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Sorghum [Sorghum bicolor (L.)] Breeding in Ethiopia: Review

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Abstract
Sorghum [Sorghum bicolor (L)] is fifth important cereal crop belonging to monocotyledon grass Poaceae family adapted to arid and semi-arid where other cereal crops cannot survive; serving as staple food for millions of Sub Saharan Africa and Asian countries where food security is rampant. The crop is indigenous to Ethiopian as far as its domestication has long time and genetic diversity exhibited variation among cultivated and wild relatives of the crop concentrated in the country. The existence of tremendous amount sorghum variability exhibiting native genetic variation to drought, disease and insect resistance, having good grain quality and high lysine, made Ethiopia as genetic resource reservoir ranking first in contributing germplasm collection worldwide in today's sorghum breeding program. Ethiopian 'zera zera' sorghum landraces and line developed from them being involved in hybrid development at ICRISAT and other countries in modern sorghum breeding program. Currently, sorghum is the third important cereal crop in both area coverage and production becoming the second in 'injera' making after 'tef' in Ethiopia. Sorghum breeding in Ethiopia has a long history began at Alemaya College of Agriculture and germplasma provision through collection started by Jimma Agricultural Technical School. The establishment of ESIP with fully funded by IDRC, formalized sorghum research in Ethiopia in early 1970s. In last four decades since today, considerable sorghum breeding progress has been made by dividing the sorghum growing areas in to four major traditional agro ecologies: dry lowland, humid lowland, intermediate altitude and high elevation areas. Problem identification and breeding strategy has been conducted according to categorized agro ecologies and efforts has been made in developing high yielder variety, resistance breeding viz drought, disease, insect and striga from existing genetic variability in local landraces and introduced materials. Beginning in early 1970s to date which was accounted about four decades, in sorghum breeding program about forty nine (49) improved sorghum varieties with various desirable characteristics were released for the four major agro ecologies. However, sorghum breeding in Ethiopia still not advanced using the existing genetically diverse sorghum resource. Particularly, application of Biotechnology in crop improvement is limited; hence reviewer recommended that further crop improvement using advanced breeding technology to be considered accordingly.
Keywords: Variability, *Sorghum bicolor*

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L) Moench) is an important cereal crop belonging to the grass family *Poaceae.* It is naturally self-pollinated monocotyledon crop plant with the degree of spontaneous cross pollination, in some cases, reaching up to 30% depending on panicle type (Poehlman and Sleper, 1995). The annual domesticated sorghums is diploid (2n = 2x = 20) and tropical origin C4 crop (Dicko *et al.,* 2006). Sorghum is fifth most important cereal crop globally after rice, wheat, barley and maize (FAO, 2012). It has been domesticated since approximately 3000 years B.C. in the Ethiopia region (Ayana and Bekele, 1998). The reports of Vavlov (Vavilov, 1951) and Doggett (1988) suggested that, sorghum was domesticated and originated in the North-East quadrant of Africa, most likely n the Ethiopian-Sudan border regions and believed to originate from North East of Africa particularly Abyssinia (Harlan, 1976).

Although sorghum is cultivated both in tropical and temperate climates (Poehlman and Sleper, 1995), it is widely grown in the arid and semi arid tropics because of its unique adaptation to harsh and drought prone environments where other crops can least survive and food insecurity is rampant (Adugna , 2007). It requires a deep, well-drained fertile soil (PH 5.0 – 8.5) and a warm, frost-free period (27 to 30^{o}c average temperature) to grow and develop well (Craufurd *et al.,* 1999).

Sorghum is cultivated on 44.4 million hectares worldwide (FAO, 2012) with average 1314 kg/ha while the average yield from Developed and developing countries is 3056 and 1127 kg/ha (Tachale *et al.,* 2014), respectively. Despite the low productivity in the developing countries, it accounts for 90% of the areas and 77% total output produced (Tachale *et al.,* 2014). United States of America is top sorghum producer followed by India, Nigeria, Sudan, and Ethiopia (FAOSTAT, 2011). The sub-Saharan Africa produces about 18 million tons of sorghum annually making it the second important cereal crop after maize (*Zea mays* L.) (Haussmann et *al.,* 2000; Mutisya, 2004).

Sorghum is produced for its grain which is used for food, feed and stalks for fodder and building materials in developing countries, while it is used primarily as animal feed and in sugar, syrup, and molasses industry (Dahlbert *et al.,* 2011) in developed countries. It is major food and nutritional security crop to more than 100 million people in Eastern horn of Africa (Gudu *et al.,* 2013) including Ethiopia, providing a principal source of energy (70% starch) , proteins, vitamins and minerals (Duodu *et al.,* 2003).

Ethiopia is the third largest producer of sorghum in Africa behind Nigeria and Sudan with a contribution of about 12% of annual production (Wani *et al.* 2011) and the second after Sudan in the Common Market for Eastern and Southern Africa (COMESA) member countries (USAID, 2010). It is the third most important crop both in sown area (ha) and total production (qt) after tef, maize and maize, tef, respectively; becoming third primary staple food crop in Ethiopia after tef, maize (CSA, 2015) and second most important crop for *injera* (common leavened flat bread) making next to tef (Adugna, 2012). Currently, sorghum is produced by 5 million holders and its production is estimated to be 4.6 million metric tons from nearly 2 million hectares of land giving the national average grain yield of around 2.3 tons per hectare (CSA, 2015). It covers 16% of the total area allocated to grains (cereals, pulses, and oil crops) and 14.58% of the area covered by cereals (CSA, 2015). The crop is cultivated in all regions of Ethiopia between 400m and 2500m altitude, mostly at lower altitudes along the country's Western, South-Western, North Eastern, Northern and Eastern peripheries (EIAR, 2014) and staple food crop on which the lives of millions of poor Ethiopians depend (Adugna, 2007).

