A Decade of Research Progress in Chickpea and Lentil Breeding and Genetics

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This paper summarizes achievements of chickpea and lentil breeding during the last decade /2005-2015/ in Ethiopia. Gentic yield gains from decadal breeding efforts were 80 kg/ha/year for chickpea and 52 kg/ha/yr for lentil. The germplasm enhancment and subsequent variety evaluation verification programs during the decade resulted in releases of 17 chickpea and 2 lentil varieties. These advanced varieties, when applied in production system with proper crop managment and protection practices, almost doubled productivity per unit area at farm level.

Keywords: Chickpea, lentil, germplasm, geneticgain, variety

Introduction

Chickpea and lentil are among key market pulse products of Ethiopia. They account for 23% of total pulses produced in 2014 (CSA, 2014). The two pulses have recently played significant roles both in local and foreign markets. Farmers in Ethiopia produce chickpea and lentil mostly for market and agro-processing. According to the Ethiopian Revenue Authority, the two crops have been generating revenue of about 50 million USD per annum on last dates of the decade. It was also noticed that these pulses have lower production cost as compared to cereals and they also save a significant amount of nitrogen fertilizer for subsequent cereals.

Chickpea and lentil share similar production geographies and over the last decade the total area has increased by 27% and 39% and production by 65% and 57 % for chickpea and lentil, respectively (CSA 2005-2014). Currently, 1.8 million households are producing chickpea and lentil combined on some 360, 000 hectares of land. On area basis, chickpea is mainly grown in Amhara (52.5%), Oromia (40.5%), SNNP and Tigry regions (Fikre, 2014). Whereas, 95 % of the lentil production is mainly concentrated in two regions; Amhara (52%) and Oromiya (43 %) (CSA 2016). Chickpea is largely grown in rainfed areas on residual soil moisture. Trials on optimum planting dates and associated crop husbandry practices have shown yield advantages of up to 100%. Advancing planting date by at least one month increased productivity significantly as it avoids terminal drought stress. However, advancing the planting date may lead to excess soil moisture at the early growth phase which needs to be properly managed.

The periodic profitability of chickpea production increased from 20,000 Birr ha^{-1} at the beginning of the decade to the current level of 90,000 Birr ha^{-1}, indicating positive and significant production gains. The periodic increment in profitability is, apparently attributed to the continuous technology flow into the farming system. Despite the profitability, however, the market potential, particularly of chickpea snacks/salads, green pea and *shiro*, is not yet fully explored.

Ethiopia is the largest producer, consumer and exporter of chickpea and lentil in Africa, and is among the top ten most important producers in the world (FAOSTAT, 2011). Ethiopian chickpea production is changing from traditional varieties to improved varieties and from the Desi type to the Kabuli type. The farmers have been increasingly using market-preferred varieties and adopting improved crop production practices recommended by researchers. Both crops are known for soil nitrogen enrichment and offer several integrative advantages with cereals. It is also an important source of diet and consumed in Ethiopian different preparations like snacks, curry, blend to bread/Enjera powder, green pea, and salad just to mention some. An assessment of producer's demand show that they are opting more for Kabuli chickpeas (Damte, 2009) tto Desi. The Kabuli types had negligible share two decades ago, but now is estimated to occupy above 1/3 of the total area (Fikre, 2014). This trend of area coverage increment is expected to continue, and Kabuli chickpea area may outsmart the Desi type in the near future. There is also a growing demand for extra-large seeded kabuli chickpea premium marketwise.

Chickpea production has shown steady increase during the past decade with currently reaching more than 400,000t $year^{-1}$. The major contributor to this increase in production is the remarkable improvement in productivity than the expansion in area. The average productivity, which is close to 2 t ha^{-1}, is now comparable to many cereals which are produced under intensive input system. The productivity in Ethiopia stands among the highest in the world and is almost double than the global average. The advantages recognized by farmers in chickpea cultivation include: (a) low input requirements and production cost compared to other crops, (b) low requirement of synthetic fertilizers, (c) improvement and sustainability of soil fertility, (d) growing chickpea demand due to increasing domestic consumption and export, (e) dependable feed protein source, and (f) increasing market prices. This report summarizes recent efforts and achievements that are not covered in our recent review paper (Keneni *et al*., 2016).

