the combination of 250000 plants/ha plant population and simultaneous intercropping of lupine with lupine sowing with 30% yield advantage. This revealed that sole cropping would require 48% and 30% more land area to equalize the yield obtained from these intercropping treatment combinations, On the contrary, the highest yield reduction (-16%) was recorded in the combination of 500000 plants/ha plant population and intercropping of lupine after six weeks of barley sowing (6WABS) compared to that of the sole cropping.

Table 4: Average production efficiency of barley-lupine intercropping as influenced by plant population and time of lupine additive intercropping in 2017 and 2018 in Gozamin highland

Lupine intercropping with barley		LER	ATER	CEY (t/ha)	RPE (%)	REE (%)
SR (plants/ha)	Intercropping time					
500000	SMPwB	1.15	0.88	2.75	9.84	-3.26
	2WABS	0.94	0.63	2.29	-8.45	-26.40
	4WABS	0.97	0.64	2.37	-5.29	-22.41
	6WABS	0.84	0.51	2.08	-16.90	-37.09
250000	SMPwB	1.30	1.00	3.08	23.04	19.62
	2WABS	1.05	0.75	2.56	1.99	-7.03
	4WABS	1.11	0.76	2.71	8.14	0.76
	6WABS	0.97	0.60	2.39	-4.46	-15.18
166667	SMPwB	1.48	1.19	3.49	39.28	42.61
	2WABS	1.15	0.82	2.77	10.71	6.45
	4WABS	0.97	0.69	2.34	-6.66	-15.54
	6WABS	0.97	0.62	2.37	-5.40	-13.94
Barley sole cropping		1.00	1.00	2.51	0.00	0.00
Lupine sole cropping		1.00	1.00	2.19	-12.50	-12.64

SR = plant population; SMPwB = simultaneous planting with barley; 2WABS = two weeks after barley sowing; 4WABS = 4 weeks after barley sowing; 6WABS = six weeks after barley sowing; LER = land equivalent ratio; ATER = area time equivalent ratio; CEY = crop equivalent yield; RPE = relative production efficiency; REE = relative economic efficiency

Except the combinations of 166667 and 250000 plants/ha plant population with simultaneous intercropping of lupine with barley, all other intercropping treatment combinations resulted in ATER values <1, indicating their yield disadvantages below the sole cropping. The intercropping treatment combination of 166667 plants/ha plant population and simultaneous planting of lupine with barley sowing resulted in the highest ATER (1.19). This showed that intercropping of lupine with barley in this treatment combination favored the growth and yield of the component crops by 19% over the sole cropping. The ATER value of lupine intercropping with barley at 166667 plants/ha plant population and simultaneous planting of lupine with barley sowing was one, indicating growth and yield complementarity between the component crops at this intercropping treatment combination.

The highest CEY (3.49 t/ha) was also recorded from the intercropping treatment combination of 166667 plants/ha plant population and simultaneous planting of lupine with barley sowing (Table 4). The intercropping treatment combination of 250000 plants/ha plant population and simultaneous planting of lupine with barley sowing gave also the second highest CEY (3.08 t/ha)). The CEY values of intercropping treatment combinations less than that of barley sole cropping (2.51 t/ha) indicated their yield inferiority performances below barley sole cropping. Several intercropping treatment combinations also generated negative RPE and REE, indicating their yield inferiority performances below barley sole cropping. Similar to LER and CEY, the highest positive RPE (39.28%) and REE (42.61%) were also recorded from the intercropping treatment combination of 166667 plants/ha plant population and simultaneous planting of lupine with barley sowing (Table 4). The second highest positive RPE (23.04%) and REE (19.62%) were also obtained from the intercropping treatment combination of 250000 plants/ha plant population and simultaneous planting of lupine with barley sowing. These and other few intercropping treatment combinations generated higher and positive RPE and REE showed their superiority over the existing sole cropping.