Sorghum is an indigenous crop of Ethiopia where tremendous amount of variability exists in the country (Adugna, 2007), having a diversity of both domesticated and wild relatives which revealed Ethiopia as center of origin and diversity (Mekibeb, 2009) supported by Vavilonian center of origin and diversity (Vavilov, 1951). Ethiopian sorghum landraces exhibit native genetic variation for drought resistance (Borrel *et al.,* 2000), having huge source of high lysine (Singh and Axtell, 1973), good grain quality and resistance to disease and insect (Yilma, 1991), post flowering drought tolerance (stay-green trait) (Borrel *et al.,* 2000), source of *zera zeras* sorghm popular at ICRISAT still today in developing food type hybrid (Reddy *et al.,* 2004).

Sorghum breeding in Ethiopia has a long history which was more than four decades began in the mid of 1950s at the Alemaya College of Agriculture (IDRC, 1978) with collaboration work of Oklahoma State University. Since today, in Ethiopia, considerable sorghum breeding progress has been made in germaplasma collection (Reddy *et al.,* 2004, IBC, 2012), developing variety (EIAR, 2014), screening germplasm for resistance to disease, insect, drought and striga (Borrel *et al.,* 2000; Adugna, 2007) and identification source of resistant in germplasm having considerable information mechanisms of inheritance for resistance was made (Yilma, 1991).

Even though Ethiopia is an important center of genetic diversity for sorghum (Vavilov, 1951) and provides germplasm having genetic diversity for yield and protein quality, host-plant resistance to insect pest (Yilma, 1991) and drought tolerance, still the research done regarding the crop improvement was limited compared to breeding program worldwide. However, in the last four decades research was conducting by dividing the sorghum growing areas in to four major traditional agro ecologies; dry lowland, intermediate altitude and high elevation areas. Landrace improvement through selection, hybridization and resistance variety development to biotic and abiotic for thematic areas was long lasting objectives of sorghum improvement program in Ethiopia. Accordingly, in the last four decades breeding program, a lot of improved sorghum varieties were released from different Research Center (Both Federal and Regional) (EIAR,2014)). Therefore the objective of this seminar review will be:

Objectives

- To review sorghum genetic resource and the potential of Ethiopia in today's breeding program
- To highlight sorghum breeding system in Ethiopia
- To asses achievements in sorghum breeding in Ethiopia since today

2. SORGHUM BREEDING IN ETHIOPIA

2.1 Sorghum Genetic Variability and Potential of Ethiopia

Ethiopia is a centre for genetic diversity for many domesticated crop plant species such as sorghum, barley, tef, chickpea and coffee, largely represented in the country by local landraces and wild types that are exceptionally adapted to adverse environmental conditions due to their genetical diverse forms (Abe, 2010). Much of this crop diversity is found in small fields of small scale farmers, have played a great role in the creation, maintenance and efficient utilization of resources (Worede *et al.,* 2000**)**

Being Sorghum is an indigenous crop of Ethiopia, tremendous amount of variability exists in the country (Adugna, 2007). Globally, in sorghum breeding program, Ethiopia serves as sorghum genetic resource reservoir for favorable genes to which it is the Vavilonian center of origin and diversity (Vavilov, 1951) ranking first among countries that have contributed sorghum collections at International Crop Research Institute for Semi-Arid Tropics (ICRISAT) (Prasada *et al.,* 1989). Ethiopian sorghum germplasm collections have already been noted as sources of valuable genes for several agronomic characteristics such as grain yield (Doggett, 1988; 1991, Kebede, 1991), pest resistance (Faris *et al.,* 1979), cold tolerance (Singh,1985) and protein quality (high lysine)- IS11167 and IS11758 (Gebrekidan and Kebede, 1979; Singh & Axtell, 1973). Similarly, Harlan (1992) and Prasada *et al.* (1989) reported that, sorghum landraces from Ethiopia are valuable sources of desirable genes for modern plant breeding programmes.

Nationally, since Ethiopia has a diverse wealth of sorghum germplasm adapted to a range of altitudes and rainfall conditions, Ethiopian farmers grow mixed sorghum landraces of diverse forms in their fields for various local purposes (Asfaw, 2014). Indeed, of the five morphological races of sorghum (*bicolo*r, *guinea*, *caudatum*, *durra* and *kafir*), all, except *kafir*, are grown in Ethiopia (Harlan and de Wet, 1972). Similarly, Reddy *et al. (*2004) reported that distinct types of sorghum from Ethiopia are *zera zeras*, *durras* and *durra-bicolor* derivatives. Moreover, studies identified two sorghum lines native to Ethiopia (B35 and E36-1) as sources of "stay-green" for drought tolerance, which are currently used in marker assisted breeding programs (Reddy *et al.,* 2009). Wu *et al*., (2006) also identified seven sorghum lines of Ethiopian origin resistant to Green bug- ETS2140 (PI452752), ETS3447 (PI455203), ETS3805 (PI455812), ETS4159 (PI456490), ETS4167 (PI456504), ETS4565 (PI457212), ETS4614-B (PI457314). IS 12662C (SC 171), the source of A2 cytoplasm (the sterile line) for the development of hybrids, which belongs to the *Caudatum Nigricans* group (*Guinea race*) was also obtained from Ethiopia (Schertz, 1977). Another example is E 35–1 (Gambella 1107), a selection from the Ethiopian *zera-zera* sorghum landrace, which has now been introduced for direct cultivation and in the modern breeding program in many countries (IBC, 2007; Reddy *et al.,* 2009); some superior varieties of Ethiopian origin were released in India, Eritrea Burkina Faso, Zambia, Burundi and Tanzania (Reddy *et al.,* 2006).