Achievement in Variety Development

The national chickpea and lentil research program came up with 17 superior varieties of chickpea and 2 varieties of lentil during the decade. The new chickpea varieties have comparative advantages in terms of earliness, Aschochyta blight tolerance, seed size, grain yield, suitability for mechanization and rust resistance among others (Table 1). The advance in release of chickpea variety for the last decade revealed that 9 Kabili type and 8 Desi tape chickpeas have been released for production. The release of the chickpea varieties so far was also based on product concepts and market oriented. Despite the release of several improved varieties, however, the variety replacement rate of both chickpea and lentil is reasonably low. The genetic gains from breeding is also low as compared to the expectation. This calls for improving breeding progress for economic attributes on one hand and effective promotion of the available technologies on the other.

Advances in Genetic Studies using genomic tools

A lot of information has been generated in the process of evaluation of available germplasm resources for different objectives during the decade. Close to 3000 germplasm resources including accessions have been employed under different breeding and evaluation schemes. Teshome (2014) conducted genotypic and phenotypic analysis of 1035 accessions of Ethiopian origin chickpea genetic resources using SNP markers and mapped into 6 phylogenic clusters of the 1035 accessions and 158 core derivatives, having 86% representation, for systematic exploitation in the breeding program. Based on the genogram map distances, existence of a sizable genetic diversity was confirmed in the Ethiopian chickpea accessions (Figure 1).

Keneni *et al.* (2011) profiled the genetic basis of 130 diverse germplams resources for response to infestation by adzuki bean beetle (*Callosobruchus chinensis* L.) and clustered them into three distinct groups. The same study found that there was a significant diversity in the genetic resources that could go through breeding-based enhancement. Heritable host diversity for Rhizobium association capacity among chickpea genotypes were also found with a good level of yield impact (Keneni, 2013; Girma, 2015) which are

Table 1. Description of chickpea varieties released between 2005 and 2016)

Official name of release	Year of release	source of the materials	Genetic background (parentage, pedigree, ancestry)	Area of potential coverage (ha)	Area of actual coverage estimate (ha)	Average yield potential kg/ha (on-farm)	Varietal driver traits(selected characteristics)
Hora	2016	ICARDA	X2000TH50FLIP98-52C X FLIP98-12C		New		Yield potential
Dimtu	2016	ICRISAT	ICCV-93954 X ICC –5003		New		Yield and big seed size
Dhera	2016	ICARDA	X98TH30FLIP-93-55C XS-96231		New		Quality and mechanical harvest
Teketay	2013	ICRISAT	JG-74 X ICCL-83105		200	2200	Potential yield
Dalota	2013	ICRISAT	ICCX-940002-F5-242PO-1-1-01		200	2300	Potential yield
Kobo	2012	ICRISAT				1800	Drought stress agroecology
Akuri	2011	ICRISAT	ICCV03402		1000	1850	Drought stress agroecology
Kassech	2011	ICRISAT	FLIP 95-31C		1000	1800	Drought stress agroecology
Minjar (D)	2010	ICRISAT	ICC97103		10000	1900	Aschochyta tolerance, drought resistance
Acos dubie(K)	2009	PVT/ Mexico	Monino	10000	2000	1800	Extra big seed size, best niche market
Natoli(D)	2007	ICRISAT	ICCX-910112-6	25000	20000	3000	Productivity, seed quality, root rot tolerance
*Mastewal(D)	2006	ICRISAT	ICCV-92006	5000	20000	2000	Better yield and seed quality
*Fetenech(K)	2006	ICRISAT	ICCV-92069		-	1750	Better yield and seed quality
*Yelibe(K)	2006	ICRISAT	ICCV-14808		-	1750	Better yield and seed quality
*Kutaye(D)	2005	ICRISAT	ICCV-92033		-	1640	Better yield and seed quality
Teji (K)	2005	ICARDA	FLIP-97-266c	2000	212	1750	Quality seed, better yield, root rot tolerance
Ejere(K)	2005	ICARDA	FLIP-97-263c	3000	5295	2250	Yield, aschochyta tolerance, earliness
lentil							
Dembi	2013	ICARDA	EL-142 X R-186-3	New			Yield potential and rust tolerance
Derso	2010	ICARDA	Alemaya X FLIP 41L AK-14		2500	2500	Yield potential and rust tolerance