Results of the present study showed that additive intercropping of white lupine with food barley at its optimum plant population and intercropping time gave higher LER, ATER, CEY, RPE and REE than the existing sole cropping of the component crops. In agreement to these results, several additive intercropping studies such as pea-wheat (Naudin *et al*., 2010), cluster bean-beet root (Sankaranarayanan *et al*., 2011), white lupine-small grain cereals (Yayeh *et al*., 2014), and haricot bean/sweet lupine-finger millet (Yayeh *et al*., 2019, 2020) at the optimum plant populations of the secondary legume crops also showed higher LER, RPE and REE compared to the respective sole cropping of the main crops. All these results revealed that intercropping of suitable legumes with cereals at their optimum plant population and intercropping time are more efficient than the existing sole cropping of the component crops in crop production and resource utilization. Li *et al*. (2013) indicated that inter-specific interactions between legumes and cereals at their optimum plant population make cereals to acquire more soil nitrogen, which pushes the legumes to fix more nitrogen and thus improves the land use efficiency of the system.

4.1. Economic profitability

Similar to production efficiency measures, the highest NR (Ethiopian Birr 38,160/ha) with acceptable MRR (598.68%) was recorded at the combination of 166667 plants/ha plant population and simultaneous intercropping of lupine with barley sowing (Table 5). Similarly, several workers also reported that legume-cereal intercropping systems at their optimum plant population resulted in significantly higher NRs with acceptable MRRs (>100%) than the existing sole cropping of the component crops (Seran and Brintha, 2010; Yayeh *et al*., 2014; FAO, 2015; Alemayehu *et al*., 2016; Wang *et al*., 2017; Marcello, 2018; Yang *et al*.; 2018; Yayeh *et al*., 2019). According to FAO (2015), intercropping of suitable secondary crop species with main crops at their optimum plant populations is highly recommendable for small scale farms (which are of labor intensive) for maximizing crop productivity and return sustainably much better than that of sole cropping. As it wouldn't be easy for field management especially for inter-row movements, intercropping may not however suitable to large mechanized crop farms.

Table 5: Average economic profitability of barley-lupine intercropping as influenced by plant population and time of lupine additive intercropping in 2017 and 2018 in Gozamin highland

Lupine intercropping with barley		TVC	GR	NR	MRR (%)	Rank
PP (plants/ha)	Intercropping time	(ETB/ha)	(ETB/ha)	(ETB/ha)		
Barley SC		7100.00	33885.00	26785.00	-	-
166667	SMPwB	9000.00	47160.00	38160.00	598.68	1
	2WABS	9000.00	37440.00	28440.00	D	-
	4WABS	9000.00	38340.00	29340.00	D	-
	6WABS	9000.00	35955.00	26955.00	D	-
250000	SMPwB	9650.00	41535.00	31885.00	D	-
	2WABS	9650.00	34965.00	25315.00	D	-
	4WABS	9650.00	36495.00	26845.00	D	-
	6WABS	9650.00	33795.00	24145.00	D	-
500000	SMPwB	11300.00	37170.00	25870.00	D	-
	2WABS	11300.00	31005.00	19705.00	D	-
	4WABS	11300.00	32040.00	20740.00	D	-
	6WABS	11300.00	30780.00	19480.00	D	-

PP = plant population; SC = barley intercropping; SMPwB = simultaneous planting with barley; 2WABS = two weeks after barley sowing; 4WABS = 4 weeks after barley sowing; 6WABS = six weeks after barley sowing; TVC = total variable cost; GR = gross return; NR = net return; MRR = marginal rate of return; ETB = Ethiopian Birr; D = dominance

4. Conclusion

In all assessment methods employed in the study, 166667 plants/ha plant population at simultaneous intercropping time of lupine with barley gave the highest LER, CEY, RPE, REE and NR with 48%, 39.04%, 39.28%, 42.61% and 42.47% more advantages, respectively, than that of barley sole cropping. The plant population of 250000 plants/ha at simultaneous intercropping time of lupine with barley gave the second highest LER, CEY, RPE and REE with 30%, 22.71%, 23.04% and 19.62% more advantages, respectively, than that of barley sole cropping. At simultaneous intercropping time of lupine with barley, the plant population of 166667 plants/ha plant population of lupine additive intercropping with barley is hence suggested as the best recommendations to barley growing smallholder farmers in Gozamin highlands and similar areas in northwest Ethiopian highlands for enhancing the productivity of barley fields sustainably.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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