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Full Length Research Paper

Evaluation of lentil varieties and seedbed types for the management of lentil Fusarium wilt disease (*Fusarium oxysporum* f. sp. *lentis*) in central highlands of Ethiopia

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An experiment was conducted at Chefe Donsa naturally infested field with *Fusarium oxysporum* f. sp. *lentis* in order to evaluate the effect of lentil genotypes and seedbed types as components of integrated management option. A factorial experiment including lentil variety and seedbed type, each at four levels, was carried out in a split-plot design with three replications. The four lentil genotypes were ILL-590 (susceptible check), Alemaya, Derash and Denbi and four seedbed types were flat bed, open raised bed, tie-raised bed and farmer's practice. Raised seedbed exhibited relatively lower disease incidence than among the seedbed types. Interaction of the used varieties and seedbed types was significant in wilt reduction. The highest wilt incidence (ca. 67.5%) was recorded on ILL-590, susceptible lentil line, planted on flat bed, whereas, the lowest (ca. 8.8%) Fusarium wilt incidence was noted on cultivar Derash planted in raised bed. A combination of cultivar Derash and raised bed resulted significantly (P<0.05) higher grain yield (3827.0 kg ha^{-1}) than all other treatment combinations. Significantly (P<0.05) lower grain yields (in the order of 68.0 kg ha^{-1}) were obtained from integration of the susceptible genotype (ILL-590) with flatbed than all other treatment integration. The highest (899.4% unit/days) in AUDPC values were observed by flat seedbed type and ILL-590, while the lowest (114.0% unit/days) in AUDPC values were obtained by raised seedbed type and Derash variety. Wilt incidence and AUDPC values were significant and negatively correlated with yield parameters. It was concluded that using moderately resistant variety (Derash) with raised seedbed significantly reduced Fusarium wilt incidence and exhibited reasonably high yields.

Keywords*:* Lentil, management, wilt, *F. oxysporum* f. sp. lentis*.*

INTRODUCTION

Lentil (*Lens culinaris medikus*) is a high value cool season pulse crop and contains about 25% protein in its seeds (Zia et al., 2011). Its production is concentrated in the northwest provinces of Australia, Bangladesh, China,

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Ethiopia, India, Middle East, Nepal, North America, Syria and Western Asia (Abraham, 2015). Ethiopia is the leading producer of lentil in Africa, followed by Morocco and Tunisia and is seventh in the world (Abraham, 2015). Its total area and production in Ethiopia is about 113,684 ha and 0.17 million tons, respectively, with an average yield of 1.2 tons ha^{-1} (CSA, 2017). The major lentil-producing regions in Ethiopia are Oromia, Amhara, Tigray and the Southern Nations, Nationalities and Peoples' (SNNP) (Senait et al., 2006).

Lentil plays a significant role in human and animal nutrition and in maintenance and improvement of soil fertility (Sarker and Kumar, 2011). Lentil has a good potentiality for increasing farm income (Das et al., 2013). Ethiopian farmers' produce the lentil crop mainly, for food, cash income, animal feed and more importantly to restore soil fertility (Altaf et al., 2014). Farmers and their families use it to make the local *Nifro* (boiled lentil), *Sambusa* (boiled whole lentil that is roasted in oil after wrapping with paste of wheat flour), and *Shorba* (soup) and *wot* (local soup for moistening and eating along with *Injera* (flat pancake) or bread).

Lentil Fusarium wilt (FW) (*F. oxysporum* f. sp. *lentis: Fol*) plays a major role in reducing lentil yield (Pouralibaba et al., 2015) and causes severe damage to leaves, stems, roots and pods (Singh et al., 2015; 1999). This pathogen can cause infection at all stages of plant growth with more incidences at flowering and podding stages than early vegetative stage (Chavdarov, 2006). Under field conditions, the typical wilting can appear within three to four weeks after sowing in susceptible variety (Taylor et al., 2007).

The yield of lentil remains low (1.5 tons ha^{-1}) in Ethiopia (CSA, 2017) and still relatively low compared to its yield potential (3.6 tons ha^{-1}) with well managed production due to biotic and abiotic stresses (Kumar et al., 2017). This low lentil production is attributed to various diseases, insect pests, poor agronomic practices, and lack of improved cultivars and crop protection technologies (Ghazanfar et al., 2010). In Ethiopia, lentil wilt/root rot complex caused by *F. oxysporum* F. sp. *lentis, Rhizoctonia solani*, *Macrophomina phaseolina*, *Sclerotium rolfsii*, Ascochyta blight (*Didymella lentis*) and rust (*Uromyces viciae fabae*) are the most important biotic factors causing lentil yield reductions (Ahmed and Ayalew, 2006; Negussie et al., 2006).

Vertisols are characterized by severe waterlogged soil during the rainy season due to its expansion, flaking and crust formation characteristics that reduces its percolation rate (Deckers et al., 2001). Excess soil moisture and waterlogged soil creates favourable condition for the development of wilt/root rot pathogen (Midmore, 2015). This causes breakdown of host resistance to Fusarium wilt of lentil, probably through retarding phenylalanine ammonia lyase (PAL) enzyme(s) activity (Midmore, 2015). Poor germination of seed in soils at or near saturation provided limited oxygen diffusion through thick water films surrounding the seed (Richard and Guerif, 1988). The availability of water must be balanced with aeration to meet requirements for germination and crop establishment (Dasberg and Mendel, 1971). The permeability of the roots to water reduced the oxygen levels and eventually the roots lose their ability to control water movement (Braunack and Dexter, 1989).

Several attempts have been directed to minimize the effects of pathogen on plants by seedbed preparation practices that are quite rare for legumes, particularly for lentil. Inadequate seedbed preparation contributes to favorable condition for Fusarium wilt pathogen. To avoid this problem, a set of appropriate seedbed type is very important to improve the soil physical conditions and well drainage system to release excess soil moisture. Solution for this and similar other problems can be realized by cultivating improved lentil crops on appropriate seedbed to make adequate drainage in soils with excess soil moisture to prevent root diseases (Feiza et al., 2010). A number of lentil FW resistant varieties had been identified at national and international levels to manage this risk through the use of wilt-sick plot technique. Resistant varieties can be highly economical and practicable method of disease management, but varieties should be resistant to all the races prevalent in the area (Kelly et al., 1994). However, none of the control measures are found to be effective and adequate individually at field level (James and Pandey, 2017). Thus, developing an integrated disease management approach was suggested to be essential to combat Fusarium wilt of lentil for increased and sustainable yields. Therefore, the objective of this study was to evaluate the effects of lentil genotypes and seedbed preparation methods on Fusarium wilt development.

MATERIALS AND METHODS

Field experiment was conducted with naturally infested with wilt/root rot causing pathogens at Chefe Donsa research sites in 2017/2018 cropping season. Chefe Donsa is located at latitude 08°57′N, longitude 39°06″E, altitude of 2450 m.a.s.l. and average annual rainfall of about 900 mm and the mean annual maximum and minimum temperatures of 26.0 and 7.0°C. Both sites have vertisol with waterlogging problem. The experiment was laid out in split plot design (seedbed types as main plot and lentil genotypes as sub-plot) with three replications. The plot size was 3.2 m^2 (4 rows per plot) with 4 m row length. The seed rate was 800 seeds per plot. Lentil seeds were drilled by hand at a depth of 3 to 3.5 cm. Four lentil genotypes (ILL-590, Alemaya, Denbi and Derash) with varying levels of resistance and four seedbed types (flat, open raised, farmer's practice and tie-ridge seedbed) were used in the study. Alemaya, Derash and Denbi are moderately resistant varieties, and ILL-590 (susceptible check).

Data collection and analyses

Disease incidence was recorded four times at every fifteen days starting from the first appearance of disease symptoms. Complete or partial wilting plants were considered as wilted and staked to avoid double counting in subsequent assessments. Percent of wilt incidence was calculated on the basis of initial plant count and total number of diseases plants in each plot using the following formula (Chavdarov, 2006). Data were analyzed using the SAS system and means were compared using least significant difference (LSD) (SAS, 2002). Disease incidence data were transformed using monomolecular, ln (1/1-y) transformation (Campbell and Madden, 1990). Transformed data were subjected to linear regression to determine disease progress rate. Disease progress rate was analyzed using the statistical software called Minitab, version or release 15.0 for windows®, 2007. Area under progress curve (AUDPC) was calculated for each treatment from the assessment of disease incidence using the formula:

$$AUDPC = \Sigma [(1/2(xi+xi+1)] [ti+1-ti]$$

where xi = disease incidence in percentage at i^{th} assessment, ti = time of the i^{th} assessment in days from the first assessment date (Campbell and Madden, 1990).

RESULTS AND DISCUSSIONS

Significant differences (P≤0.05) were observed among varieties and seedbed preparation methods on disease mean incidence percent (Table 1). The first lentil Fusarium wilt symptom was appeared at 25 days after planting (DAP). The performance of lentil genotypes resistance to Fusarium wilt in field test with the integration of seedbed types was varied. The final wilt incidence ranged from about 20.4% for variety Derash and to 57.6% for the susceptible check (ILL 590) and wilt incidence of 23.8% was recorded for cultivar Alemaya. Wilt incidence was significantly (P≤0.05) lower on all improved lentil varieties than the wilt susceptible lentil line. Cultivars Alemaya and Derash showed significantly (P≤0.05) lower amount of infection than cultivar Denbi and susceptible check, ILL-590 (Table 1). This finding is similar to the observation by Taylor et al. (2007) and Pouralibaba et al. (2015) who found that the use of resistant varieties showed the most effective, economical and environment-friendly method to manage lentil Fusarium wilt. Teklu et al. (2006) reported that seedbed type induced the highest surface runoff as compared to farmers' practice and flat seedbed for vertisol in the central highlands of Ethiopia. This result was in accordance with the investigations of Cowie et al. (1996) who observed that persistence of wetness within rooting zone adversely affected the crop growth since legumes were too sensitive to high soil moisture.

Significant differences (P≤0.05) were observed in interaction of variety x seed bed preparation method in diseases incidence (Table 2). The highest (67.5%) final Fusarium wilt incidence was obtained by planting susceptible check, ILL-590 on flat seedbed (Table 2). This might be excess soil moisture condition predisposes resistant varieties to be easily attacked by pathogens, which are not problems during normal growing seasons and facilitating spore germination and penetration into the host by the pathogen. Similar results were reported by Isleib (2014) and Binagwa et al. (2016) who also observed higher population of Fusarium wilt fungus that can also be explained by presence of high soil moisture, poor drainage of excess soil moisture and soil compaction that favors the pathogen development.

The lowest 8.8% final Fusarium wilt incidence was obtained in planting variety Derash on the raised seedbed type (Table 2). This indicated that integration of Derash variety with raised seedbed type resulted lower wilt incidence than susceptible check with planting on the flat seedbed. The reason for such variation might be the removal of excess water from the raised beds that might have helped the drained plots to produce higher yield than the flat seedbed and enhanced the movement of required soil moisture through the root system. This result agrees with the observations made by other researchers (Srivastava et al., 2000) who indicated that many attempts were made to manage this disease using cultural, varietal, biological and chemical methods.

Area under disease progress curve (AUDPC)

The highest (899.4% - days) AUDPC values were found from the integration of flat seedbed and ILL-590, while the lowest (114.0% - days) in AUDPC values were noted in the integration of raised seedbed with the variety Derash (Table 2). The overall results indicated that integrated resistance and /moderately resistance variety and raised seedbed type practice was effective to slow down the epidemics of Fusarium wilt and to sustain lentil production and productivity which confirmed with the finding of Negussie et al. (2006) and Palti and Katan (1997) they reported that substantial reductions in plant mortality with wilt/root rots were recorded when a combination of moderately resistant varieties and drainage methods that was used in raised seedbed type. Similarly, Merkuz and Getachew (2012) reported that growing resistant and moderately resistant varieties on raised seedbed that drained excess water with recommended seeding rate to reduce plant mortality in case of by chickpea wilt. Fusarium wilt pressure on the susceptible line and high inoculum presence exhibited major influence on disease development and reproduction in conformity with the reports of de Jensen et al. (2002) and Abawi and Ludwig (2005). They observed that root diseases were most severe in susceptible crop varieties, because the pathogen inoculum could build up quickly when favourable conditions were conducive for disease development. Hence, the present study indicated that Fusarium wilt incidence might be minimized by careful selection of resistant lentil genotypes and raised seedbed type that enforced as the most important agronomic factors to increase lentil productivity.

Disease progress rate and curve

The disease progress rate was significantly differed among varieties and seedbed practiced (Table 3). The

Table 1. Main effects of seedbed type and varieties on the lentil Fusarium wilt incidence (%) at Chefe Donsa, Ethiopia, in 2017/2018 main cropping season.