*D = Desi type, K = Kabuli type

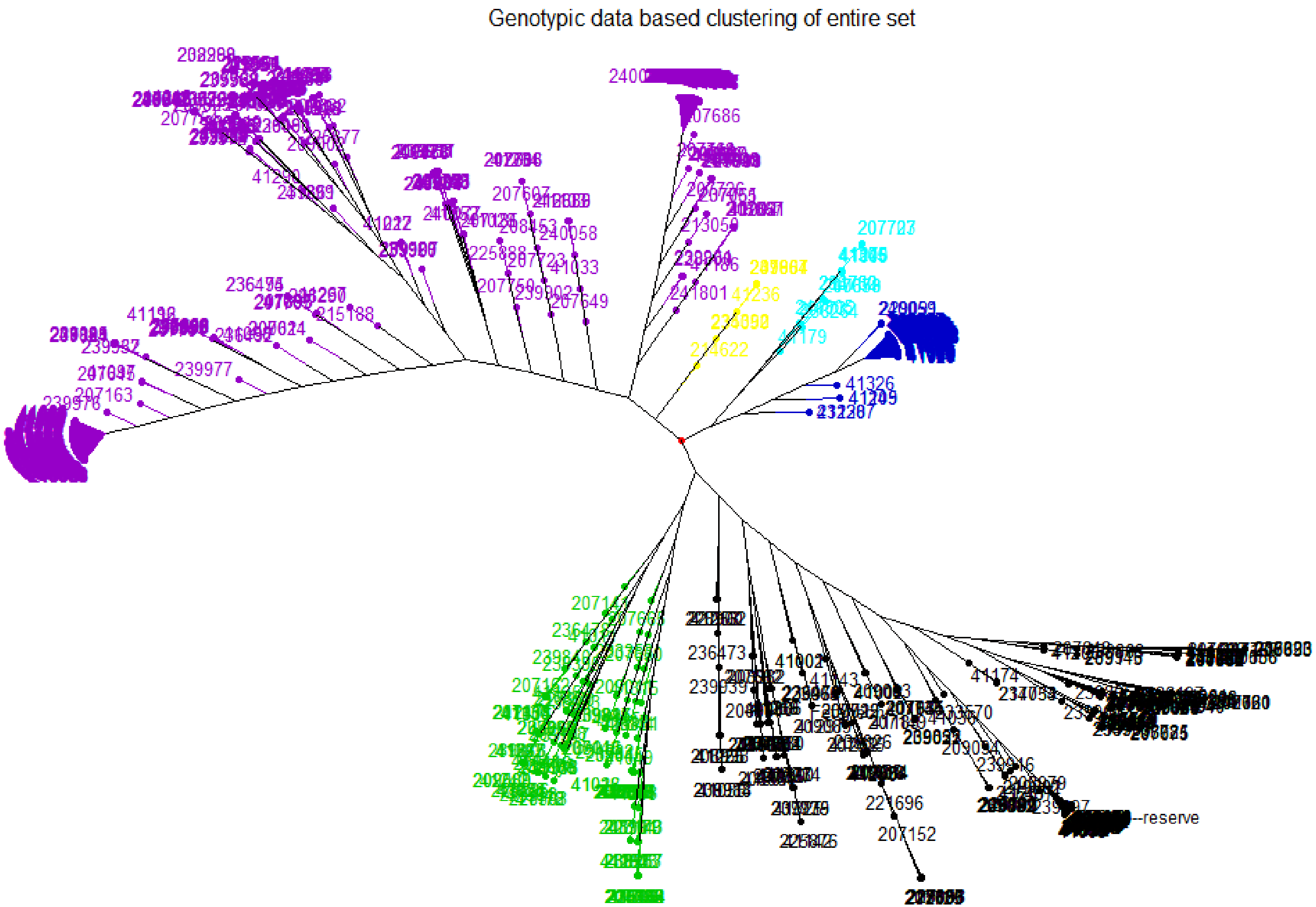

Figure 1. Genogram of Ethiopian chickpea germplasm collections (Source: Teshome, 2014)

important parameters in chickpea production. Genetic variability in germination power of some commercial cultivars with seed priming treatment was also examined. The result showed high differences for response to germination treatment among the tested genotypes (DZ-10-4, Arerti, Habru, DZ-10-11, Akaki and Natoli). Moreover, seedling vigor index in all varieties (except DZ-10-4 and Habru) and yield was improved (15%) using hydro-priming (Sori, 2014).

Farm level productivity for grain yield has been increasing by 80 kg/ha/yr for chickpea and 52 kg/ha/yr for lentil (Figure 2). This productivity gain is by far greater than improvements during the previous decades as reported by Fikre (2016), implying that the current decade demonstrated better progress to the previous decades. The productivity gain of chickpea and lentil was positive being almost closer to double during the last few decades (Admasu *et al*., 2015; Fikre, 2016). The increment is considered as the impact of the increased use of improved varieties with better biomass partitioning power and crop management and proper crop protection packages. Admasu (2015) estimated genetic gain of lentil varieties released during the last 3 decades to be 18.02 kg ha^{-1} $year^{-1}$ at Enewari and 27.82 kg ha^{-1} $year^{-1}$ at Debre Zeit, suggesting that the breeding effort does not have a similar effect over locations. There has also been information on nutritional quality differences of chickpea and lentil cultivars developed so far. Olika (2014) reported that the crude protein for Arerti (Kabuli) was 19.59 %, crude fiber was 3.87% and the fat content was 8.17%. The corresponding values for Natoli (Desi) were 16.78 %, 5.32 % and 6.59 %, respectively. The same study found that Arerti had better nutritional quality (in terms of low anti-nutritional factors) short cooking time as compared to Natoli variety.

Genotype by environmental interaction effects were found to be significant for germplasm lines evaluated in divergence agro-ecologies (Tilahun *et al*., 2015; Tadesse *et al*., 2016), indicating the need for multiple year multi-location yield trial. The national chickpea and lentil research program, in collaboration with key partners, has come up with the integration of modern breeding tools into the breeding system. In collaboration with the Tropical Legume III (TL III) project which is managed by ICRISAT, marker-based breeding (MABC,MARS) has been mainstreamed into the national chickpea breeding program since 2011. There have been attempts to improving drought tolerance capacity of otherwise well adapted varieties. To this effect one genomic region harboring quantitative trait loci for several drought tolerance traits has been identified (Thudi *et al*., 2014).