White grain *Zerazera* germplasm accessions from Sudan and Ethiopia were found as less susceptible to disease under natural conditions and possessed desirable food quality used to develop sorghum variety (Thankur *et al.,* 2006). For instance, CSV 4 variety devolved from *Zerazera* germplasm was subsequently used as a restorer parent of several hybrids and used as one of parent in developing hybrid being used at ICRISAT in crossing program to generate genetic variability for resistance to disease (Thankur *et al.,* 2006). Furthermore, several *zerazera* germplasm accessions and their derivatives having high yielder and adapted lines has been used extensively in crossing to widen the genetic base of disease resistant lines (Murthy *et al.*, 1980; Thankur *et al.,* 2006)

2.2 Historical Development of Sorghum Breeding in Ethiopia

Sorghum research began in Ethiopia in the mid-1950s at the Alemaya College of Agriculture. As starting of sorghum breeding, local collections and U.S. introductions were screened for high yield and adaptability to highland environments by a team from Oklahoma State University who had developed the College under a grant from the United States Agency for International Development (USAID). In the late 1960s the Ministry of Agriculture formed the National Crop Improvement Committee (NCIC), and delegated the national responsibi1ity for sorghum improvement to the Alemaya College of Agriculture. This national responsibility entailed organizing the annual sorghum National Yield Trials (NYT) for all experimental stations. Although Alemaya served well in identifying suitable cultivars for highland areas, NYT results confirmed that it was impossible to develop and screen suitable varieties for lowland and low rainfall conditions at Alemaya. It became evident that a national sorghum improvement program was required to cater to the needs of all the sorghum growing zones of Ethiopia (IDRC, 1978); which is categorized now as four major traditional agro ecologies; dry lowland, intermediate altitude and high elevation areas (EIAR, 2014).

2.2.1 Project Establishment and Advancement of Sorghum Breeding

Sorghum research in Ethiopia has continued for the last four decade, with the objectives of solving problems related to production and productivity. The establishment of Ethiopian Sorghum Improvement Project (ESIP) was in 1972 with funds the International Development Research Center (IDRC) can be considered to be the start of formal research on the crop in the country. In 1973, ESIP started fully functional and served as home for the popular zerazera (*caudatum race*) type sorghums in sorghum improvement at ICRISAT (Reddy *et al*., 2004). In 1982 Institute of Agricultural Research (IAR), now the Ethiopian Institute of Agriculture Research (EIAR) was established and sorghum breeding started advancing. Since today, a lot of research has been conducted to develop technologies in the areas of variety development, crop management and cropping system, crop protection, food science, socioeconomic and research extension with the major out comes in the variety development (EIAR, 2014).

2.2.2 Germplasma Resources and Collections

Ethiopia is the center of origin and diversity for many crops including sorghum (Vavilov, 1951). There is huge source high lysine (Singh and axtell, 1973), good grain quality and resistance to disease and insect (Yilma, 1991) and post flowering drought tolerance (stay-green trait) (Borrel *et al.,* 2000). Primarily, considering genetic variability and diversity of sorghum in Ethiopia, collection started in between 1958 and 1960 by Jimma Agricultural Technical School (Rosenow and Dalhberg, 2000). Later this activity was taken over by ESIP and continued collections since the 1970s (IBC, 2012). After ESIP started in full-scale in 1973, it served as home for the popular *zera zeras* (*caudatum* race) type sorghums, which were extensively used as parents in ICRISAT sorghum improvement programs until the 1990s and being extremely provided germplasm for the improvement of food type sorghums (Reddy *et al.,* 2004). Through the early 1980s only, ESIP had amassed a collection of approximately 5500 accessions (Doggett, 1988). Nationally, the ESIP made good progress with release of the varieties, Awash 1050, the popular ETS series, and Gambella 1107 (E 35-1) that has been widely used in ICRISAT breeding programs (Reddy *et al.*, 2004).

In general, about 9, 824 sorghum germplasm accessions were collected and maintained by ESIP and the Institute of Biodiversity Conservation (IBC). Recently, diverse source of more than 10,000 sorghum accession were collected and conserved in Ethiopian Institute of Biodiversity and Conservation (EIBC); consisting diversity form cultivated and its wild relatives represent possible of germaplasma for crop improvement and providing source of noble traits (EIAR, 2014).

2.3 Sorghum Breeding in Ethiopia from Introduced materials

The primary and most important source of sorghum germplasm introduction for Ethiopia has been the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and International Sorghum and Millets (INTSORMIL) collaborative research support program (Adugna, 2007). From the very beginning of sorghum research in Ethiopia, a significant number of sorghum germplasm lines have been introduced from ICRISAT and evaluated annually for various desirable traits. The East African Regional Sorghum & Millets Network (EARSAM), now East and Central African Sorghum & Millets Network (ECARSAM), Southern African Food Grain Research (SAFGR), Texas A&M and Oklahoma Universities, and Centro Internacional de Mejoramiento del Maïzy del Trigo (CIMMYT) were also the sources in different times. The introduced materials include varieties/lines in the form of regional and international trials and nurseries, hybrids for evaluation, hybrid parents (A-, B- and R-lines) and populations were imported and evaluated in Ethiopia time to time (Adugna and Tesso, 2006); a large number of lines/varieties were introduced in the form of international trials and nurseries for various traits such as earliness and disease and insect resistance (Adugna, 2007)

2.3.1 Early-Maturing Sorghum Varieties/lines.

The main interest of introducing sorghum germplasm in Ethiopia is to evaluate and release high yielding and early-maturing sorghum varieties that can escape drought occurring late in the season in the dry lowlands and over the years, a large number of early-maturing sorghum varieties and lines have been introduced and evaluated for yield and yield related attributes (Adugna and Tesso, 2006). For instance, all the sorghum varieties that have been released so far by the national sorghum research program for commercial production in drought stressed areas were from exotic sources except Gambella 1107 (Adugna , 2007).