Factor		Percent of disease incidence at 15 days interval after the disease onset			
		First score	Second score	Third score	Fourth score
		DAP 25	DAP 40	DAP 55	DAP 70
Variety	ILL-590	13.2^{c}	25.1^{c}	40.4^{c}	57.6^{c}
	Alemaya	6.5^{a}	10.9^{a}	16.1^{a}	23.8^{a}
	Denbi	9.1^{b}	16.8^{b}	23.5^{b}	31.6^{b}
	Derash	7.4^{a}	12.4^{a}	15.6^{a}	20.4^{a}
Mean		7.3	13.1	25.6	28.5
LSD (0.05)		1.5	2.0	2.3	4.0
CV (%)		7.4	11.8	11.4	12.0
Bed type	Flat bed	16.4^{b}	23.3^{c}	30.9^{c}	46.0^{c}
	Raised bed	10.7^{a}	10.8^{a}	17.7^{a}	23.8^{a}
	Farmers' practice	15.8^{b}	17.1^{b}	25.4^{b}	38.0^{b}
	Tied ridge bed	11.8^{a}	14.0^{ab}	21.9^{ab}	32.8^{b}
Mean		13.7	16.3	23.9	33.6
LSD (0.05)		1.7	3.8	4.7	7.9
CV (%)		19.5	14.5	11.5	16.5

Table 2. Interaction effects of lentil variety and seedbed type on Fusarium wilt (*F.oxysporium* f.sp. *lentis*) of final disease incidence (%) at Chefe Donsa, Ethiopia, in 2017/2018 main cropping season.

Treatment combinations		Final percent of disease incidence at every 15 days interval at Chefe Donsa (Var)				
		ILL-590	Alemaya	Denbi	Derash	Mean
	Var.	PDI$_{f}$^{1}				
Bed type	Flat bed	67.5 ^{g}	35.1^{de}	39.8^{e}	31.2^{d}	67.5 ^{g}
	Raised bed	52.5 ^{f}	11.4^{a}	20.5^{bc}	8.8 ^{a}	52.5 ^{f}
	Farmers' practice	51.1 ^{f}	31.6^{de}	36.3^{de}	29.0^{cd}	51.1 ^{f}
	Tied ridge bed	59.8^{fg}	16.8^{ab}	30.1^{cd}	15.6^{ab}	59.8^{fg}
Mean		63.37	24.40	28.0	20.0	24.40
LSD (0.05)				4.9		
CV (%)				15.2		

PDI$_{f}$ ^{1} = final percent of disease incidence of lentil Fusarium wilt at every 15 days interval; LSD = Least significant difference at P ≤ 0.05; CV= Coefficient of variation; Means followed by same letter(s) within a column are not significantly different at 5% level of significance.

disease progress rates on flat seedbed, raised seedbed, tie-ridge and farmers' practice were 0.0249, 0.0107, 0.0103, and 0.0.0134 units per day for the variety ILL-590; 0.0.00699, 0.0.00400, 0.00565, and 0.00483 units per day for Derash; 0.00776, 0.0044, 0.00469 and 0.00512 units per day for Alemaya; 0.00821, 0.00432, 0.00499 and 0.0061 for Denbi respectively (Table 3).

The disease progress rate was faster (0.315) on the susceptible check, ILL-590 than on other varieties in all seedbed types. The disease progress curves of Fusarium wilt (incidence versus DAP) were sketched separately for each lentil variety (Figure 1). Fusarium wilt incidence progressively increased for each curve of all lentil varieties starting from the first typical wilt symptom appeared to the final wilt incidence recorded during the period of assessment. However, the increasing trend in the raised seedbed method was comparatively lower than in the other tested seedbed types (Figure 1).

Effect of seedbed types and varieties on lentil aboveground biomass

Aboveground biomass showed highly significant (P≤0.01) difference in the main effects and interaction effects of seedbed types and lentil varieties (Table 4). Higher

Table 3. Interaction effects of seedbed type and lentil variety on Fusarium wilt (*F.oxysporium* f.sp. *lentis*) area under disease progress curve (%-days) at Chefe Donsa, Ethiopia, during the 2017/2018 main cropping season.

Treatment combinations		**Area under disease progress curve (%-days) at Chefe Donsa (Var.)**				
	Var.	**ILL-590**	**Alemaya**	**Denbi**	**Derash**	**Mean**
Seedbed type	Flat bed	899.4^{h}	396.0^{cd}	518.0^{e}	415.2^{d}	561
	Raised bed	679.0^{fg}	155.5^{a}	295.0^{bc}	114.0^{a}	326
	Farmers' practice	679.2^{f}	423.0^{de}	446.0^{de}	352.0^{cd}	374
	Tied ridge bed	752.6^{g}	207.0^{ab}	397.0^{cd}	215.0^{ab}	376
Mean		738.6	278.9	379.9	238.9	
LSD (0.05)				62.9		
CV (%)				11.0		

LSD = Least significant difference at P ≤ 0.05; CV= Coefficient of variation; Means followed by same letter(s) within a column are not significantly different at 5% level of significance.

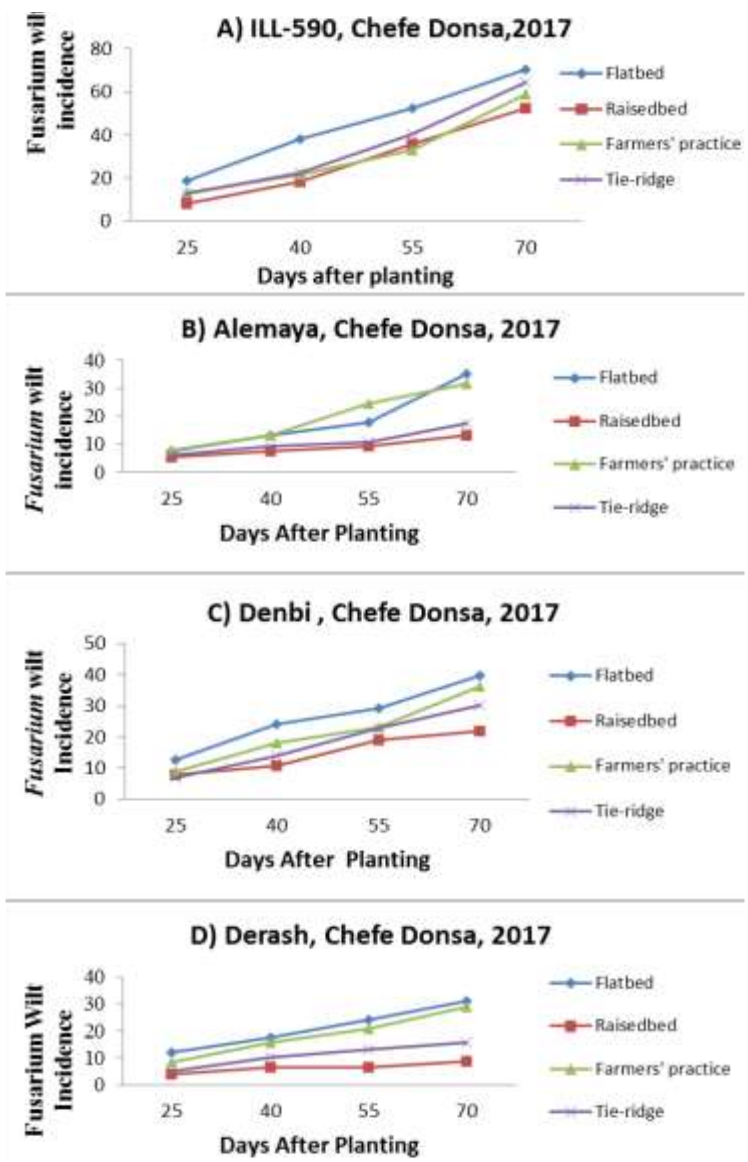

Figure 1. Fusarium wilt progress curves as influenced by seedbed types and lentil varieties at Chefe Donsa.

Table 4. Disease progress rates on lentil varieties with seedbed types at Chefe Donsa in 2017/2018 main cropping season.

Treatments		Variety	Intercept	SE of Intercept	Progress Rate	R^2
Seedbed type	Planting on the open raised bed type	ILL-590	- 0.254	0.15569	0.0107	89.9%
		Derash	- 0.0515	0.0387780	0.00400	71.3%
		Denbi	- 0.0420	0.0966788	0.00432	96.1%
		Alemaya	- 0.0367	0.086691	0.00440	72.1%
	Planting on the farmer practice seedbed type	Denbi	- 0.0755	0.0715654	0.00616	94.3%
		ILL-590	- 0.064	0.190048	0.01340	63.0%
		Derash	- 0.107	0.15111	0.00483	79.1%
		Alemaya	- 0.137	0.18332	0.00512	71.5%
	Planting on the flat seedbed type	Denbi	- 0.0526	0.141774	0.00821	64.6%
		Alemaya	- 0.159	0.14171	0.00776	81.3%
		ILL-590	- 0.253	0.31489	0.0249	84.2%
		Derash	-0.035	0.089524	0.00699	80.6%
	Planting on the tie- ridge bed type	Derash	- 0.0101	0.111725	0.00565	77.3%
		Alemaya	- 0.152	0.322408	0.00469	65.4%
		Denbi	- 0.113	0.274120	0.00499	63.3%
		ILL-590	- 0.114	0.0931541	0.0103	75.6%

aboveground biomass (1767.0 g per plot) was obtained by the integration of raised seedbed with Derash variety (Table 4). Relative to the flat seedbed, aboveground biomass yield was increased by 40.16% in the raised bed. The lowest 196.67 g per plot aboveground biomass weights of lentil were obtained from the plots planted with ILL-590 genotype on the flat seedbed (Tables 4).

Effect of seedbed types and lentil varieties on the mean grain yield

Highly significant ($P \leq 0.01$) differences were obtained in the main effects and the interaction effects of seed bed type practiced and lentil varieties at Chefe Donsa (Table 5).

The highest (3827.0 kg ha^{-1}) mean lentil grain yield was observed from plots where Derash variety was planted on raised seedbed type but, the lowest 68.0 kg ha^{-1} mean grain yield of lentil was found from the integration of ILL-590, susceptible line with flat seedbed type (Table 5). Derash variety showed better performance on all seedbed types than other varieties. Similarly, growing lentil crops on raised seedbed produced significantly superior agronomic characteristics; yield attribute traits, seed and straw yields as compared to the flat bed sown crop (Rathore et al., 2010). Absolutely this interpretation indicated that the best management option to reduce the wilt problem was approached to use improved varieties with resistance to wilt. Potential mean grain yields (3827.0, 3268.0 and 2893.0 kg ha^{-1}) of lentil were obtained when the varieties Derash, Alemaya, and Denbi were integrated with raised seedbed type respectively (Table 5). This result is in agreement with the results of Schulthess et al. (1997) who reported that significant increase in lentil grain yield vertisol with the appropriate seedbed type and improved variety were used. Similarly, Abate et al. (1993) reported 58% yield increase in durum wheat and 106% in chickpea and lentil were obtained when planted on raised bed over planting on flatbed.

Correlations of disease incidence and AUDPC with growth and yield

There was highly significant ($P \leq 0.01$) and negatively correlated between disease incidence with seed grain yield and biomass yield of lentil.

Table 5. Interaction effects of seedbed types and lentil varieties on aboveground biomass at Chefe Donsa in 2017/2018 main cropping season.

Treatment combinations	Aboveground biomass weight of lentil (gram per plot) at Chefe Donsa				
	ILL-590	Alemaya	Denbi	Derash	Mean
Flat bed	326.67[c]	1000.0[a]	1053.3[a]	1167.0[a]	854.2
Raised bed	623.0[a]	1367.0[ab]	1433.0[ab]	1767.0[b]	1197.4
Farmers' practice	423.33[a]	1200.0[a]	1216.7[a]	1500.0[ab]	1085.0
Tie ridge bed	760.0[a]	1200.0[a]	1100.0[a]	1467.0[ab]	1006.7
Mean	275.75	1191.67	1200.83	1475.0	
LSD (0.05)			228.2		
CV (%)			15.5		

LSD =Least significant difference at P ≤ 0.05; CV-Coefficient of variation; Means followed by same letter (s) within a column are not significantly different at 5% level of significance.

This indicated that the higher wilt incidence resulted in the lower lentil aboveground biomass and seed grain yield. Similarly, there was a strong negative correlation between Fusarium wilt incidence and seed grain yield, which was estimated at 8.8% yield loss for every 10% Fusarium wilt incidence (Erskine and Bayaa, 1996). It is also true for area under disease progress curve that exhibited highly significant (P≤0.01) and negatively correlated with biomass and seed grain yield. Positive association was calculated between days to 90% physiological maturity and seed yield. These results were in agreement with findings of Anjam et al. (2005) who reported that the increase in biomass would have a positive and significant effect on grain yield. Similarly, Singh et al. (1999) reported that plant height, plant biomass, branches/plant, and days to maturity resulted in significant positive correlation with grain yield.

Conclusions

Lentil is one of the most important leguminous crops widely grown in central highlands of Ethiopia. It is also a major cash crop and farmers earn high income. In Ethiopia, lentil is produced under a wide range of altitude from 1600 to 2700 m.a.s.l. mainly in main season. Due to several biotic and abiotic factors, lentil production and productivity has been low in Ethiopia. Of all constraints, lentil wilt caused by *Fusarium oxysporum,* was one of the most economically important that tackle the lentil farming systems in growing areas.

