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Review Article

Barley Production Trend, Breeding Efforts, Achievements and Constraints: The case of Ethiopia

Zerihun Jalata

Department of Plant Science, Wallaga University, P.O. Box 38, Shambu, Ethiopia

Abstract

Barley is a dependable crop for subsistence farmers mainly for food security, income, and animal feeds. The presence of large genetic resources of barley in Ethiopia gives better prospects for barley genetic improvement. Recently global production and productivity (>3.0 t ha^{-1}) of barley showed fluctuation while in Ethiopia it indicated a steady increase. An increment in average productivity (~2.5t ha^{-1}) in Ethiopia was partly attributed to the contribution of barley breeding in the variety development of several improved barley varieties across different agroecologies. Despite there are enormous opportunities for barley production in Ethiopia, the yield is still low as compared to the world average due to major production constraints such as the low genetic potential of varieties, genetic erosion, foliar diseases, shoot fly insects, and lodging which were not adequately reported. Therefore, improving understanding of barley production trends, past breeding efforts and achievements may be useful for future progress. The efficient utilization of genetic resources, availability of high-yielding potential barley varieties with a broad spectrum of resistance to pests, and lodging resistance adaptable to the different agroecologies of Ethiopia would play a crucial role in sustainable barley production and productivity. Thus, the objective of this review paper was to discuss Ethiopian barley genetic resources, barley production trends, breeding efforts, achievements, and constraints.

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Corresponding Author:
E-mail:
Email:jaluu_z@yahoo.com.

INTRODUCTION

Barley *(Hordeum vulgare* L.) is a diploid (2n=2x=14) that belongs to the tribe *Triticeae* of the grass family (von Bothmer *et al*., 1991) and *Hordeum* ssp. spontaneum (Koch) Thell is a wild progenitor of cultivated barley within the same crop species that belongs to the primary gene pool of barley (von Bothmer *et al*., 2003). Barley is estimated to have been cultivated in Ethiopia since 5,000 years ago (Zemede, 2000) and Gamst (1969) indicated barley had been cultivated by the people of *Agew* or *Qimant* in northwest Ethiopia about 3000 B.C. Barley is a cool-season crop grown mainly in temperate areas and high altitudes of the tropics and subtropics (Nevo, 1992). Barley is among the major staple crops in marginal highlands of Ethiopia with a high contribution to food security and other uses (Bayeh and Berhane, 2011) its grain consists of an essential nutritional composition with some medicinal properties, and barley breakfast foods and snacks are increasingly available (Anderson *et al*., 1991).

Ethiopia is recognized as a center of diversity for barley, and its landraces are known for the distinct genetic features compared to other barley collections which most likely result from the highly diverse topography, altitude, climate conditions, soil types, and farming systems (Teklemariam *et al*., 2022). Attempts made to conserve the crop is very less except few explorations and rescue collections targeting maintenance under ex situ conditions at the Ethiopian Biodiversity Institute (EBI), formerly established as the

Plant Genetic Resources Centre of Ethiopia (PGRC/E) through the International Board on Plant Genetic Resources in 1974 (currently the International Plant Genetic Resources Institute (IPGRI) (Fekadu *et al*., 2021) is among the potential opportunities to improve barley in Ethiopia. The landraces were collected over 41 years, ranging from1976 to 2017 and conserved at ex situ genebank EBI in Ethiopia (Allo *et al*., 2021). However, the current low national barley productivity (~2.5 t ha^{-1}) (CSA, 2021) as compared to the global barley average yield (3.0 tons ha^{-1}) (FAOSTAT, 2022) and an increasing trend of genetic erosion in Ethiopian barley (Firdissa *et al*., 2010; Girma, 2014). Besides this, low-yielding potential varieties and the effect of scald, net blotch, spot blotch, and rusts can cause yield reduction reaching 67% in Ethiopia (Bayeh and Berhane, 2011). The heavy infestation of barley shoots fly (*D. flavibasis*) infestation on improved barley varieties in southeastern Ethiopia resulted in a complete loss of production (Tafa and Bayeh, 2011), as well as the lodging nature of Ethiopian barley due to its long height and weak stem (Berhane *et al*., 1996**),** are among the major challenges which have not been adequately reported.

In this review, relevant literature on barley was extracted from agency reports, documents, research findings, proceedings, and books to present theoretical and empirical evidence to improve understanding of barley production and challenges hindering sustainable barley production in Ethiopia. Analyzing the strengths and weaknesses of past efforts is useful for making changes in future breeding. Thus, this review paper aims to highlight Ethiopian barley genetic resources, production trends, research efforts, achievements, and major challenges in barley production.