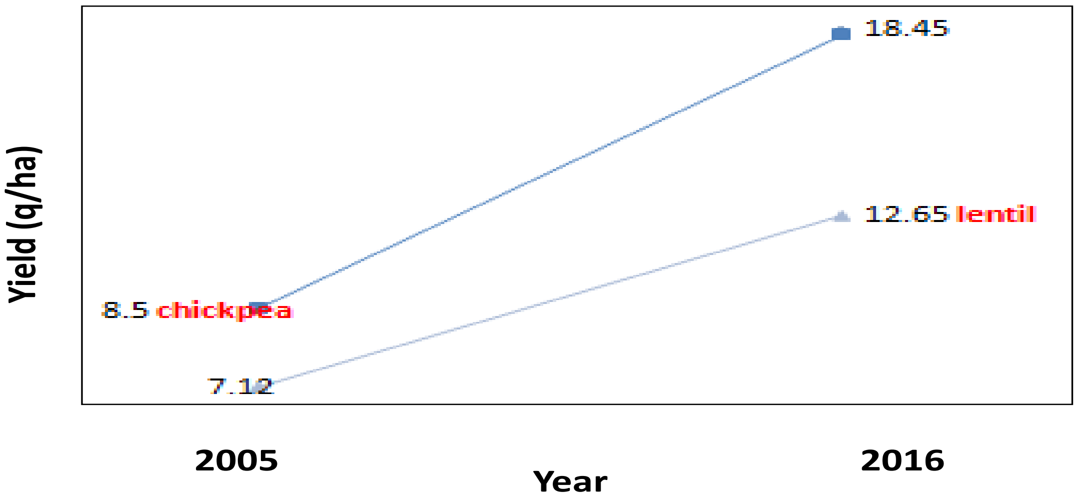

Figure 2. Trends in grain yield (q/ha) in chickpea and lentil during the last decade (Source: modified from CSA 2005-2016)

Advances in Germplasm Pool Enhancement

The identified QTL for drought tolerance was successfully introgressed using the marker-assisted backcrossing approach into three prominent chickpea varieties (JG 11, Chefe and KAK 2), Chefe being a released variety in Ethiopia in 2004. A multi-location evaluation of the lines developed through marker-assisted backcrossing exhibited 10–24% higher grain yield than their respective recurrent parents (Thudi *et al*., 2014). Currently, the national program is embracing marker-assisted breeding where lines developed reached at an advanced stage and soon the research program is expected to come up with a candidate variety for release.

On the other hand,) the recent development of wild x cultivated cultivar crossing as stated reverse introgression means to restore gentic diversity pools again, has been initiated since 2014 in collaboration with the University of California Davis through Feed the Future, Chickpea Innovation Lab (FtF), to further broaden the genetic diversity of the domesticated chickpea gene pool. Ecological mining of the gene pool was made and characterized (Eric *et al* 2018) to set inter-crossing to migrate desirable traits. The wild x cultivated introgression approach combines: (1) systematic survey of wild diversity, and (2) introgression of a representative set of wild genotypes. A total of 26 diverse wild donors of *C. reticulatum* (20) and *C. echinospermum* (6) were selected from 270 wild accessions based on their genomic sequence information and the ecology of their origin. Each of the 26 wild founders were crossed to two Ethiopian elite cultivars (Habru and Minjar), and the super early India genotype (ICCV-96029). Involving three parents (ICCV 96029, Habru and Minjar) in the crossing, a total of 43 F_1:F_2 introgressed lineages/families were created, which gave rise to more than 11,000 individual introgressed appreciably segregating individuals (Table 2 and Figure 2). At the F_2 stage, a subset of progenies within each lineage was intercrossed to increase chromosomal recombination and thus genetic power in the resulting populations. To this end, a total of 906 intercrossed first filial (iF_1) generation were created on top of the selfing F_2 populations. In parallel, F_2s were grown separately to establish early generation segregant (EGS) populations (F_2:F_4) and field phenotyping has been underway at Debre Zeit (Ethiopia) and ICRISAT (India).The wild x cultivated introgression is on its level of advancement as promising means of gene pool enhancement for the obvious narrow genetic bases in chickpea (Sharma *et al*., 2013), thereby enhancing genetic gain through the breeding program. Populations of extremely diverse make up have been generated and giving hope of sources to combat some standing challenges in chickpea. As part of the genetic base enhancement for favorable genes, there has also been Multi-parent Advanced Generation Inter-cross /MAGIC/ population development initiatives designed and proceeded since 2014/15 in the program using four way crosses which would go far un tapped genetic gains using 8 founder Kabuli released parents for crossing: (A). Arerti, (B). Habru, (C). Ejere, (D). Chefe, (E). Shasho, (F). Acos Dubie, (G). Teji and (H). Yelibe (Figure3). Besides, the national chickpea research program, with other partners, is making 50-100 crosses yearly on developing multiple trait target population, which enhance the germplasm enhancement leading to effective genetic gain. Along this, there are close to 2000 germplasm resources within the program that could be ready for variety development.