The interactions effects of varieties by seedbed types showed significant (P<0.05) difference. The highest (67.5%) final Fusarium wilt incidence was obtained by planting susceptible check, ILL-590 on flat seedbed type, while the lowest 8.8% final wilt incidence was obtained from the integration of variety Derash with raised seedbed. The highest (736.2% - days) AUDPC was recorded on the susceptible genotype, ILL-590, followed by Denbi variety (414.0% - days). AUDPC value clearly indicated that varietal difference among the treatments. Fusarium wilt disease rate progressed rapidly on genotype ILL-590 with flatbed than the others. Association of disease incidence with yield and yield components were negatively correlated and significant and inverse relationship.

For Chefe Donsa Derash with raised bed was suggested and the uses of raised seedbed type integrated with improved variety (Derash) will be comprehensive to improve lentil production and reduce the lentil wilt disease. Thus, planting improved lentil variety on the raised seedbed type to reduced Fusarium wilt should be regarded as one facet of the integrated control program rather than used alone. In this current study, it was observed that moderately resistance variety and raised seedbed type reduced disease parameters of lentil Fusarium wilt.

CONFLICT OF INTERESTS

The author has not declared any conflict of interest.

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Assessment of Yield and Yield Related Traits in Durum Wheat (*Triticum Turgidum*) Genotypes in Northern Ethiopia

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The main objective of this study was to evaluate 21 durum wheat genotypes for grain yield and agronomic traits under rain fed condition in three districts of Axum Agricultural Research Center, namely Hatsebo, Tahtay-Maichew and Ahferom during 2014 cropping season. Completely randomized block design with three replications was conducted for each location. The result of analysis of variance indicated that there was a significant difference among the genotypes for all the traits except harvest index. Thus, considerable variation was recorded among durum wheat genotypes. However, the effect of location on grain yield was non-significant. Among the genotypes, the highest grain yield was obtained from genotype 34thIDONMD/134/off2011 (2.39 t ha^{-1}) across all environments. High value of genotypic coefficient of variation (GCV) was calculated for panicle length, biomass yield, grain yield and harvest index both at Hatsebo and Tahtay-Maichew. However, at Ahferom, medium GCV was observed for these traits, which might be due to terminal moisture stress during the cropping season. High genotypic coefficient of variation, heritability and genetic advance as percent of mean were found in panicle length, biomass yield, grain yield and harvest index at Hatsebo and Tahtay-Maichew. This indicated that these characters could be useful basis of selection. The association of grin yield was positive and significant with harvest index (0.67), days to maturity (0.25), days to heading (0.22) and biomass yield (0.2), however the association between biomass yield and harvest index was negative (-0.54).

Key words: Durum wheat, genetic variation, heritability, quantitative traits.

INTRODUCTION

Durum wheat is the oldest traditional crop in Ethiopia covering significant proportion of arable land devoted to national wheat production. It is among the most diversified crop species in Ethiopia accounting for about 12% (more than 7000 accessions) of the national gene bank holdings. Negassa et al. (2012) indicated that durum wheat covers about 20% of the total area under wheat production, and estimated to contribute between 18 to 20% to the national wheat production with average productivity of 1.8 t ha^{-1} (Teklu and Hammer, 2008).

Farmer varieties, which are often referred as ‘landraces’ in the literatures, are characterized a

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Table 1. Altitude, rainfall, temperature, latitude, longitude and soil type of study locations.

Location	Altitude (m.a.s.l)	Total annual rainfall (mm)	Temperature (°C)		latitude	longitude	Soil type
			Min	Max			
Hatsebo	2118	782.8	10	29	14° 06’ 40.2’’	038° 45’ 45.8’’	Verti soil
Tahtay maichew	2090	656.6	12.6	25.51	14° 06’76.2’’	038° 39’14.5’’	Clay loam
Ahferom	2014	618.0	11.3	27.1	14° 06’40.2” N	039° 04’15.6’’E	loamy

National Meteorological Agency (Mekelle Branch).

significant genetic variability, even though their genetic constitution is mostly unknown, attributed to a number of factors including the natural and artificial selections (Mengistu and Pè, 2016). Environmental conditions and seeds exchanges among farmers resulted as key factors in the landrace variability (Pagnotta et al., 2005) and the pattern of variability is different among some of the Ethiopian regions (Mondini et al., 2010). As reports suggested, Ethiopian durum wheat have valuable genetic basis for abiotic and biotic stresses adaptations like resistance to *Erysiphe graminis* f. Sp. *Tritici, Puccinia* spp. and *Septori anodorum* (Negassa, 1986), stem rust (Ug99 or TTKS race) (Klindworth et al., 2007) and drought tolerance (Mengistu et al., 2015). Despite such merits endowed in the farmer’s cultivars, their cultivation was progressively minimized with the advent of improved and genetically uniform modern varieties. The farmers cultivars were seldom, if any utilized in modern wheat breeding efforts to improve production and productivity. For example, only less than 2% of the improved varieties cultivated in Ethiopia were composed of gene from Ethiopian landraces (CIMMYT, 2014). The remaining 98% of the improved durum wheat varieties are introductions of exotic materials from international breeding blocks. Identification of better genotypes with desirable traits and their subsequent use in plant breeding program and establishment of suitable selection criterion can be helpful for successful varietal improvement program. Analysis of variability among the traits and association of a particular character in relation to other traits contributing to yield of a crop would be great importance in planning a successful breeding program (Mary and Gopalan, 2006). Development of high yielding varieties requires a thorough knowledge of the existing genetic variation for yield and its components. The observed variability is a combined estimate of genetic and environmental causes, of which only genetic one is heritable. However, estimates of heritability alone do not provide an idea about the expected gain in the next generation, but have to be in conjunction with estimates of genetic advance, the change in mean value between generations (Shukla et al., 2006). One of the main objectives of any breeding program is to produce high yielding genotypes for release as cultivars to farmers. Introduction of new populations can be made from one region to the other easily and may be used for further manipulation to develop breeding genotypes (Jamal et al., 2009). Adaptability and yield stability of the outstanding genotypes will be tested in the national uniform yield trials and in farmer's fields, and the best ones will be proposed for release, after being evaluated for their grain yield and quality. The present study was conducted to evaluate the performance of twenty-one promising durum wheat genotypes in order to assess the presence of variability for desired traits and a significant amount of variation for different parameters.

MATERIALS AND METHODS

The experiment was conducted at three locations named Hatsebo, Tahtay-Maichew and Ahferom under rain fed condition during 2014 main cropping season. These locations represent the varying agro-ecologies of the major wheat growing areas of central Tigray. Climatic condition, soil type, altitude and longitudes of the experimental sites are presented in Table 1. It was conducted using RCBD design with three replications at three locations. A total of 21 durum wheat genotypes including two checks (Mukiye and Mangudo), and one local check (Shehan) were planted in a plot that consisted of four rows with 2.5 m long and 20 cm apart. The middle four rows were used for data collection. Planting was done by hand drilling using a seed rate of 150 kg/ha for each variety. Nitrogen and phosphorous fertilizers were applied at the rate of 100 kg/ha Urea (in split) and 100 kg/ha Di-ammonium phosphate (DAP) at planting. All other management practices were uniformly applied to all plots.

Data collected

Both the phonological and agronomic data were collected from plot and plant basis. The four central rows were used for data collection based on plots, such as days to 50% heading, days to physiological maturity, grain yield, bio-mass yield and harvest index. Ten randomly selected plants from the four central rows of each plot were used for data collection on plant basis and the averages of the ten plants in each experimental plot were used for statistical analysis for traits such as plant height and spike length.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using the linear model SAS version 9.1.3 (SAS Institute Inc, 2004) after testing the ANOVA assumptions. The phenotypic and genotypic coefficients of variation were estimated according to the methods suggested by Burton and De Vane (1953). However, cluster analysis was carried out using the Squared Euclidean distance-Ward's clustering method and conducted using the statistical package for social sciences (SPSS Inc., 2009) software. Mean separations were estimated using Duncan’s Multiple Range (DMRT) test at 5% probability levels.

Estimation of variance components and association among components

The phenotypic and genotypic variances were estimated according to the methods suggested by Burton and De Vane (1953).

$\delta^2 p = \delta^2 g + \delta^2 e$

$\sigma^2 g = \frac{MSg - MSe}{r}$

Where, $\delta^2 p$ = phenotypic variance
$\sigma^2 g$ = Genotypic variance
$\delta^2 e$ = Error variance

(Error mean square)

Mg= mean sum square of genotypes
Me= mean sum square of error
r=Number of replications.

The phenotypic and genotypic coefficient of variation was estimated according to the methods suggested by Burton and De Vane (1953).

Phenotypic coefficient of variation

$PCV= \frac{\sqrt{\sigma 2\ p}}{\bar{X}} * 100$

Where, σ^2 p = phenotypic variance and
$\bar{X}$ = mean of the characters evaluated

Genotypic coefficient of variation

$GCV= \frac{\sqrt{\sigma 2\ g}}{\bar{X}} * 100$

Where, $\delta^2 g$ = genotypic variance
$\bar{X}$= mean of the characters evaluated.

Broad sense heritability was computed for each character based on the formula developed by Allard (1960) as:

$H^{2} = \frac{\sigma 2g}{\sigma 2p} * 100$

Where, $\delta 2\ p$ = phenotypic variance, $\delta 2g$ = Genotypic variance,

$\delta^2 p = \delta^2 g + \delta^2 e$,

$\delta^2 e$ = Environmental (error) variance.

The genetic advance (GA) for selection intensity (K) at 5% was calculated by the formula suggested by Allard (1960) as:

$GA=K*\sigma_p*H^2$

Where, GA= Expected genetic advance, δp = the phenotypic standard deviation, H^2 = broad sense heritability, K= Selection differential (K=2.06 at 5% selection intensity).

GA (as % of the mean) (GAM) $= \frac{GA}{\bar{X}} * 100$

Where, $\bar{x}$ = population mean

Estimation of genotypic correlation coefficients was done based on the procedure of Dabholkar (1992).

$$r_g = \frac{g \operatorname{cov} x.y}{\sqrt{\sigma^2{}_g x.\sigma^2{}_g y}}$$

Where, r_g is genotypic correlation coefficients.

Cluster analysis

Based on the squared distances values, clustering of genotypes was done using Ward's method as described by Singh (2001). Cluster analysis was conducted using the statistical package for social sciences (SPSS Inc., 2009).

RESULTS AND DISCUSSION

The analysis of variance revealed that there was a significant variation ($p<0.05$) among the genotypes for most of the traits studied (Table 2). However, the interaction effect (genotype by location) was non-significant for grain yield (Table 3). This tells us that varieties responded constantly to the different locations suggesting the best genotype here identified can be recommended for all the three locations. The mean performances of the genotypes over three locations for the characters are presented in Table 2. Genotypes showed variation for days to heading ranging from 59 to 64.08 days with a mean of 61.19 days, and days to maturity ranging from 99 to 104.33 days with a mean of 100.81 days. Dejene et al. (2016), Yonas et al. (2016), and Rathwa et al. (2018) also reported variation among durum wheat genotypes for days to heading and days to maturity.

In this study, almost all the genotypes have matured early, hence these genotypes could be classified as early to the study area, suggested the chance of selecting early genotypes which can reduce the risk to face with the terminal moisture stress which is one of the wheat production problems in the study area. However, earliness alone is not guarantee as other characters like grain yield matters for adaptation of genotypes by farmers. The good thing is that some of the identified early maturing genotypes (that is, Mangudo and CD11-Y10 BIR SEL/67/off2011) were found to give average to high grain yield which makes them desirable as they contain both earliness and high grain yield which are mostly contradicting traits. Hence, after testing these genotypes in more locations and different seasons they can be the best varieties for the testing regions and other similar agro-ecologies. Panicle length ranged from 4.19 cm for CD11-Y10 BIR SEL/67/off2011 to 6.2 cm for 34thIDONMD/134/off2011 with mean value of 4.5 cm. The computed harvest index for genotypes ranged from 35% for Mukiye to 48% for CD11-Y10 BEK SEL/82/off2011. The effect of locations on the performance of the genotypes was non-significant with respect to grain yield (Table 3). It can be inferred that the

Table 2. Mean performances of durum wheat genotypes over three locations for yield and other agronomic characters.