2.3.2 Hybrids and Hybrid parents.

A number of male sterile lines (A-lines), their maintainers (B-lines) and restorer lines (R-lines) have been introduced and screened for their adaptation and hybrids have been developed from them (Adugna, 2007). Early in the program, very good male sterile lines like CK 60A, IS10360A and Tx622A were used to make hybrids. Using these lines, some hybrids were developed in the 1980s. However, the yield advantage they exhibited over the standard open-pollinated varieties was not encouraging. Afterwards, the introduction and hybrid development activities were continued. Currently, two better yielding sorghum hybrids (ICSA 21 ×ICSR 50 and ICSA 15 ×M5568) than the best open-pollinated standard check variety, Teshale are on the pipeline (Adugna and Tesso, 2006).

2.3.3 Sorghum populations.

Population improvement using recurrent selection is part and parcel of the sorghum improvement program in Ethiopia to concentrate genes that are distributed in the population into a single background by effecting random mating. About three decades ago, two sorghum populations were introduced from Texas A&M, TP 24 white and TP 24 brown. Though both were introduced for dry lowlands, the brown population was specifically intended for bird prone rift valley areas (Adugna, 2007)

2.4 Sorghum Breeding for Biotic and Abiotic Stress Resistance

2.4.1 Breeding for Parasitic Weed (*striga*) Resistance

Striga spp.(witch weed), a root parasitic (obligate parasite) flowering plant, is common in Sub Saharan Africa (SSA) causing severe constraints to crop production (Hayelom, 2014) diverting essential nutrients from crop such as sorghum (Altera *et al.,* 2011). It affects the life of more than 100 million people in Africa and cause economic damage equivalent 1 billion $ US per year (Labrad *et al.,* 2008; Waruru, 2013). It has broad host range and affects important cereal crops such as sorgum , maize, peal millet, Finger millet, and upland rice (Hayelom, 2014).

Striga is known by 'Akenchira', 'Metselem' local name (Fischer, 2006) in Ethiopia which is serious the problem in dry lowland agroecologies characterized by erratic rain fall, low soil fertility and fragile ecosystem (EIAR, 2014). Annually, sorghum loss by striga in SSA is estimated 22-27 %, while Ethiopia share 25% estimated to US$75 million (AATF, 2011).

In Africa, relatively Ethiopia has strong sorghum breeding program on striga (AATF, 2011). Ethiopia becoming strong with collaborative research work focused on the introduction of varieties/lines that combine high yield and Striga resistance has been a high priority thematic area of research (Adugna, 2007). Such germplasm have been introduced from ICRISAT and International sorghum and millet (INTSORMIL) collaborative research and evaluations have been made in Striga prone areas. Over the years the apparently available Striga resistant varieties and lines have been introduced and tested in hot spot areas. Recently, two Striga resistant sorghum varieties, Gubiye (P9401) and Abshir (P9403), initially introduced from Purdue University, USA, were released for commercial production in Striga infested areas of the country. Furthermore, a new backcrossing program has been started in collaboration with the Purdue University to introgress the Striga resistance gene(s) from the introduced resistance sources (SRN 39 and Framida) into the otherwise better yielding locally adapted sorghum cultivars (Adugna, 2007).

2.4.2 Breeding for Disease Resistance

2.4.2.1Anthracnose

Sorghum anthracnose, caused by *Colletotrichum sublineolum* Henn., is found in most sorghum producing regions of Ethiopia (Chala *et al.,* 2010). The disease can be successfully managed using resistant varieties; however, the pathogen population is highly variable which reduces the longevity of resistant sources (Marley *et al.,* 2001); new sources of resistance are needed and germplasm collections have been an important resource for resistance (Erpelding, 2010).

Sorghum has its origin in Africa and the greatest genetic diversity in native sorghum is found in Ethiopia (Sleper and Poehlman, 2006); this centre of origin could also serve as a centre of diversity for host plant resistance to anthracnose as sorghum is a diverse crop providing ample opportunity to look for sources of resistance (Erpelding, 2010). In the mean while, the use of resistant cultivars is considered the most cost effective and efficient option in combating sorghum anthracnose. Hence, searching for possible sources of resistance and breeding for disease resistance are important tasks for researchers engaged in finding effective and sustainable means of controlling anthracnose (Alemayehu and Anne, 2012). For instance, in Southern Ethiopia considerable variation in response of 56 sorghum accessions collected from different regions of Ethiopia showed significantly lower disease levels compared to the susceptible checks, indicating that germplasm from Ethiopia may be useful sources of anthracnose resistance (Alemayehu and Anne, 2012). Similarly, Erpelding (2010) identified 44 lines which were developed at USA from Ethiopian source showed high frequency of resistance to anthracnose; suggests that Ethiopian germplasm could be an important source of anthracnose resistant accessions. Chala *et al.* (2010) also identified resistant germplasm from Ethiopia and indicated that Ethiopia is an important source of resistance to anthracnose for sorghum improvement. These all reports suggest that, the potential Ethiopian sorghum germplasm may have in serving as sources of resistance in future breeding programs.

However, Even though Ethiopia is native to sorghum where greatest genetic diversity of the crop for host plant resistance to anthracnose is found (Chala *et al.,* 2010), the variability of *C. sublineolum (*Afanador *et al*., 2003), diverse nature of the farming system and climatic condition under which sorghum is grown in Ethiopia (Berhanu, 2015, Chala *et al.,* 2010), limits the breeding progress to develop anthracnose resistant varieties that could be used across locations. Hence, the identified resistant materials need to be tested across locations before the deployment of resistance in breeding programs (Girma, 1995).