Table 2. Wild x cultivated introgression, introgressed (iF1) population advancement under three elite cultivars background

Parental combination	No of introgressed family (W x C)	No of individuals per family (F_1:F_2)	Total no of F_3 individuals established (F_3)	No of putative intercrossed seeds (iF_1)
Wild x Habru	14	125	2,875	218
Wild x Minjar	9	85	2275	281
Wild x ICCV 96029	20	321	6815	407
Total	**43**	**531**	**>11,000**	**906**

Figure 2. Appreciable morphological, phenological, ideotypical and color variability in *C.reticulatum/echinospermum* X *C. arietinum* introgressed resources

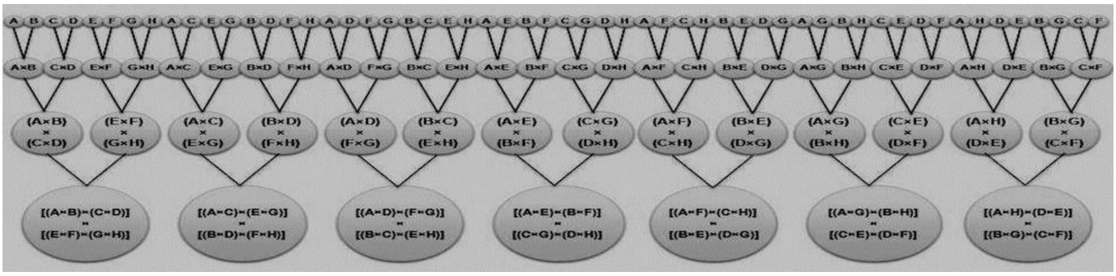

Figure 3. MAGIC population development design

Gentic Variability for Symbiotic Nitrogen Fixation

Niguse *et al*. (2016) reported that estimate of the magnitude of heterosis for host nitrogen fixation and yield and yield associated traits in chickpea from six F_1 crosses obtained from crossing of four parents (two nodulated and 2 non-nodulated) in a half-diallel showed significant ($P < 0.05$) differences among the entries for all traits studied. Considering key traits, relative to the mid-parent (MPH), better parent (BPH) and standard heterosis (SH), ranged from 0.01 to 59.80. The hybrid ICC5003 x ICC19180 scored the highest heterosis for number of nodules on the basis of MPH and BPH and demonstrated positive and significant Specific Combining Ability (SCA) effects for key economic traits including grain yield. Another study on the combination of four rhizobial inoculant (EAL-029, ICRE-025, ICRE-03 and ICRE05) and three chickpea cultivars (Natoli, Teketay and ICC-4918), indicated existence of significant genotype by strain interaction.

Food Quality Characteristics of Improved Varieties

The released varieties were evaluated for food quality characteristics including soak absorption and cooking time. The result showed varieties released over time demonstrate existence of considerable variability for these traits (Table 3). Cooking time among newly released varieties ranged from 22 to 37 minutes, indicating possibilities to shorted cooking time through selection thereby save fuel.

Table 3. Cooking time and associated parameters in recent released cultivars.