Treatments	GY (t ha^{-1})	DH	DM	GFP	PH (cm)	PL (cm)	BM (t ha^{-1})	HI
CD11-Y10 BIR SEL/18/off2011	1.92	62.08	100.08	38.00	68.42	4.75	5.17	0.38
34thIDONMD/21/off2011	2.26	63.58	104.33	40.75	69.98	4.92	5.08	0.45
CD11-Y10 BIR SEL/12/off2011	2.10	61.17	98.92	37.75	64.35	4.87	4.83	0.44
CD11-Y10 BEK SEL/82/off2011	2.05	60.42	101.58	41.17	68.12	5.08	4.42	0.48
34thIDONMD/66/off2011	2.15	62.75	101.08	38.33	70.95	4.42	5.00	0.44
34thIDONMD/109/off2011	1.98	61.08	99.00	37.92	67.52	4.72	5.58	0.36
CD11-Y10 BEK SEL/117/off2011	1.85	59.83	99.75	39.92	83.35	4.80	5.08	0.38
34thIDONMD/134/off2011	2.39	64.08	103.42	39.33	69.98	6.32	5.42	0.45
CD11-Y10 BIR SEL/172/off2011	1.91	61.42	101.25	39.83	68.22	4.88	5.75	0.35
CD11-Y10 BIR SEL/64/off2011	1.91	59.08	99.08	40.00	66.05	4.20	4.67	0.41
CD11-Y10 BIR SEL/67/off2011	2.20	59.92	99.50	39.58	65.97	4.19	5.42	0.42
CD11-Y10 BIR SEL/11/off2011	1.82	59.08	97.67	38.58	70.27	4.95	5.00	0.37
CD11-Y10 BIR SEL/68/off2011	2.06	60.67	101.50	40.83	72.18	4.70	5.00	0.43
34thIDONMD/60/off2011	2.10	63.75	102.83	39.08	65.98	4.68	5.25	0.39
CD11-Y10 BIR SEL/70/off2011	1.92	60.25	100.50	40.25	70.25	4.63	4.83	0.41
EGYPT-KUL/26/off2011	1.79	60.75	101.42	40.67	63.58	4.82	5.08	0.38
CD11-Y10 BIR SEL/114/off2011	2.06	60.75	102.67	41.92	71.50	4.98	4.58	0.45
CD11-Y10 BIR SEL/181/off2011	2.07	61.18	99.67	38.50	68.55	4.83	5.00	0.41
Mangudo	2.38	60.08	100.25	40.17	68.62	4.63	5.67	0.43
Mukiye	1.61	61.08	102.75	41.67	67.18	4.70	4.75	0.35
Local/ shehan/	2.04	62.08	99.67	37.58	66.63	4.53	5.25	0.39
LSD(0.05)	0.13	1.70	1.18	0.99	1.44	0.30	0.25	1.02
MEAN	2.03	61.19	100.81	39.61	68.91	4.50	5.08	`0.41
R2	0.43	0.78	0.60	0.74	0.62	0.72	0.50	0.43

DH= days to heading, DM= days to maturity, GFP= grain filling period, PH= plant height, PL= panicle length, BM= biomass yield, GY= grain yield, HI= harvest index.

Table 3. Sum of squares and its percentage (out of total) contribution of the combined analysis of grain yield of 21 durum wheat varieties tested over 3 locations.

Source	DF	SS	MS	F value
Location	2	2.85	1.42	7.90*
Rep(loc)	9	3.19	0.35	1.96*
Treatment	20	8.75	0.44	2.42*
Loc*trt	40	9.75	0.24	1.35^{ns}
Error	180	32.49	0.18	
Total	251	57.03		
CV(%)= 20.96				

**, * Significant at p<0.01 and p<0.05, respectively; ns= non-significant, Where: loc*trt= location by treatment interaction.

overall performance of the genotypes was better at Hatsebo followed by Tahtay-Maichew and then Ahferom (Table 4). The lack of significance in the genotype by location interaction for grain yield indicating a stability of the genotypes over location which is a very determinant factor for crop adaptation. The non-significant effect of location on genotypes for grain yield may indicate that genotypes selected for better performance for the trait at one location may display a similar relative performance at another location.

Phenotypic and genotypic coefficient of variation, H^2 (heritability in broad sense) and GAM (genetic advance as percent of mean)

The estimated GCV, PCV, heritability in broad sense and expected genetic advance are presented in Tables 5, 6

Table 4. Mean grain yield (t ha) and rank of 21 varieties at 3 locations in central Tigray, Ethiopia, 2014.

Genotypes	Hatsebo		Tahtay maichew		Ahferom	
	Yield (t ha^{-1})	Rank (R)	Yield (t ha^{-1})	Rank (R)	Yield (t ha^{-1})	Rank (R)
CD11-Y10 BIR SEL/18/off2011	2.225	10	1.700	21	1.820	15
34thIDONMD/21/off2011	2.67	2	1.850	13	2.260	5
CD11-Y10 BIR SEL/12/off2011	2.1251	12	1.750	19	2.47	2
CD11-Y10 BEK SEL/82/off2011	2.251	8	1.800	17	2.098	6
34thIDONMD/66/off2011	2.75	1	2.100	7	2.064	7
34thIDONMD/109/off2011	1.900	17	2.125	5	1.945	9
CD11-Y10 BEK SEL/117/off2011	1.875	20	1.80	15	1.867	13
34thIDONMD/134/off2011	2.175	11	2.425	1	2.58	1
CD11-Y10 BIR SEL/172/off2011	2.250	9	1.975	11	1.522	19
CD11-Y10 BIR SEL/64/off2011	1.725	21	1.950	12	2.030	8
CD11-Y10 BIR SEL/67/off2011	2.35	6	2.300	3	1.938	10
CD11-Y10 BIR SEL/11/off2011	2.100	14	1.750	20	1.628	18
CD11-Y10 BIR SEL/68/off2011	2.1250	13	2.125	6	1.924	11
34thIDONMD/60/off2011	2.57	3	1.800	16	1.912	12
CD11-Y10 BIR SEL/70/off2011	1.8750	19	2.225	4	1.672	17
EGYPT-KUL/26/off2011	1.8751	18	2.075	8	1.414	20
CD11-Y10 BIR SEL/114/off2011	2.27	7	2.050	10	1.836	14
CD11-Y10 BIR SEL/181/off2011	2.050	15	1.825	14	2.263	3
Mangudo	2.55	4	2.350	2	2.260	4
Mukiye	1.950	16	1.750	18	1.122	21
Local/ shehan/	2.40	5	2.050	9	1.702	16

Table 5. Genotypic and phenotypic coefficient of variation, broad sense heritability, genetic advance and genetic advance as percent of mean for 8 characters of 21 durum wheat varieties at Hatsebo.

Character	δ^2g	δ^2p	δ^2e	GCV (%)	PCV (%)	H^2 (%)	GA	GAM
Days to heading	19.57	23.33	3.76	7.08	7.73	83.89	8.36	13.38
Days to maturity	31.97	39.65	7.68	5.46	6.08	80.63	10.47	10.11
Grain filling periode	11.33	18.44	7.11	8.19	10.45	61.45	5.44	13.24
Plant height	19.91	29.45	9.54	6.44	7.83	67.61	7.57	10.93
Panicle length	1.35	2.17	0.82	23.86	30.25	62.21	1.89	38.82
Biomass yield	1.45	1.96	0.51	24.80	28.84	73.94	2.13	43.99
Grain yield	0.42	0.47	0.05	29.98	31.70	89.44	1.27	58.50
Harvest index	0.01	0.01	0.002	22.22	24.34	83.33	0.19	41.85

δ^2g = Genotypic variance, δ^2e = Environmental variance, δ^2p= Phenotypic variance, H^2 (%) = Broad sense heritability, GCV (%) = Genotypic coefficient of variation, PCV (%) = Phenotypic coefficient of variation, (%) GA= Genetic advance, GAM= Genetic advance as percent of mean.

and 7. Higher magnitude of differences of genotypic and phenotypic variances was observed for some of the traits studied. The higher genotypic variance was computed for days to maturity while the lowest was for harvest index at all locations. Generally, the phenotypic variance was higher than the corresponding genotypic variance for days to heading, days to maturity, grain filling period and plant height, this indicated greater influence of environmental factors for the phenotypic expression of the traits. This result was in close agreement with the findings of Tesfaye et al. (2016). According to Sivasubramanian and Madhavamenon (1973), genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) can be categorized as high (>20%), moderate (10-20%) and low (<10%). As per this category, high values of genotypic coefficient of variation was calculated for panicle length, biomass yield, grain yield and harvest index both at Hatsebo and Tahtay-Maichew. Medium GCV was recorded for panicle length (14.98%), grain yield (14.15%) and harvest index (13.36%) at

Table 6. Genotypic and phenotypic coefficient of variation, broad sense heritability, genetic advance and genetic advance as percent of mean for 8 characters of 21 durum wheat varieties at Tahtay-Maichew.

Character	δ^2g	δ^2p	δ^2e	GCV (%)	PCV (%)	H^2 (%)	GA	GAM
Days to heading	19.15	25.11	5.96	6.90	7.90	76.26	7.88	12.43
Days to maturity	22.28	53.36	31.08	4.82	7.46	41.75	6.29	6.43
Grain filling period	5.20	24.11	18.91	6.61	14.23	21.58	2.19	6.33
Plant height	19.91	29.45	9.54	6.44	7.83	67.61	7.57	10.93
Panicle length	1.59	1.67	0.08	25.97	26.62	95.22	2.54	52.29
Biomass yield	1.36	2.19	0.83	23.77	30.18	62.04	1.89	38.63
Grain yield	0.62	0.75	0.13	39.66	43.64	82.59	1.47	74.36
Harvest index	0.04	0.05	0.01	46.70	52.69	78.57	0.35	85.41

δ^2g = Genotypic variance, δ^2e = Environmental variance, δ^2p= Phenotypic variance, H^2 (%) = Broad sense heritability, GCV (%) = Genotypic coefficient of variation, PCV (%) = Phenotypic coefficient of variation, (%) GA= Genetic advance, GAM= Genetic advance as percent of mean.

Table 7. Genotypic and phenotypic coefficient of variation, broad sense heritability, genetic advance and genetic advance as percent of mean for 8 characters of 21 durum wheat varieties at Ahferom.

Character	GCV (%)	PCV (%)	H^2 (%)	GA	GAM
Days to heading	3.64	5.02	52.56	3.33	5.44
Days to maturity	3.02	3.78	63.64	4.87	4.97
Grain filling periode	3.96	9.15	18.72	1.40	3.53
Plant height	9.47	11.71	65.44	10.89	15.81
Panicle length	14.98	16.90	78.63	1.31	27.41
Biomass yield	8.75	18.54	22.25	0.43	8.51
Grain yield	14.15	21.04	45.21	0.40	19.63
Harvest index	13.36	20.41	42.86	0.07	18.04

δ^2g = Genotypic variance, δ^2e = Environmental variance, δ^2p= Phenotypic variance,H^2 (%) = Broad sense heritability, GCV (%) = Genotypic coefficient of variation, PCV (%) = Phenotypic coefficient of variation, (%) GA= Genetic advance, GAM= Genetic advance as percent of mean.

Ahferom. This indicated the marked influence of environmental factors for the expression of these traits was less, hence traits can respond to selection. This is because estimation of genotypic coefficient of variation provides measure for comparing variability in the various traits and better improvement through selection (Guendouz et al., 2014). The phenotypic coefficient of variation was high for panicle length, biomass yield, grain yield and harvest index but medium for grain filling period both at Hatsebo and Tahtay-Maichew. However, at Ahferom Medium PCV was calculated for plant height, panicle length, biomass yield, grain yield and harvest. For some of the traits at both locations the difference in magnitude between GCV and PCV was high; this suggested large influence of environmental factors in masking the expression of these traits in durum wheat genotypes along with the practicality difficult for their improvement.

The heritability values ranged from 61.45 to 89.44% at Hatsebo, from 21.58 to 95.22% at Laelay-Maichew and from 18.72 to 78.63% at Ahferom. High heritability (>80%) was computed for grain yield (89.4%), days to heading (83.8%), harvest index (83.3%) and days to maturity (80.6%) at Hatsebo; for panicle length (95.22%) and grain yield (82.59%) at Tahtay-Maichew. According to Singh (2001), heritability of a trait is considered as very high or high when the value is 80% or more. The traits which exhibited high heritability suggested selection could be fairly easy and improvement is possible using selection breeding. In agreement to this study results, Jalal and Ahmad (2012), Adhiena (2015) and Tesfaye et al. (2016) also reported high estimates of heritability for days to heading, days to maturity and grain yield. Moderate heritability (>40 and <80) was computed for plant height, panicle length and biomass yield both at Hatsebo and Tahtay-Maichew and, for days to heading, days to maturity, plant height, panicle length, grain yield and harvest index at Ahferom. This suggested that selection should be delayed to more advanced generations for these traits (Singh, 2001). Large heritability values showed relative ease with which selection can be made based on phenotype but their practicality in plant breeding is further enhanced if accompanied by high genetic advance estimates

Table 8. Genotypic correlation coefficient of 21 durum wheat varieties over 3 locations.

Variable	DM	GFP	PH	PL	BM	GY	HI
DH	0.32**	-0.41**	0.004	0.26**	-0.06	0.22*	0.19*
DM	1	0.73**	0.01	0.11	0.15*	0.25**	0.11
GFP		1	0.01	-0.08	0.19*	0.08	-0.03
PH			1	0.19*	0.18*	-0.07	-0.17*
PL				1	-0.03	0.03	0.06
BM					1	0.2*	-0.54**
GY						1	0.67**

DH= days to heading, DM= days to maturity, GFP= grain filling period, PH= plant height, PL= panicle length, BM= biomass yield, GY= grain yield, HI= harvest index.

(Johnson et al., 1955). The estimated genetic advance as percent of mean for the traits studied at Hatsebo, Tahtay-Maichew and Ahferom are presented in Tables 5, 6 and 7, respectively.