Currently, in national sorghum improvement program source of anthracnose and other foliar disease resistant were identified. Sorghum landraces from Western and South Western parts of the country were resistant to multiple leaf disease including anthracnose (Prasada and Mengesha, 1981; Dilooshi *et al.,* 2016); these locations are serving as sorghum screening under natural condition (hot spot area) in national sorghum improvement program particularly for disease resistance breeding.

2.4.2.2 Panicle disease

In the past, panicle diseases of sorghum such as grain mold, smut and ergot were recognized as major production constraints (Reddy *et al.,* 2004). Grain mold resistant *Zera zera* genotypes were identified and still in use as a donor parent to develop grain mold resistant varieties in world including Ethiopia. Reliable screening techniques and resistant genotypes to grain mold, smut are identified and efforts are underway to exploit the genetic potential of the resistant lines to develop mold resistant varieties and explore the possibility of developing smut resistant male-sterile female parents (A-lines) that could be used in the hybrid sorghum seed production (Girma, 1995).

The Western of parts of Ethiopian regions harbors a unique set of sorghum germplasm adapted to conditions not conventional to sorghums grown in other parts of the world. Accessions from the region and parts of South Western possess unique resistance to multiple leaf and grain diseases (Dilooshi *et al.,* 2016). Though the region is conducive for growing variety of sorghum as the primary choice and variants of sorghum sources serving as global germplasm such as Zere-Zera sorghum (Prasada and Mengesha, 1981), warm temperature, high rain fall a near humidity (100%) agro ecology of the area is challenging sorghum breeding due to grain mold and various leaf diseases (Dilooshi *et al.,* 2016) received favorable environment for development. Basically, in national sorghum improvement program Western and South western parts of the country are serving as hot spot multi environment testing for disease in variety verification before release. Ethiopian national sorghum research program and other regional research centers has been conducted sorghum breeding in this agro ecologies, particularly on leaf and grain mold resistance breeding. For instance, Bako Agricultural Research Center (BARC), Asosa Agricultural Research Center (AARC), Pawe Agricultural Research Center (PARC) and Jimma Agricultural Research Center (JARC) has been conducted a lot of sorghum breeding particularly for leaf and grain mold diseases. Since today, Only from BARC , AARC and JARC foliar and grain disease resistant varieties (Chemeda, Gemedi, Lalo, Dano, Adukara, Asosa-1 and Aba melko) were released and under production (ECVR, 2014, EIA, 2014).

2.4.2.3 Sorghum Breeding for Drought Resistance

Drought is a major limiting factor for crop expansion. Currently efforts are focused on improving crop genotypes for drought-prone area by evaluating various growth attributes, physiological, biochemical and agronomic performances of different Stay-Green (SG) sorghum accessions. Ethiopian sorghum landraces exhibit native genetic variation for drought resistance yet not exploited in development of sorghum cultivars with resistance to these important stresses. For instance, Afeso and Sorcoll 163/07 sorghum accessions showed better stress tolerance and the Stay green (SG) property in Ahmara lowland areas recorded maximum grain yield per hectare (Zelalem et *al., 2015).*

Line B35 is a BC1 derivative of IS12555 *dura* sorghum from Ethiopia (Harris *et al.,* 2007) shows distinct responses to drought at both pre- and post-flowering stages (Rosenow *et al.,* 1996), being highly resistant to post-flowering drought (stay-green trait), with a relatively low yield. In contrast, line E36-1 is a high-yielding breeding line assigned to the *Guinea caudatum h*ybrid race of Ethiopian origin (Haussmann *et al.,* 2002). Hence, these Ethiopian materials are the best suggested for improvement in terminal drought areas, serving as donor for high yielder but susceptible to drought prone areas of recipient parents at ICRISAT and USA (Edema and Amoling, 2015).

In Ethiopia, being tremendous genetic resource sorghum for drought tolerance landraces are existed, the breeding strategy in Ethiopia mainly focused on screening the landraces and verities in drought prone areas. For instance, areas such as Werer, Kobo, Miesso, etc representative used as dry lowland areas for verification of drought tolerant land races or variety before release (EIAR, 2014).

2.5 Sweet Sorghum Breeding

The improvement of sweet sorghum (*Sorghum bicolor*) for biofuel traits is getting more attention globally due to its sugar-rich stalk that can be used as a renewable energy product (Tesfaye *et al.,* 2016); an understanding and proper assessment of biofuel-related traits in sweet sorghum crop is an important step toward the development of superior cultivar. Ethiopia is the center of origin and diversity of sorghum having sweet type sorghum can be exploited for biofeul utilization.

Nationally, research revolution has been started on sorghum for utilization of biofeul energy particularly from sweet sorghum. For instance, recently Tesfaye *et al.(*2016) conducted research on 180 sweet sorghum accessions collected from different parts of the country, revealed wide variability among the accessions collected from different regions. In general, the study concluded that, collections from northern part of Ethiopia (Wello and Tigray) showed significantly high 0Brix value while collections those of from the rest of the regions (Hararge, West Shewa, East Wollega and Gojam) expressed lower 0Brix mean value but higher biomass for stalk sugar yield. Most of the accessions showed higher 0Brix mean value, which is similar to globally known sweet sorghum cultivars. Accessions with high 0Brix degree combined with high biomass traits like stalk diameter and plant height will be an ideal germplasm to be used for biofuel production (Tesfaye *et al.,* 2016); hence, it is imperative to utilize these accessions in sweet sorghum breeding program in order to develop superior sugar-rich sweet sorghum cultivars.