Chickpea varieties	TKW (g)	Soak absorption (%)	Cooking time (min.)
DZ-00155/08 (Minjar)	208.075	211.28	22
DZ-2012 CK-031/ICCV-10107 (Dimtu)	333.02	207.85	20.33
DZ-00156/08 (Ejere)	400.245	206.39	25.33
DZ-2012 CK-001/FLIP 04-9C (Hora)	413.105	204.01	24.67
DZ-10-4/DZ-00158/08	130.88	213.28	37
DZ-2012 CK-009/FLIP 0163 (Dehra)	387.74	206.97	25
DZ-00160-08 (local check)	128.67	207.89	22

Source: TLIII annual report (2017)

Nutritional studies on released cultivars also showed different nutritional compositions. Comparing two popular Kabuli (Arerti) and Desi (Natoli) varieties of chickpea through proximate analysis indicated the highest moisture content, ash, crude protein, crude fat, energy, zinc and iron respectively was 9.07%, 3.87%, 21.78%, 7.41%, 366.46 k cal/100 g, 7.15 and 10.88 mg/kg in Arerti (Olika, 2014). However, Arerti had lower crude fiber, total carbohydrate, calcium, tannin and phytic acid (4.71%, 53.16%, 1545.58 mg/kg, 0.13% and 84.61mg/100g, respectively). Moreover, the same variety exhibited higher bulk density, hydration capacity, swelling capacity, hydration coefficient and swelling coefficient (0.47 g/ml, 0.26 g/seeds, 0.34 ml/seeds, 1.94 and 1.96, respectively) and lower water absorption capacity, oil absorption capacity, solubility, swelling power, hydration index, swelling index, un-hydrated seeds and cooking time (1.43 g/g, 1.94 g/g, 25.19 % , 13.01% 0.28, 0.35, 1.64% and 21 min, respectively). Natoli was found to have higher crude fiber, total carbohydrate, calcium, tannin and phytic acid (6.91%, 58.65%, 1545.58 mg/kg, 0.19 %, and 91.95 mg/100 g, respectively). The main factors of variety by processing methods significantly influenced the proximate composition, mineral, anti-nutritional factor and functional properties of improved chickpeas (Olika, 2014). The results indicated that boiling was the most effective and recommendable technique in reducing ant-nutritional factors. Under different processing treatments, Arerti variety exhibited low ant-nutritional concentrations. Hence, it can be used as raw material in the food processing industries in production of quality food formulation especially conventional flours which are low in protein to increase utilization of improved chickpea flour, thereby alleviating protein malnutrition in developing countries like Ethiopia. Protein contents of two improved chickpea varieties exhibited significant ($p < 0.05$) difference with values of 15.63 % and 21.78 % for Natoli and Arerti, respectively

Another similar study by Admasu *et al*. (2014) on two popular varieties of lentil showed that the varieties Alemaya and Derso contained 4.64 and 3.14% total ash, 27.18 and 26.86% crude protein, 1.76 and 0.75% crude fat, 4.97 and 3.65% crude fiber, and 61.45 and 65.60% carbohydrates contents respectively.

Conclusion and Future Prospects

Chickpea and lentil breeding in the last decade have resulted in releases of varieties that are adopted, increased farm level productivity, economic benefits and impact. Use of modern breeding tools stimulated and enhanced development of several chickpea germplasm with desirable traits. This indicated that the traditional breeding that brought good level of success may not provide ending solutions to some of the complicated problems unless new breeding tools are applied. Longstanding biotic challenges including Ascochyta blight (*Ascochyta rabiei*)), Fusarium wilt (*Fusarium oxysporum* f.sp. *ciceris*) and lentil rust (*Uromyces viciae-fabae*), chlorotic dwarf virus and abiotic stresses including heat and drought need further focus.

Diversified demands from the farming community and other users urge for modernization of the production, processing system, and the product concept approach. Recent initiatives like breeding program modernization (BMGF), wild gene source massive intrograssion, breeding management system, electronic data capturing, and value addition are hoped to provide ending solution to some of the problems.

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