Genetic advance as percent of mean showed a wide range of variations across locations. It ranged from 10.11 to 58.5% at Hatsebo, from 6.3 to 85.4% at Tahtay-Maichew and from 3.5 to 27.4% at Ahferom. Johnson et al. (1955) reported that high genotypic coefficient of variation along with high heritability and genetic advance as percent of mean provide better information than each parameter alone. High genotypic coefficient of variation, heritability and genetic advance as percent of mean were found in panicle length, biomass yield, grain yield and harvest index at Hatsebo and Tahtay-Maichew. Similarly, Jalal and Ahmad (2012) reported high heritability accompanied with high genetic advance as percent of mean in case of kernel weight of main spike, grain yield per plant, number of kernel per main spike, biological yield per plant, number of spikelet per main spike and plant height. Rathwa et al. (2018) also reported high heritability coupled with high genetic advance expressed as percentage of mean for days to 50% flowering, grain filling period, number of productive tillers per plant, number of grains per main spike, grain weight per main spike, grain yield per plant, biological yield per plant and harvest index. This indicated that these characters could be useful basis of selection. However, at Ahferom the values for GCV, H^2 and GAM are low comparing with the other locations, this might be due to low rain fall pattern during 2014 cropping season.

Association of characters

The analysis of variance indicated the presence of variability among the genotypes tested for 8 traits that allow breeders to make improvement through selection. The analysis of the relationship among the characters and their association with grain yield is essential to establish selection criteria (Singh et al., 1990). Environment also plays an important role in the correlation. In some cases, environment affects both the traits in the same direction or some time in different directions. The genetic and environment causes of correlation combine together and give phenotypic correlation. Genotypic correlation coefficient estimates between each pair of characters are presented in Table 8.

The association of grain yield was positive and highly significant with harvest index (0.67). Grain yield have also positive and significant correlation with days to maturity (0.25), days to heading (0.21) and biomass yield (0.22). Therefore any improvement of these characters would result in a substantial increment on grain yield. These results are sustained with those of Dawit et al. (2012) and Alemu et al. (2016) that stated positive and significant correlation of grain yield with harvest index, days to maturity and biomass yield. Besides, grain yield have positive and non-significant correlation with grain filling period and panicle length. This suggested that improvement of these traits would not affect the increment of grain yield. Biomass yield have positive and significant correlation with days to maturity, grain filling period and plant height; however, it has negative and highly-significant correlation with harvest index. This suggested that selection of genotypes for high biomass yield might lower harvest index. In line with this finding, Adhiena (2015) indicated negative and significant correlation of biomass yield with harvest index in bread wheat genotypes.

Clustering of genotypes

The D^2 values calculated based on Euclidean dissimilarity distance using Ward's method from the pooled mean of genotypes for the eight traits resulted in classifying the 21 durum wheat genotypes into four distant clusters (Figure 1). This indicated that the presence of genetic divergence among the tested genotypes. Cluster I was the largest cluster consisted of twelve genotypes (57.1%), cluster II contained only one genotype. The third and the fourth clusters contained five and four genotypes respectively. Different authors also reported the presence of diversity among the durum wheat genotypes classifying into

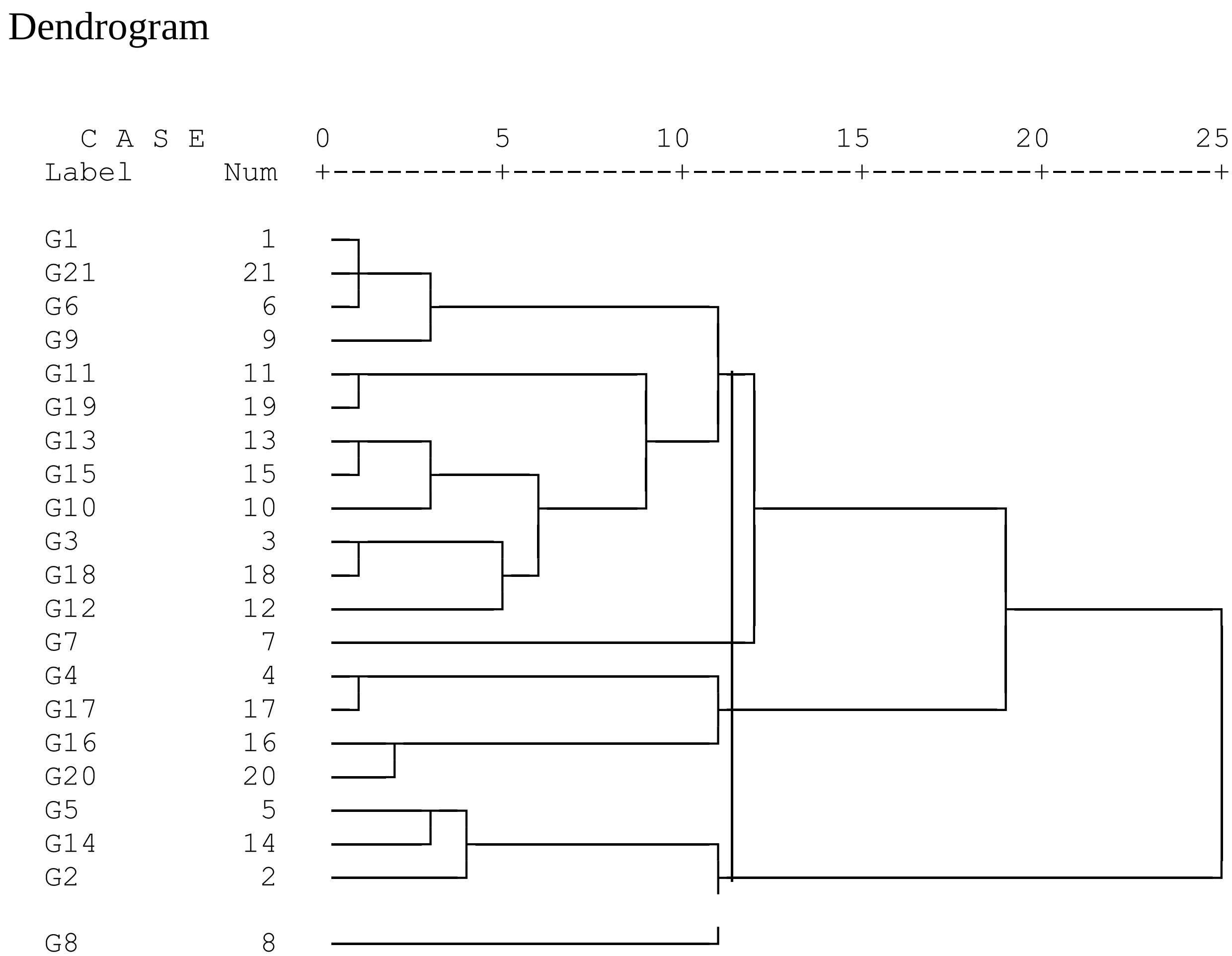

Figure 1. Dendrogram depicting the clustering of 21 genotypes using means of 3 locations, Where, **G1**= CD11-Y10 BIR SEL/18/off2011, **G2**= 34thIDONMD/21/off2011, **G3**= CD11-Y10 BIR SEL/12/off2011, **G4**= CD11-Y10 BEK SEL/82/off2011, **G5**=34thIDONMD/66/off2011, **G6**= 34thIDONMD/109/off2011, **G7**=CD11-Y10 BEK SEL/117/off2011, **G8**=34thIDONMD/134/off2011, **G9**= CD11-Y10 BIR SEL/172/off2011, **G10**= CD11-Y10 BIR SEL/64/off2011, **G11**= CD11-Y10 BIR SEL/67/off2011, **G12**= CD11-Y10 BIR SEL/11/off2011, **G13**= CD11-Y10 BIR SEL/68/off2011, **G14**= 34thIDONMD/60/off2011, **G15**= CD11-Y10 BIR SEL/70/off2011, **G16**= EGYPT-KUL/26/off2011, **G17**= CD11-Y10 BIR SEL/114/off2011, **G18**= CD11-Y10 BIR SEL/181/off2011, **G19**= Mangudo, **G20**= Mukiye, **G21**= Local/ shehan.

different number of distinct clusters. Geleta and Grausgruber (2013) study on morphological and quality traits variation in tetraploid (*Triticum turgidum* L.) and hexaploid (*Triticum aestivum* L.) wheat accessions from Ethiopia and classified 53 bread wheat accessions into four clusters. Similarly, Dargicho et al. (2015) grouped 68 bread wheat germplasm into six clusters using Mahlanobis D^2 statistics based on the pooled mean of germplasm. Thus, the presence of such kind of variability among the germplasm is crucial to develop desirable recombinants for developing high yielding durum wheat varieties through crossing between superior germplasm.

Conclusion

Knowledge on the extent and pattern of genetic variability in a population, interrelationship among different agronomic characters and information on the naturally occurring diversity are essential to design breeding program in crop improvement. To generate such information, 21 durum wheat genotypes were tested using randomized complete block design under rain-fed condition at Hatsebo, Tahtay-Maichew and Ahferom testing sites of Axum Agricultural Research Center in 2014. Results of analysis of variance showed statistically significant difference among the tested durum wheat genotypes suggesting the genotypes was phenotypically divergent. However, the effect of locations on the performance of the genotypes was non-significant with respect to grain yield. This indicates that genotypes selected for better performance for the trait at one location may display a similar relative performance at another location; thus there may be no need for spatial replication as evaluation at a single location may be sufficient for the purpose. High values of genotypic coefficient of variation were calculated for panicle length, biomass yield, grain yield and harvest index both at Hatsebo and Tahtay-Maichew. This indicated that the marked influence of environmental factors for the expression of these traits was less; hence traits can respond to selection. Genetic correlation coefficient analysis indicated that important agronomic traits (days to maturity, biomass yield and harvest index) were positively and significantly correlated with grain yield. This suggests a common genetic/physiological basis among these traits. Hence, simultaneous improvement of these traits would be possible. Generally, the national durum wheat program should plan and implement good breeding strategy to improve the genetic gain via releasing early and high yielder durum wheat varieties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Cowpea (*Vigna unguiculata* (L.)Walp., Fabaceae) landrace (local farmers' varieties) diversity and ethnobotany in Southwestern and Eastern parts of Ethiopia

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The present research was carried out to identify and document the landrace diversity and ethnobotanical uses of cowpea (*Vigna unguiculata* (L.) Walp) (Fabaceae) in Southwestern and Eastern Ethiopia. Data were collected through field observations, semi-structured interviews, guided field walk with cowpea farmers and users, and market surveys. Descriptive statistics, preference ranking and informant consensus were employed in the analysis. Forty-four cowpea accessions were collected from geographical locations ranging from 428- 2128 m.a.s.l. and 05° 17' 06.6" to 09°33' 58.5'' N and 34° 15' 54.5'' to 42° 26' 30.4'' E. The landraces had diverse seed sizes, colours, growth habits and germination potentials. Local variety 'Rapo' (Anywaa language) of *V. unguiculata* subsp. *dekindtiana* was found in Gambella Region; 'Atera babile' (Oromo language) of *V. unguiculata* subsp. *cylindrica* and subsp. *unguiculata* were found in all regions studied. Farmers grew cowpea for the purposes of human food, livestock Feed, improving soil fertility and medicine. The majority of farmers (63.33%) preferred the widely known 'Atera babile' which belongs to subsp. *unguiculata* because of its spreading nature, ability to produce more biomass than other varieties, effectiveness for improving soil fertility and ability to supersede weeds as a ground cover. Further research should focus on local landraces maintained by farmers and the crop wild relative is a worthwhile undertaking given its local importance and for future genetic improvement both as a food and feed crop.

Key words: Cowpea, ethnobotany, inter-cropping, landrace, sole cropping.

INTRODUCTION

Grain legumes are important sources of proteins with essential vitamins and minerals for food (Abebe et al.,

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2005; Patil et al., 2013) and can therefore be used as a substitute for animal protein in the regions of the third world where production of the latter is limited (Fall et al., 2003) with an added role of increasing animal production through use as feed and forage. Legumes contribute to smallholder income, as a higher-value crop and to diet, as a cost-effective source of protein (Chilot et al., 2010; Patil et al., 2013). Moreover, pulses offer natural soil maintenance benefits through nitrogen-fixing, which improves yields of cereals through crop rotation or intercropping, and can also result in savings for smallholder farmers from low rate of fertilizer use (Chilot et al., 2010). Among legumes grain, cowpea (*Vigna unguiculata* (L.) Walp.) is the most widely cultivated and consumed especially in Asia, Tropical Africa, South America, parts of Southern Europe and the United States (Singh et al., 1997; Lemma et al., 2009; Patil et al., 2013). However, Africa is the main area of production, where the crop is very important for low input agriculture, which characterizes most countries of the continent (Pasquet, 1998; Ba et al., 2004).