In the same year, Tesfaye *et al.(*2016) characterized 202 sorghum accessions using 13 polymorphic markers and identified distinct grouping between Ethiopian(175) and ICRISAT (27) sweet sorghum lines released in eastern and southern Africa. The distinctness of these accessions showed the lack of exploitation of the abundant sweet sorghum genetic variability from Ethiopia and calls for more inclusion of the unique germplasm in various local and global breeding programs in the future. The abundance of rare and private alleles observed among Ethiopian collections provides more evidence for novel alleles that can be efficiently exploited through future Genome-Wide Association Studies (GWAS) for sugar related traits. This research results create an opportunity to enrich both national and global gene banks with diverse sweet sorghum landraces but also provide immediate germplasm resources that can be used directly in breeding programs (Tesfaye *et al.,* 2016).

2.6 Malt Sorghum breeding

In Ethiopia and elsewhere, barley is the preferred grain for malting in modern brewing industries. However, intensive cultivation of barley in tropical areas, including Ethiopia, is limited. In Ethiopia, most of the cultivated areas are characterized by a warm and dry climate and are not suitable for barley production and even pockets of areas in the highlands where barley is normally grown have frequently suffered from infestations by biotic agents that have limited the production of this crop (Teshome *et al.,* 2011). As a result, local brewery industries have increased the import of malt barley and at present 67% of the barley used by local breweries is imported (Getachew *et al.,* 2008).

Sorghum becoming the most important industrial crops including malt production in brewery industry in developed countries and some African countries (Dahlbert *et al.,* 2011). In the meanwhile, Ethiopia owing the wide ecological diversity and the wealth of sorghum germplasm (diverse local accessions), various types of sorghum is produced in different parts of the country and the opportunity to identify cultivars suited for the brewery industry is tremendous (Aychew *et al*., 2011). Today, Ethiopian Research system not only focused on sorghum variety development for food, but also, a considerable research has been conducted on developing variety having good quality malt for brewery industry. Nationally, about two lowland adapted varieties (Macia and Red-Swazi) were released for malt quality by Malkassa Agricultural Research Center (ECVR, 2014). Beside released varieties for malt production, the report of Aychew *et al*. (2011) showed that food type released sorghum varieties viz. Teshale and Gambella 1107 produced the better malt quality tasted against with Macia and Red-Swazi; indicating that Ethiopia sorghum landraces are the other venue for Brewery industry

2.7 Achievements in Sorghum Breeding in Ethiopia

2.7.1 Variety Development and Achievements

In the last four decades research was conducing by dividing the sorghum growing areas in to four major traditional agro ecologies; dry lowland, humid lowland, intermediate altitude and high elevation areas. Dry lowland agro ecology is the vast majority sorghum growing area of the characterized by erratic rain fall, low soil fertility and fragile ecosystem. For this agro ecology the major constraints are drought, striga, and stalk borer and research emphasis has been given in developing early and striga resistant sorghum varieties (up to 120 days to maturity) which can escape the early offset of rain fall a number of varieties were released for production. However, early maturity sorghum varieties lack of high biomass a trait preferred by farmers for cattle feed, construction and fuel wood as a result low preference of the variety by farmers. Varieties are developed by either evaluating exotic introduced from foreign collaborating research institute (ICRISAT, Purdue university ant Texas A and M University) or through hybridization of local by exotic or exotic by exotic materials followed subsequent generation selection and multi environment evaluation for the target trait of interest in target areas (EIAR, 2014). In recent year efforts are being made to introgressed stay-green and striga resistant trait in to high yielding varieties in support of Harnessing Opportunities for Productivity Enhancement (HOPE) project the sorghum crop improvement works resulted in the identification of more than 12 stay-green QTL introgressed sorghum lines that are in the final stages for release and delivery to farmers.

Regarding the humid lowlands, the major production constraints are leaf and grain disease and focus has been given to identify leaf and grain disease tolerant/resistant varieties. The resource of breeding materials for the agro ecology is from local source and effort has been made towards identifying the resistant materials in the local sources and there by introgression of resistant traits in to adapted varieties through crossing and back crossing. However, due to complex nature of the disease and limited effort less number of varieties was released as compared to the other agro ecologies. In the intermediate and high elevation agro ecologies the emphasis was develop multipurpose sorghum varieties (high grain yield, feed, construction, and fuel wood) and a number of varieties were released to address aforementioned purpose. The source germplasma for breeding for these agro ecologies is also only from local sources (EIAR, 2014).

Over the past four decades about 49 (Table 1) improved sorghum varieties with various desirable characteristics were released for the four major agro ecologies. Of these more than 25 were open pollinated varieties and two hybrids are on the current recommendation (EIAR, 2014; ECVR, 20140. Crrently three varieties (Jiru, Adele and ETS-4) were released in 2016 (Ethiopian Crop Variety Register Directorate Personal Communication).