Cowpea is a multipurpose grain legume; in which the entire plant can be used for either human or livestock consumption (Pottorff et al., 2012). Its major importance is to the livelihoods of millions of relatively low income people in less developed countries of the tropics. Cowpea young leaves, pods and seeds are mainly used for human consumption and animal feeding (Ogbemudia et al., 2010). According to Islam et al. (2006), all parts of the plant are used as food, which is nutritious, providing protein and vitamins. Immature pods and seeds are used as cooked vegetables while several snacks and main dishes are prepared from the grains (Agbogidi and Egho, 2012). The pulses as a group constitute considerable number and diversity of crop species and are critical to smallholder livelihoods in Ethiopia (Chilot et al., 2010; Fikreselassie, 2012). The EBI (2004) has archived a total of 94 germplasm accessions of cowpea collected over the years and conserved at the gene bank for subsequent utilization in breeding and enhancement. Additionally, a total of 54 germplasm accessions and six representative botanical voucher specimens of cowpea were collected from different geographical locations of northern Ethiopia (Alemu et al., 2016) and deposited in custody of the Cowpea Research Coordination Office at Melkassa Agricultural Research Center to be given to EBI at a later date, and at the National Herbarium (ETH) of Addis Ababa University, respectively. Although Vavilov (1951) as cited by Westphal (1974) indicated that Ethiopia is a secondary center of diversity for cowpea, there is limited information regarding the diversity, ethnobotany, utilization and production status of cowpea landraces in Ethiopia at present. The main objective of this study was to identify and document the landrace diversity, the local nomenclatural systems and ethnobotanical uses of cowpea in Gambella, Oromia, Dire Dawa and SNNP Regions.

MATERIALS AND METHODS

Site and informant selection

The study sites were selected based on the ecological requirements of the crop as shown by suitability map, assistance of district agricultural office workers and accessibility of the area and the availability of time. The study was undertaken in areas distributed in four regions (Gambella, Oromia, Dire Dawa and SNNP) located in the Southwestern parts of Ethiopia. Nine administrative zones, 20 Woredas (districts) and 20 kebeles (sub district, smallest administrative unit in Ethiopia) were purposively sampled for the study. From each kebele, three cowpea farmers were randomly selected in which one of them was deliberately included with the facilitation and help of local guides and agricultural extension experts of each wereda as key informant. A total of 60 local farmers (38 males and 22 females) aged 28 to 78 were interviewed using pre-prepared semi-structured interview guide. Thus, 20 of the informants were marked as key informants and further interview and discussion was conducted with them. The questions included the local names of the landraces of cowpea that farmers cultivated and those they used to cultivate in the past, the parts used, how the parts were prepared as human food, other uses of cowpea, seed sources, methods of cultivation and management, production constraints including pests and diseases, wild forms that the farmers recognized and related aspects.

Ethnobotanical data collection

Ethnobotanical data were collected between September 2014-December 2015, following the method by Martin (1995), Alexiades (1996) and Cotton (1996). Semi-structured interviews, direct field observations and recording of information and market surveys were among the main techniques employed in data collection. During each field trip, voucher specimens were collected and dried using a plant press, a GPS was used to record the geographical coordinates and other materials including plastic bags, notebook, secateurs and a digital photo camera were used to facilitate collection of both specimens and other relevant ethnobotanical data. All of the interviews were held based on a checklist of questions prepared beforehand in English and later translated into Amharic and other languages as was necessary in the respective localities with the help of translators. Voucher specimens and seed accessions of cowpea were collected from different geographical provenances. The voucher specimens obtained from farmers' fields were used for taxonomic determination and as reference collection following IBPGR (1983) cowpea descriptor list. The georeferenced (passport data) of the crop was collected using GPS. Colored photos of cowpea accessions were also used for ease of communication with farmers and local guides regarding the identity, distribution and local names of cowpea landraces before starting the interview.

Primary data were collected from farmers' fields, threshing grounds, home gardens and local market places. Sources for secondary data were both from offices of governmental and non-governmental organizations including agriculture and rural development offices and the National Meteorological Service Agency. Additional data were sourced by further casual discussions with local communities and researchers. After taxonomic determinations, the voucher specimens were deposited at the National Herbarium (ETH), Addis Ababa University while the seed samples were delivered to Melkassa Agricultural Research Center with the understanding that the Center will eventually transfer sufficient germplasm material to the Ethiopian Biodiversity Institute (EBI) for proper safe keeping and conservation at the gene bank.

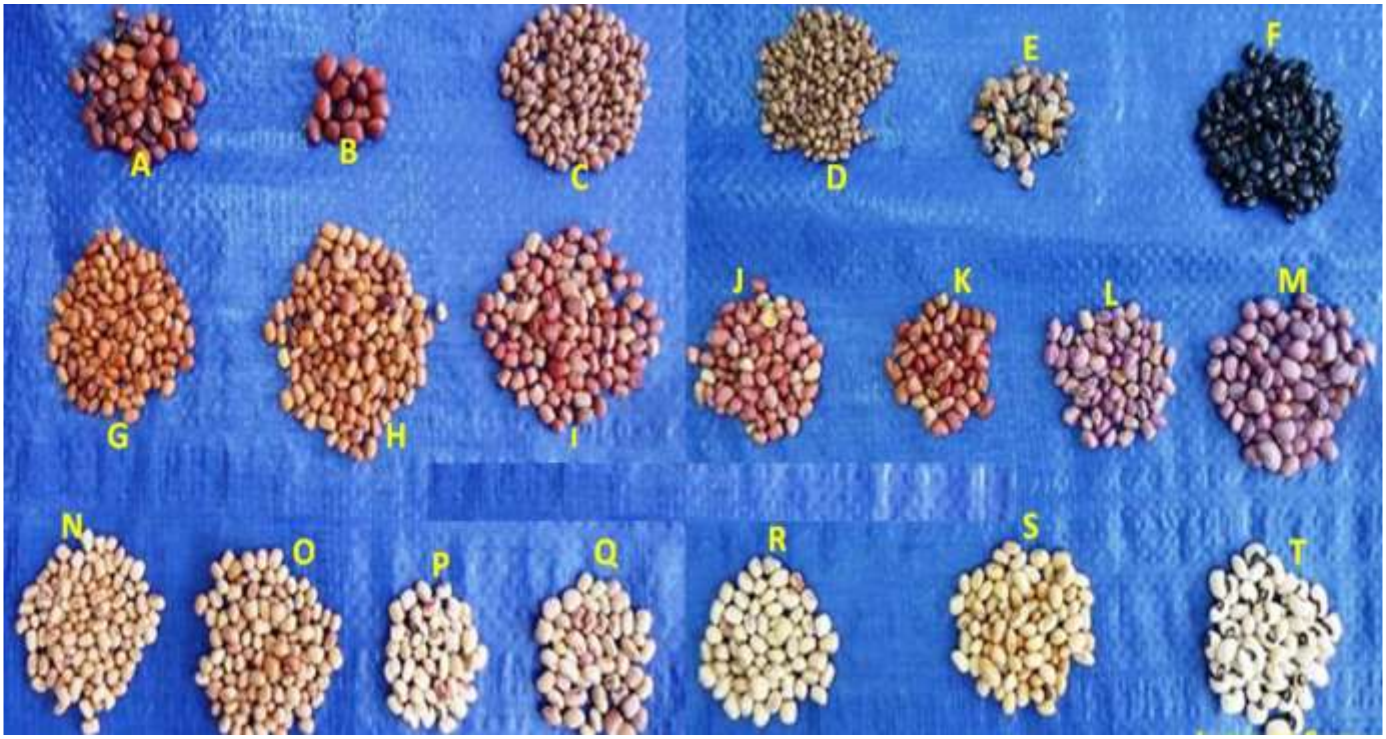

Figure 1. Seed samples and morphological variations of cowpea germplasm accessions (**A**, **B** and **P** from Gambella Region; **C**, **D**, **G**, **H**, **J**, **K**, **M** and **R** from Oromia Region; **E**, **F**, **L** and **N** from Dire Dawa Region and **I**, **O**, **Q**, **S** and **T** from SNNP Region). The details of the pictures are described in Table 1.

The collected ethnobotanical data were summarized in tables and figures and analyzed using both quantitative and qualitative approaches as recommended by Martin (1995), Cotton (1996) and Phillips (1996). Descriptive statistics, preference ranking and informant consensus tools were used to analyze the quantitative data. MS Excel 2010 was used to quantify and sort data, determine proportions, and to show the results in tabular form.

RESULTS

Cowpea landrace diversity in southwestern and eastern parts of Ethiopia

A total of 44 cowpea germplasm accessions were collected in the 20 surveyed kebeles of the four regions. Among these collections, 10 (23%) were collected from three Woredas of Gambella Region. The ten landraces collected from Gambella Region are locally called 'Rapo', 'Wenu' and 'Boho' (Anywaa language) and 16 (36%) cowpea germplasm accessions were collected from SNNPR. Additionally, in Oromia and Dire Dawa regions a total of ten Woredas were surveyed and 18 (41%) (ten from Oromia and eight from Dire Dawa) cowpea germplasm accessions namely QECHINE, 'Atera babile' and 'Atera yusufi' (Oromo language) were collected (Figures 1 and 2). The details of the pictures are described in Table 1.

Traditional nomenclature of cowpea landraces and the indigenous knowledge encoded in the names

The local names of the cowpea landraces collected from different Woredas and kebeles were different. The naming system is also based on morphological characteristics, appearance, adaptation, seed colour, growth habit, seed size, locality of source and the multipurpose nature of the crop. The names collected from the different areas together with indigenous knowledge encoded in the names are given in Tables 2 growth habit, seed size, locality of source and the multipurpose nature of the crop. The names collected from the different areas together with indigenous knowledge encoded in the names are given in Tables 2 and 3 show information retrieved on wild forms of cowpea recognized by farmers in the respective areas.

Cowpea landrace distribution in Southwestern and eastern parts of Ethiopia

The collected cowpea landraces from different geographical locations were determined using Flora of Ethiopia and Eritrea and IBPGR (1983) cowpea descriptor list. Accordingly, the collected cowpea landraces namely 'Rapo' or 'Boho' (*V. unguiculata* subsp.

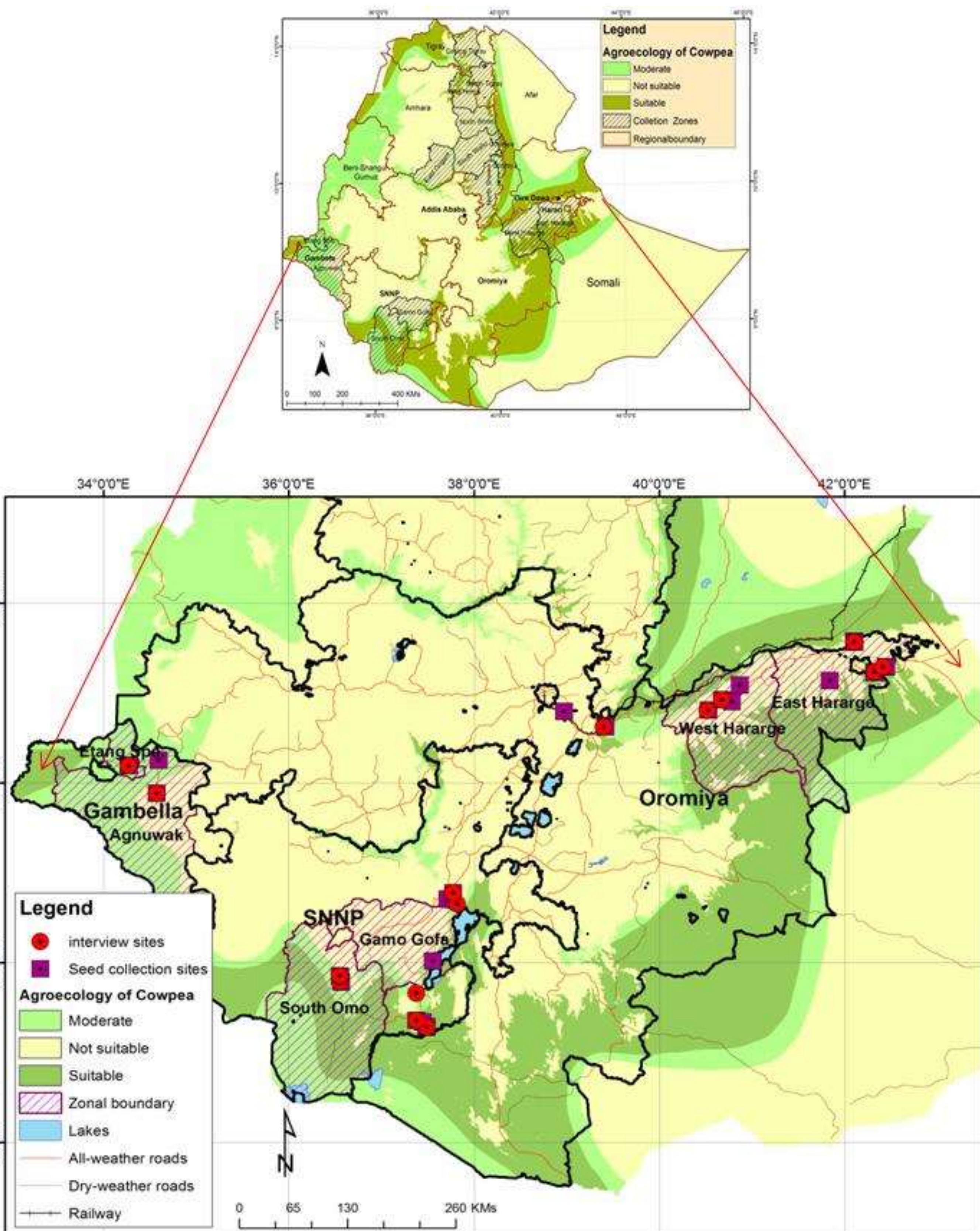

Figure 2. Map of the southern half of Ethiopia showing regional states and collection zones and districts for cowpea landraces (Map credit: Demeke Nigusse, GIS specialist, EIAR).

Table 1. Proportions of cowpea germplasm accessions collected from the four regions.

Landrace provenance	Proportions of cowpea germplasm accessions	Sample code	Local name of cowpea landraces*	Local language used in the study area
Gambella	10 (23%)	A	'Boho'	Anywaa
		B	'Rapo'	Anywaa
		P	'Wenu'	Anywaa
Oromia	10 (23%)	D	'Qechine'	Afaan Oromo
		H, J, K, M and R	'Atera yusufi'	Afaan Oromo
		C and G	'Atera babile'	Afaan Oromo
Dire dawa	8 (18%)	E, F, L and N	'Atera babile'	Afaan Oromo
SNNPR	16 (36%)	I	'Alita'	Derashigna
		O	'Ohoda'	Konsogna
		I and T	'Woqa'	Aari
		Q and S	'Aeqa'	Wolayita

Source of local name: Local informants.

dekindtiana) were found only in Gambella Region and *V. unguiculata* subsp. *cylindrica* and *V*. *unguiculata* subsp. *unguiculata* were found in all the study areas. Among the above subspecies, 'Atera babile', 'Boho', 'Ohoda', 'Qechine' and 'Woqa' (*V. unguiculata* subsp. cylindrica) and 'Aeqa', 'Alita' 'Atera yusufi' and 'Wenu' (*V. unguiculata* subsp. unguiculata) were widely distributed and found in all the regions of Southwestern and eastern parts of Ethiopia covered in this study. The distribution map (Figure 2) made using the GPS readings taken by the first author during the fieldwork shows the collection sites of the landraces.

Importance of cowpea in the Southern half of Ethiopia

Based on farmers' perception, cowpea is primarily used for human food, livestock fodder, and medicinal purpose. In Gambella and SNNP regions (South Ari and Konso special wereda) the majority of respondents (53%) used different parts of the crop (fresh leaves, young shoot and grain) for home consumption in the form of traditional foods. The remaining respondents (47%) in Oromia, Dire Dawa and SNNP regions (Wolayeta, Arbaminch zuriya and Derashe Woredas) farmers said they grew cowpea for the purpose of human food in the form of boiled grains (NIFRO) (Figure 4), local sauces as SHIRO WET or KIKE WET (split grain sauce), local soup (SHORBA) and porridge (GENFO). In addition to its human food value, the crop is also used for animal feed which can be prepared from grain and leaf. In Gambella Region (Itang and Abobo Woredas) and SNNPR (Konso and South Aari Woredas), the local farmers mostly preferred the fresh leaves of cowpea as green vegetable for home consumption to eat in the form of traditional stew and sauce. In addition, the local farmers used cowpea landrace for improving soil fertility via crop rotation and intercropping with cereals, mainly with sorghum and maize. In the areas studied, a reasonable number of respondents (23.3%) used the green leaves and seed of cowpea for medicinal purpose to cure liver disease, gastric discomfort and malarial infection. Furthermore, the farmers are using the crop for income generation including by selling the grains and the leaves in the local markets (Figure 3) and cowpea grains used as NIFRO and leaves used as cooked vegetables (Figure 4).

Farmers' seed source

Among the total respondents, the majority of local farmers (92%) used their own home saved seed and gifts from neighbours and relatives. Only 8% of the respondents said that annually they are obtaining cowpea seeds from government agricultural offices.

Production constraints and traditional management techniques

In the Southern half of Ethiopia, local farmers are facing different constraints on production and utilization of cowpea. In this connection, farmers listed major constraints such as storage pests, field insects, parasitic weeds and diseases for production and utilization of cowpea. Among these problems, diseases such as 'Guteni' (Wolayita language), 'Machole/keshekeshe'

Table 2. Traditional nomenclature of cowpea landraces and indigenous knowledge of local farmers in southwestern and eastern parts of Ethiopia.

Region	Collection Woredas (Kebeles)	GPS reading latitude and longitude (dd mm ss)	Local name of cowpea landrace	Encoded indigenous knowledge	Scientific name
Dire Dawa	Biya Awale (Belewa Kebele,)	09 29 28.2N 41 45 15.0E	'Atera babile' (Afaan Oromo)	Landrace origin	*V. unguiculata* subsp. *cylindrica*
Gambella	Abobo (Chobo Kere Kebele,)	07 53 34.8N 34 32 29.8E	'Rapo' (Anywaa)	Climbing habit that hold on to other plants	*V. unguiculata* subsp. *dekindtiana*
	Gambella Zurya (Abole Kebele,)	08 15 58.2N 342711.5E	'Boho' (Anywaa)	Climbing habit	*V. unguiculata* subsp. *dekindtiana*
	(Abole Kebele-Itang Village,)	08 11 29.4N 34 15 53.1E	'Wenu' (Anywaa)	Creeping habit	*V. unguiculata* subsp. *unguiculata*
Oromia	Ada (Godino Kebele-Boset (Dengoro Kebele)	08 51 17.4N 39 01 02.9E	'Qechine' (Afaan Oromo)	Seed morphology that is thin and small	*V. unguiculata* subsp. *cylindrical*
	Babile (Ifa Kebele,)	09 14 11.7N 42 19 06.5E	'Atera yusufi' (Afaan Oromo)	Name of a person and attractiveness of flower or seed	*V. unguiculata* subsp. *unguiculata*
	Gursum (Awdei Kebele)	09 22 06.0N 42 23 35.9E	'Atera yusufi' (Afaan Oromo)	Name of a person and attractiveness of flower or seed	*V. unguiculata* subsp. *unguiculata*
	Oda Bultum (Badessa,)	08 5216.5N 40 40 57.6E	'Atera babile' (Afaan Oromo)	Landrace origin	*V. unguiculata* subsp. *cylindrical*
	Habro (Gelemso)	08 47 08.4N 403136.6E	'Atera babile' (Afaan Oromo)	Landrace origin	*V. unguiculata* subsp. *cylindrical*
	Kurfa Chelie	09 13 51.5N 41 49 11.7E	'Atera babile' (Afaan Oromo)	Landrace origin	*V. unguiculata* subsp. *cylindrical*
SNNPR	Derashi (Walayeti Kebele)	05 38 19.2N 37 21 25.7E	'Alita' (Derashi language)	Grain legume	*V. unguiculata* subsp. *unguiculata*
	Konso (Nalyasegen Kebele)	05 21 13.2N 37 28 53.8E	'Ohoda' (Konso language)	Grain legume	*V. unguiculata* subsp. *cylindrical*
	South Aari (Aykamer Kebele)	05 50 18.8N 36 32 42.8E	'Woqa' (Aari language)	Grain legume	*V. unguiculata* subsp. *cylindrical*

Table 2. Contd.

South Aari (Geza Kebele)	05 49 06.4N 36 32 55.7E	'Woqa' (Aari language)	Grain legume	*V. unguiculata* subsp. *cylindrica*
South Aari (Yetnebershe Kebele)	05 51 42.0N 36 33 42.8E	'Woqa' (Aari language)	Grain legume	*V. unguiculata* subsp. *cylindrica*
Wolaita (Larena Kebele,)	06 41 43.9N 37 45 31.5E	'Aeqa' (Wolayita)	Seed morphology	*V. unguiculata* subsp. *unguiculata*

Table 3. Information retrieved on wild cowpea (Vigna spp.).

Local names of wild *Vigna*	Language	Encoded indigenous knowledge
'Yezinjero Boho' (boho mere ajamo/ bime/)	Anywaa (Gambella)	Monkey cowpea
'Yecha kaboho (Boho merpape),	Anywaa (Gambella)	Forest cowpea or found in forest area
'Yayete qechine'	Amharic (Dire dawa)	Mostly eaten by Rat
'Atera werabo'	Afan Oromo (East Harerege)	Mostly eaten by Monkey
'Atera werabo'	Afan Oromo (West Harerge)	Mostly eaten by Monkey
'Dikala babile'	Afan Oromo (East Harerege)	Hybrid with local cowpea
'Yechaka alita'	Wolayetigna (SNNPR)	Forest cowpea or found in forest area
'Yechaka ohoda'	Konsigna (SNNPR)	Forest cowpea or found in forest area
'Woka beysi'	Aarigna (SNNPR)	Thin seeded cowpea
'Brwoke'	Aarigna (SNNPR)	Looks like cowpea
'Turna'	Aarigna (SNNPR)	Wild cowpea
'Berbera'	Wolayetigna (SNNPR)	Wild cowpea

Source: local farmers and agricultural office experts.

(Oromo language), 'Sinta' (Anywaa language), 'Roja', 'Jegedo', 'Atorena' (Aari language) are the most important constraints that attack the leaves, grains and pods during the growth stages of the crop (Table 4). In addition, as per the information gathered from local farmer respondents the most serious problem for production and utilization of cowpea is insect pests locally known as 'Alora', 'Jore' and 'Awero' (Anywaa language) which are mainly found in Gambella Region and insect type 'Bawsha' (Aari language) is found in SNNPR. In addition to that, 'Akanchira' (*Striga* spp.), 'Astenager' (*Datura stramonium)*, 'Lemboche' (*Parthnenium* spp.), 'Asheket' (*Gallium purpureum*.) and 'Yewofenkur' (*Commelina* spp.) were recorded as weeds of cowpea (Table 4). To solve this problem, the farmers use different traditional techniques including hand weeding, combination of spreading ash with chemicals (malathion) to prevent the severity of storage pest problem. In addition, farmers reported and demonstrated that in their traditional practice they cut the shoot part of the crop to promote lateral growth which, as they say, also reduces weed infestation.

Cropping system and management

In the southern half of Ethiopia, cowpea planting

Figure 3. BOHO *(Vigna unguiculata* subsp. *dekindtiana)* cowpea landrace green leaves presented in the local market by women at Itangn town in Itang Wereda, Gambella Region.

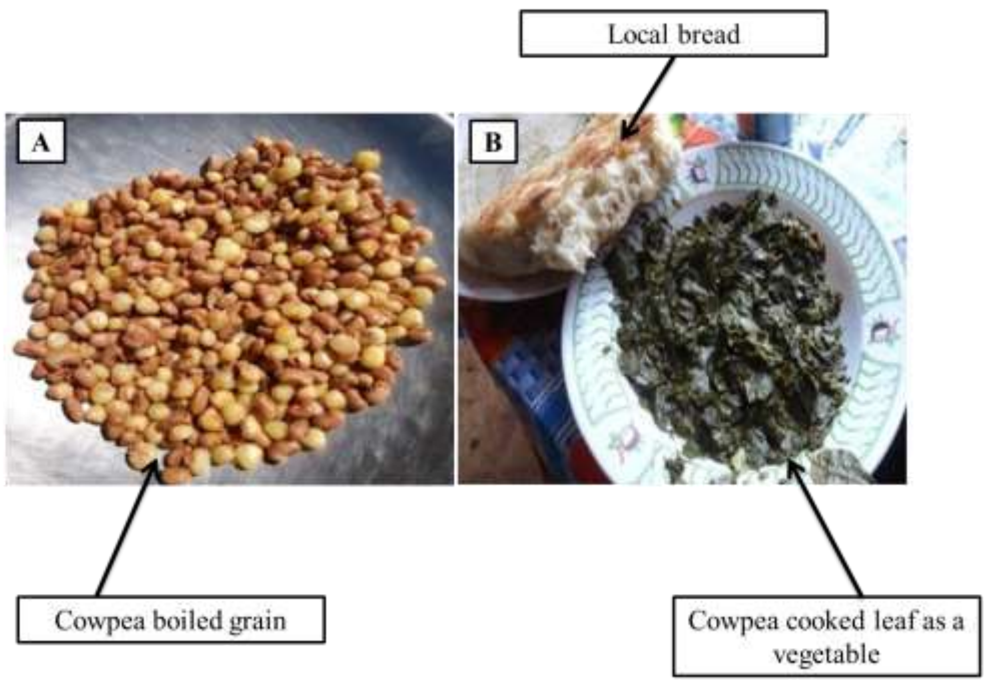

Figure 4. A) Boiled cowpea grain locally called NIFRO in Amharic used in Babile in Oromia Region; **B)** Cooked cowpea as leafy vegetable to be eaten with local bread.

begins from June and goes to September and by the end of January, all farmers harvest cowpea from the field depending on the Agroecological conditions. The majority of farmers (60%) produce cowpea using broadcast sowing, 18% use row sowing with intercropping of maize and sorghum, 12% use only hoeing and 10% use row and broadcast sowing then weeding and hoeing. About 53% of the farmers grow cowpea via sole cropping and 31% use intercropping. Intercropping is mainly with maize (60%) and sorghum (40%) (Figure 5). Farmers also used hand weeding and sometimes hoeing to reduce the severity of weeds. In addition, local farmers used crop rotation system in order to harvest diverse products, reduce weed infestation, and improve soil fertility. The

Table 4. Information on pests and diseases reported by farmers.