Table 1: List of released sorghum varieties from Ethiopia since 1970 - 2015/16

No.	Varieties	Year of release	Breeder/maintainer
1	Jiru(ጅሩ) (yellow)/ETS-2752)	2016	Melkassa Agricultural Research Center
2	Adele(አደለ)(ACC#70583)	2016	Melkassa Agricultural Research Center
3	ESH-4 (PU209A/PU304)	2016	Melkassa Agricultural Research Center
4	Adukara	2015	Asosa Agricultural Research Center
5	Asosa -1	2015	Asosa Agricultural Research Center
6	Dibaba	2015	Melkassa Agricultural Research Center
7	PAC537	2014	Melkassa Agricultural Research Center
8	ETH-3 (ICSA-15 X M-5568)	2014	Melkassa Agricultural Research Center
9	Chemeda (Acc- BRC-18)	2013	Bako Agricultural Research Center
10	Gemedi (Acc-BRC-5)	2013	Bako Agricultural Research Center
11	Dekaba (ICSR 24004)	2012	Melkassa Agricultural Research Center
12	Mesay (Meko x Gobye-2)	2011	Sirinka Agricultural Research Center
13	Dagem (97 MW 6130(IS 10892 X RS/R-20-8614-2 X IS 9379)	2011	Melkassa Agricultural Research Center
14	Chare (PGRC #222880)	2011	Dbarc
15	Melkam (WSV 387)	2009	Melkassa Agricultural Research Center
16	ESH-1 C=nL-1 (P-9501 A x ICSR14)	2009	Melkassa Agricultural Research Center
17	ETHS-2 C=nL – 2 (ICSA 21A X ICSR50)	2009	Melkassa Agricultural Research Center
18	Gedo (Gambella 1107 x P-9403)	2007	Sirinka Agricultural Research Center
19	87 BK- 4122 (Geremew- food type)	2007	Melkassa Agricultural Research Center
20	Red swazi (Malting type)	2007	Melkassa Agricultural Research Center
21	Macia (malting type)	2007	Melkassa Agricultural Research Center
22	Emaboy (Pw 01-0920)	2007	Melkassa Agricultural Research Center
23	RAYA (PGRC/EX222878 X KAT369-1)	2007	Sirinka Agricultural Research Center
24	MISKIR(PGRC/E#69441 X P-9401)-Early maturing	2007	Sirinka Agricultural Research Center
25	GIRANA-1 (CR:35 X DJ 1195 X N-13)-Early maturing	2007	Sirinka Agricultural Research Center
26	Lalo (BRC-245)	2006	Bako Agricultural Research Center
27	Dano (BRC-378)	2006	Bako Agricultural Research Center
28	Chelenko ETHS 1176	2005	Melkassa Agricultural Research Center
29	Hormat (ISCV 112 BF)	2005	Sirinka Agricultural Research Center
30	Aburae (90 MW 5353)	2003	Sirinka Agricultural Research Center
31	Birhan (Key #8566)	2002	Sirinka Agricultural Research Center
32	ETS 2752	2002	Melkassa Agricultural Research Center
33	Teshale (3443-2-op)	2002	Melkassa Agricultural Research Center
34	Yeju (ICSV 111 Inc)	2002	Sirinka Agricultural Research Center
35	Aba – Melko (Sartu)	2001	Jimma Agricultural Research Center
36	Muyra- 1 (EST-1005)	2000	Haramaya University
37	Muyra-2	2000	Haramaya University
38	Gubiye (P-9401)	2000	Melkassa Agricultural Research Center
39	ABSHIR (P-9403)	2000	Melkassa Agricultural Research Center
40	MEKO-1(M-36121)	1997	Melkassa Agricultural Research Center
41	Baji (85 MW 5334)	1996	Melkassa Agricultural Research Center
42	Chiro (Coll#4)	1996	Melkassa Agricultural Research Center
43	Birmash	1989	Melkassa Agricultural Research Center
44	Seredo	1986	Melkassa Agricultural Research Center
45	Dinkimash	1986	Melkassa Agricultural Research Center
46	IS 9302	1981	Melkassa Agricultural Research Center
47	76 TI # 23	1979	Melkassa Agricultural Research Center
48	Gambella 1107	1976	Melkassa Agricultural Research Center
49	Alemaya 70	1970	Melkassa Agricultural Research Center

Source= Ethiopian Crop Variety Register, 2014; EIAR, 2014

2.8 Research and Development Gaps in Sorghum Improvement to Value Chain

Nationally, Ethiopian Institute of Agriculture Research (EIAR) has developed strategic plan for sorghum for the coming 10 years (2014 – 2024) on sorghum improvement to the end users value chin (EIAR, 2014). The document contained both research and developmental gaps for the last four decades being challenging in sorghum improvement program to end users (value chain).

Research gaps

- Lack of improved that combine high grain yield, multiline tolerance/resistance traits, grain quality and biomass adapted to different agroecologies
- Inadequate package of agronomic recommendation on agricultural input use, cropping system, weed control, crop and soil fertility management, soil moisture conservation
- Lack of recommendation of host plant resistance for different pests
- Inadequate popularization and dissemination of the existing technologies
- Limited research on grain quality for *injera* making, agro-processing/alternative marketable products and breweries
- Lack of value added sorghum products
- Lack of information and knowledge on input – output market of sorghum
- Inadequate value chain development (incubation and industrialization of sorghum products)

Developmental gaps

- Lack of strong seed system particularly the formal sector
- Un availability of grain markets
- Most of the sorghum grain produced is sold in local markets
- There are no available agro- processing industries
- Lack of supportive police to sorghum seed system, grain marketing

3. SUMMARY AND CONCLUSION

Sorghum (*Sorghum bicolor* (L) Moench) is fifth an important cereal crop belonging to monocotyledon grass *Poaceae* family. It is predominantly self-pollinating crop with the degree of spontaneous cross pollination up 30% depending on panicle type. It has been domesticated since approximately 3000 years B.C. in the Ethiopia region and most reports including vavilov suggest that as its origin was the North-East quadrant in Ethiopian-Sudan border region believed particularly in Ethiopia. It is widely grown in the arid and semi-arid tropics because of its unique adaptation to harsh and drought prone environments where other crops can least survive and food insecurity is rampant. It requires a deep, well-drained fertile soil (PH 4.0 – 8.5) and a warm, frost-free period (27 to 30^{o}c average temperature) to grow and develop well.

Sorghum is produced for food, fodder and building materials in developing countries, while it is used primarily as animal feed and in sugar, syrup, and molasses industry in developed countries. It is major food and nutritional security crop to more than 100 million people in Eastern horn of Africa including Ethiopia, providing a principal source of energy (70% starch), proteins, vitamins and minerals.