S/N	Pests and diseases reported by farmers in local language	Language	Region	Problem type	Mainly attached parts of cowpea
1	'Guteni'	Wolayita	SNNP	Disease	
2	'Machole/keshekeshe'	Afan Oromo	Oromia	Disease	Cowpea leaves, grains and pods
3	'Sinta'	Anywaa	Gambella	Disease	
4	'Roja', 'Jegedo', 'Atorena'	Aari	SNNP	Disease	
5	'Alora',' Jore' and 'Awero'	Anywaa	Gambella	Insect pest	Cowpea leaves
6	Bawsha	Aari	SNNP	Insect pest	Cowpea leaves
7	'Akanchira' (*Striga* spp.), 'Astenager' (*Datura* spp), 'lemboche' (*Parthnenium* spp.), 'Asheket' (*Gallium* spp.) and 'Yewofenkur' (*Commelina* spp.)	Amharic	Found in all regions of the study area	Weeds	Has a great impact of the overall growth and development of the crop via nutrient competition

Figure 5. Cowpea sole cropping in Oromia Region (Welenchiti) and intercropping with CHAT/Khat (*Catha edulis*) and Sorghum in Oromia Region (East Harerge).

majority of respondents (90%) do not use inorganic fertilizer to increase productivity of the crop. The remaining 10% of respondents used organic fertilizers (compost and manure) for better growth and development of the crop.

Farmers' perceptions and practices in relation to cowpea

From the farmers' point of view, cowpea landraces have better performances than other crops under difficult conditions and are well adapted to drought and extreme heat conditions. About 17% of the informants responded that, the crop has better performance in poor soil fertility and better resistance to grow in unusual rainfall pattern, 15% of respondents said local cowpea varieties have better adaptation to unusual timing of rainfall (early or late) and 17% of the respondents mentioned that the crop has better growth in poor soil fertility and the remaining respondents mentioned that, cowpea has an ability to grow in hailstorm area and tolerant to harsh conditions.

In the study area, farmers stated some general limitations on cultivation and utilization of cowpea in their locality. Among these, disease prevalence, extreme and frequent drought and shortage of rainfall, pest infestation, shortage of land, low production capacity and low market demand, demand for frequent weeding, problem of wild grazing animals are the most series limitations to grow cowpea for farmers. Additionally, in Gambella Region (Itang and Abobo Woredas), because of the increased use of the leaf of cowpea as a vegetable, there is a limited amount of seed production and this leads to shortage of cowpea seed for the next growing season. In order to overcome the aforementioned limitations, the local farmers reported using and suggesting different techniques such as disease preventing chemicals, herbicides, developing irrigation systems, and the culture of frequent weeding, protecting the crop from wild grazing animals, developing access to markets and raising awareness of urban dwellers to consume cowpea and its varieties.

DISCUSSION

Cowpea landrace diversity in Southwestern and eastern parts of Ethiopia

Farmers have different farming traditions and food cultures and their maintenance of cowpea subspecies and landraces are varied. Thulin (1989) reported that *V. unguiculata* subsp. *sesquipedalis* and subsp. *dekindtiana* are mainly cultivated in northern Ethiopia. The results of this study, however, showed much wider distribution than that indicated in the Flora of Ethiopia and Eritrea. In the present study, landraces belonging to 'Rapo' (*V. unguiculata* subsp. *dekindtiana)* were found only in Gambella Region. A similar study recently undertaken in northern parts of Ethiopia (Alemu et al., 2016) did not find landraces of this subspecies. On the other hand, 'Atera babile', 'Boho', 'Ohoda', 'Qechine' and 'Woqa' belonging to *V. unguiculata* subsp. *cylinderica* and AEQA, 'Alita', 'Atera yusufi' and 'Wenu' belonging to *V. unguiculata* subsp. *unguiculata* were found in the southern and eastern parts of Ethiopia. The study by Alemu et al. (2016) also showed that landraces of the latter subspecies are widely cultivated in the northern parts of the country. Similarly, the landrace diversity at the field level is greater for farmers who apply more selection criteria to define their diverse needs and requirements. In this process, both natural factors and farmers' selection criteria shape crop genetic diversity at the field and landscape levels as shown for sorghum in central Ethiopia (Teshome et al., 2015). Genetic diversity is also shaped by selections by women and men based on food quality and acceptability for various local dishes in the diverse ethnolinguistic communities found in the southern parts of the country.

As indicated in the cowpea suitability map, the crop can grow in many parts of southern Ethiopia but still the production is low because of low market demand and poor production management system i.e. cultivation as border crop as a buffer for main crops to protect them from livestock damage. In the last three decades, agricultural research and extension services favoured improved varieties. But mitigation or preservation methods suggested by Eticha et al. (2010) reported that landrace conservation can be influenced by their end-use, market demand and price. The presence of wild cowpea species in parts of the study area is another important finding that could be taken up by cowpea breeders not only for the present study areas but also for other parts of Ethiopia. Thus, the EBI can do germplasm collections and the pulse research group can include these species in their future breeding programmes.

Use values of cowpea landrace varieties

As observed in Gambella Region in this study, Chilot et al. (2010) reported that young cowpea leaves are eaten as boiled pot herbs and enjoyed in many parts of Africa. The same paper explains that freshly harvested leaves are sold in local markets in many parts of Ghana, Mali, Benin, Cameroon, Ethiopia, Uganda, Kenya, Tanzania and Malawi. Other researchers have shown that cowpea young shoots and leaves are rich sources of calcium, phosphorous and Vitamin B (Barrett, 1987). The young leaves are especially important in drought-prone regions of Sub-Saharan Africa as they are used the local populations to bridge and pass over the "hungry period" which usually occurs after planting but before the main harvest of fresh pods and dry grains. Similarly, this research showed that the leaves and young shoots of local landraces including RAPO, BOHO and WENU in Gambella and OHODA in Konso Woreda are mainly used as leafy vegetables for home consumption. In addition, in Gamo Gofa and Wolaita zones and Oromia Region, farmers use the seeds of cowpea for food and leaves and crop residue as fodder for their livestock. Prepared food types from cowpea are mostly boiled grain locally known as NIFRO and KIKE WET (Amharic language) in all study sites. In Woredas found in Dire Dawa and East and West Harerge farmers' variety 'Atera babile' is used to prepare traditional sauce. In South Aari Wereda, the variety WOQA is used by the local community as cultural foods known as 'Ayebza' and 'Zegola'. Similarly, farmers' variety 'Ohoda' in Konso Wereda, ALITA in Derashe Wereda, AEQA in Wolayita are used as local food preparations known as 'Changa', 'Kurkufa' and 'Polando' (POCHE/HOCHE) respectively. Accordingly, 23% of respondents said that cowpea variety 'Boho' and 'Atera babile' are mainly used for medicinal purpose in Gambella, Oromia and Dire Dawa regions by using green leaf for treating human liver pain and local farmers use cowpea seed to treat malaria pain and gastric discomforts.

Cowpea cultivation and management

Cowpea cultivation and management practices such as crop rotation and intercropping with maize and sorghum are the major practices which are mainly used by the local farmers in the study areas. In Gambella and eastern Oromia region (West Harerge Zone), farmers do not use any crop rotation system instead they use intercropping with sorghum and maize to maximize and optimize space utilization due to the shortage of land they face. In contrast, all SNNPR and East Shewa and East Harerege zones farmers used crop rotation system for the purpose of enhancing or improving soil fertility, reducing weed infestation and to boost production. SNNPR, South Omo and Wolayita zones and in Gambella Region, farmers used broadcast sowing method and hand weeding to manage cowpea farm land. Likewise, in West and East Harerge zones farmers used row planting method via intercropping with sorghum and maize. In East Shewa Zone, Boset Wereda farmers used broadcast sowing and hoeing. Farmers in SNNPR, Segen Peoples Zone, Konso and Gidole Woredas used combination of row and broadcast sowing methods. Intercropping cowpea with sorghum has been adopted in Cameroon to show the effects on suppression of parasitic weeds (Carsky et al., 1994). The results indicated that the ground cover ranged from 20 to 80% and the density of mature capsule-bearing *Striga* plants was low when the cowpea ground cover was high. This suggested that any spatial arrangement that increases cowpea ground cover at the base of the sorghum plants can reduce the density of mature *Striga hermonthica* (Carsky et al., 1994). This technique can be adopted by Ethiopian farmers (particularly in the north) where the case of *Striga* in sorghum fields is very serious.

Sole-crops are becoming important as cowpea production is commercialized to meet the demands of a rapidly increasing urban population. In Senegal, most cowpea is sole-cropped (Thiaw et al., 1993). Intercropping is an important agricultural technique that improves diversification of food supply and ensures high economic returns. It also suppresses weeds particularly when short stature, bushy cowpea varieties are used (Zimdahl, 1999). Our research results showed that, in Welayita Zone of SNNPR and Gambella Region, all farmers grow cowpea crop as sole-cropping method and in Konso and South Aari Woredas cowpea is mainly grown as intercropping with maize and sorghum. In Oromia Region, except Boset wereda, all farmers produced cowpea via intercropping with sorghum and maize.

Women's contribution to maintenance of cowpea diversity

It should be noted that in Ethiopia women are the one and only members of the households who are fully responsible for the processing of food and beverages. Women's contribution in agriculture and their decisions about the utilization of biological resources to satisfy the needs of rural households are often ignored (Eticha et al., 2010). In this study, 22 (37%) respondents were female farmers who were better suited to describe the landraces particularly in regard to the organoleptic properties of the edible parts, flour taste, cooking characteristics and preparation of cultural foods, while men had better knowledge about agronomic traits such as plant height, maturity, disease tolerance, threshing quality, yield performance and straw quality. In SNNPR and Gambella regions, women have the bulk of responsibilities both in the farm and household activities including weeding, hoeing and harvesting, grain separation and treating and handling the grain during storage using ash and/or Malathion.

Cowpea cultivation advantages

Cowpea is a grain legume which is highly drought resistant and tolerates a wide range of soil types (Kolawole et al., 2000; Zuofa et al., 2000; Mashingaidze, 2004). This research result also showed that, in the study areas cowpea landraces have ability to tolerate pests, diseases and weeds. Cowpea can perform better than other crops under difficult conditions because of its ability to adapt to extreme drought and heat occurrence; it can grow in poor soil fertility areas, unusual rainfall pattern and in hilly stone areas such as those observed in Dire Dawa and Gambella regions in particular.

Production constraint and traditional management technique

Cowpea is faced with so many constraints, such as diseases and the limited use of fertilizers and irrigation input for the sake of cowpea production and utilization as mentioned by Brisibe et al. (2011), insect pests are one of the major constraints for cowpea production in southern parts of Ethiopia. Cultural management techniques of local farmers on disease, insect and weeds are less emphasized by wereda agricultural office experts on field protection of the crop. Similar results were reported by Singh and Allen (1982), fungal diseases, seedling mortality disease, stem, root and foot rots (*Anthracnose)* disease, *Phthium* and *Sclerotium* stem rot, Wilts (*Fusarium wilts*), leaf diseases; like *Cercospora* leaf spot Target spot, *Septoria* leaf spot, and *Dactuliophora* leaf spot. In Africa, *Striga gesneriodes* and *Alectra vogelii* are the most known weed species which affect cowpea production (Duruigbo, 2010; Timko and Singh, 2008; Dudu, 1996). After some periodic exposure to the sun of grains in order to remove pest and putting the seed in closed stone pots, tins or plastic bottles; seeds were mixed with DDT and some preservative chemicals supplied from agricultural input suppliers to prevent post-harvest pests. Accordingly, in SNNPR leaf and seed diseases locally known as GUTENI and SINTA are the most common problems in Wolayita and South Aari Woredas respectively; seed disease namely 'Roja', 'Jegedo', 'Atorena' in South Aari Woreda were recorded and similarly in Oromia Region leaf and seed disease called 'Machole' and 'Keshekeshe' were reported. Common insect pests found in Gambella Region are locally known as 'Alora', 'Awero' and 'Jore' (Anywaa language). Insect pests in SNNPR are a common problem and locally called BAWSHA and wild nocturnal grazing animals and this is also found in Oromia Region as pests which mainly attack cowpea plants.

Conclusion

In the study area, cowpea is a multipurpose crop where the green leaves are primarily used as cooked vegetables and the crop also has medicinal uses in parts of the study area. In addition, the majority of local farmers use the grain of cowpea for home consumption and for livestock feed. *V. unguiculata* subsp. *unguiculata* farmers' variety ATERA BABILE is preferred by the majority of farmers because of the spreading nature of the crop, ability to produce more leaves than other varieties, improving soil fertility and ability to supersede weeds as a ground cover. Could this preference of farmers for soil fertility improvement have relation to more nodulating ability of this landrace? Further research that compares this landrace with others may throw some lights in this regard. This study discovered that, there is a moderate existence of important diversified cowpea landraces but the production coverage has been declining over the year as affirmed by farmers. Local farmers mainly grew cowpea in marginal land and crop protection mechanism of cowpea is underdeveloped. The decrease in production is due to limited use of improved inputs, small fragmented plots, sowing in marginal soils, inadequate farm management practices and gaps in scientific knowledge of local farmers and agricultural extension agents. The agricultural research system must be keen towards such crops that play multiple roles in the field, at market places and at home. The wild *Vigna* spp. that farmers talked about also need further studies for possible useful traits and use in the development of feed and as breeding stocks.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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