Ethiopia is the third largest producer of sorghum in Africa behind Nigeria and Sudan and second after Sudan in COMESA member contributing about 12% of annual production. It is the third most important crop both in sown area (ha) and total production (qt) after *tef,* maize and maize, *tef*, respectively. It is third primary staple food crop after tef, maize and second most important crop for *injera* making next to *tef*; being serving millions of poor Ethiopians people. Currently, sorghum is produced by 5 million holders and its production is estimated to be 4.6 million metric tons from nearly 2 million hectares of land giving the national average grain yield of around 2.3 tons per hectare. The crop is cultivated in all regions of Ethiopia between 400m and 2500m altitude, mostly at lower altitudes along the country's Western, South-Western, North Eastern, Northern and Eastern peripheries.

Sorghum is an indigenous crop of Ethiopia where tremendous amount of variability (both cultivated and wild relatives) existed; exhibiting native genetic variation for drought, disease and insect resistance, having good grain quality and high lysine content and source of *zera zeras* in modern sorghum breeding program at ICRISAT and global wise. Indeed in global sorghum breeding program, Ethiopia serves as sorghum genetic resource reservoir ranking first among countries that have contributed sorghum collections at ICRISAT. Furthermore, sorghum lines native to Ethiopia (B35 and E36-1) as sources of "stay-green" for drought tolerance served as marker assisted breeding programs and Ethiopian selection *zera-zera* sorghum landrace E 35–1 (Gambella 1107) has been introduced for direct cultivation and in the modern breeding program in many countries.

Sorghum breeding in Ethiopia has a long history which was more than four decades began in the mid of 1950s at the Alemaya College of Agriculture with collaboration work of Oklahoma State University and started sorghum breeding on local collections and USA introduced materials for their adaptability and yield to highland environments. Later after establishment of ESIP in 1972 and fully funded by IDRC, sorghum breeding in the country become formal and about 5,500 sorghum landraces were collected by ESIP in 1980s served as home for the popular zerazera (*caudatum race*) type sorghums in sorghum improvement at ICRISAT. Nationally, ESIP also made good progress with the release of Awash 1050 and Gambella 1107 (E 35-1) varieties. In 1982 Institute of Agricultural Research (IAR), now the Ethiopian Institute of Agriculture Research (EIAR) was established and sorghum breeding started advancing.

Since today, in Ethiopia, considerable sorghum breeding progress has been made in germaplasma collection, developing variety, screening germplasm for resistance to disease, insect, drought and striga and identification source of resistant in germplasm having considerable information mechanisms of inheritance for resistance. Regarding gemplasm collection, as far as it was started by Jimma Agricultural Technical School in between 1958 and 1960, later with collaboration of ESIP, IBC, Research Centers and University more than 10,000 sorghum accessions were collected and conserved in IBC since today. Currently the Sorghum breeding program in the country focused on local landraces improvement and evaluating high yielder early maturing varieties introduced materials that can escape drought in the dry lowlands. From landraces only a lot of high yielder, disease and insect resistant open pollinated varieties were released while those for drought and striga tolerant from introduced released varieties except Gabella 1107 from *zera zera* landrace drought tolerant released variety.

In general, in the last four decades research was conducing by dividing the sorghum growing areas in to four major traditional agro ecologies; dry lowland, intermediate altitude and high elevation areas. Dry lowland agro ecology is the vast majority sorghum growing area characterized by erratic rain fall, low soil fertility and fragile ecosystem; drought, striga, and stalk borer are major constraints. The research emphasis has been given in developing early and striga resistant sorghum varieties which can escape the stress were released developed by either evaluating exotic introduced or through hybridization of local by exotic or exotic by exotic materials followed subsequent generation selection and multi environment evaluation for the target trait of interest in target areas.

Regarding the humid lowlands, the major production constraints are leaf and grain disease and focus has been given to identify leaf and grain disease tolerant/resistant varieties from local source and effort has been made towards identifying the resistant materials in the local sources and there by introgression of resistant traits in to adapted varieties through crossing and back crossing. In the intermediate and high elevation agro ecologies the emphasis was develop multipurpose sorghum varieties (high grain yield, feed, construction, and fuel wood) and a number of varieties were released from local landraces to address aforementioned purpose.

Accordingly, over the past four decades about 49 improved sorghum varieties with various desirable characteristics were released for the four major agro ecologies and observable great impact in increment of production and productivity was recorded. However, application of biotechnology in crop improvement was at infant stage; hence further hybridization and application of biotechnology must be considered accordingly.

4. PROSPECT

Nationally, Ethiopian Institute of Agriculture Research (EIAR) has developed strategic plan for sorghum for the coming 10 years (2014 – 2024) on sorghum improvement to the end users value chin (EIAR, 2014). The document contained the future line of sorghum improvement program:

Germaplasma Enhancement and Variety Development

- Broaden and enrich the genetic base through collection and characterization of cultivated and wild relatives, acquisition and hybridization
- Targeted breeding for quality traits (i.e nutritional and industrial)
- Improve local landraces by introgression of defensive and quality trait
- Identify and develop varieties with high grain yield, biomass and multiple resistance traits for the different AEZs
- Generate the basic scientific information on pest resistance, inheritance of trait and other genetic aspects
- Enhance breeding for resistance to major pests, disease and weeds (eg. striga) and abiotic stress (eg. drought);
- Include farmers view in all breeding process
- Enhance generation of basic knowledge on genetics and breeding of sorghum
- Employ modern molecular tools (MAS, genomic selection, trait mapping, etc) to accelerate and complement conventional breeding
- Sorghum parental line breeding for hybrid development
- Studies on genotype by environment by management interaction

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