Ethiopian barley Landrace collections

The significance of Ethiopian barley landraces has been recognized a long time ago. In 1923, the first exploration by Harlan reported that several international expeditions had been made to Ethiopia to collect barley, wheat, and other crops which has been widely utilized worldwide in breeding activities as donor source of resistance genes to diseases and viruses (Harlan *et al*., 2008). Moreover, Ethiopian barleys are a source of resistance genes for barley yellow dwarf virus, powdery mildew, lysine content, better vegetative vigor, drought, and resistance to barley diseases, leaf rust, net blotch, scald, spot blotch, and stripe mosaic virus (IBC, 2008). Recent studies on barley landrace collections showed high phenotypic diversity in quantitative traits and the diversity showed a poor connection with geographic areas of collection suggesting extensive gene flow (Gadisa *et al*., 2021a). A similar report revealed the presence of low-to-high genetic diversity among the landraces and grouped the landraces into three clusters showing a close relationship between landraces along geographic proximity with genetic distance increases along with geographic distance and the molecular analysis indicated low-to-high genetic differentiation between Ethiopian landraces (Dido *et al*., 2021a) and another report also showed higher genetic variation (89%) within the clusters than between the clusters (11%) of Ethiopian barley accessions among three genetically distinct clusters of 260 accessions (Teklemariam *et al.,* 2022).

Besides this, a study on diversity within and among 585 Ethiopian barley landraces revealed that variations between and within barley landraces in terms of regions of origin, altitude classes, and ear types were significant. Among this 198 (33.85%) had significantly lower disease than the susceptible check, of which 12 (2.05%) and 186 (31.79%) landraces, respectively, showed resistant (R) and moderately resistant (MR) infection types (Dido *et al*., 2021b). An earlier study response of 1800 Ethiopian barley landraces to leaf rust and scald diseases indicated high infection type but nearly all the landraces had at least some partial resistance (Alemayehu, 1995). The recent data of total landrace collections of different crop types at the Ethiopian gene bank is about 68014 accessions, of which barley landrace accessions constitute the maximum proportion (24%) followed by wheat (19%), sorghum (15%) and tef (9%) (IBC, 2012; Figure 1) and from overall collections in genebank supplied to researchers, about 20.8% are barley seed sample. This indicated that the utilization of barley landraces in crop improvement and other research activities is high. Nevertheless, there is scarce information on how many of these landraces were characterized for various morphological and agronomic traits studied and the novel genes or unique genes identified for utilization in crop improvement. Landraces are used in breeding due to the unique variability of their adaptive traits (Dwivedi *et al*., 2016), and better use of a wider variety of the world's plant genetic resources is crucial for ensuring the food and nutrition security of all people (FAO, 2012).

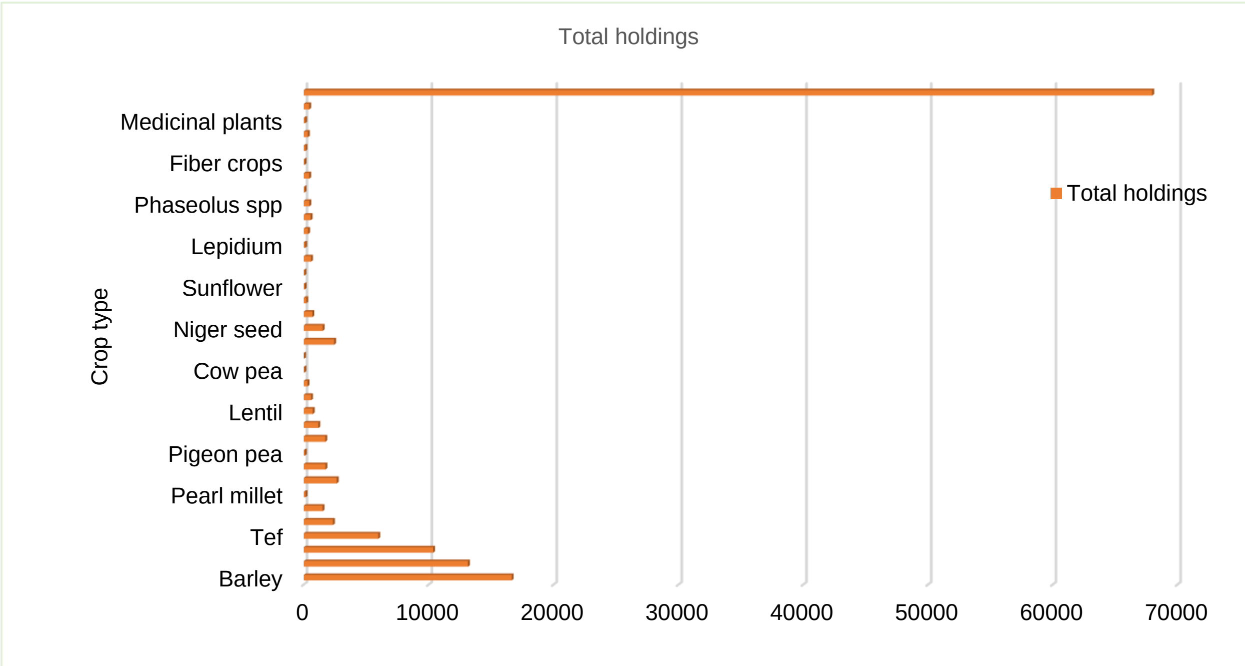

Figure 1. Germplasm holdings of the Ethiopian Genebank (Source: IBC, 2012).

Global barley production and trends in Ethiopia

According to FAOSTAT data 2020 (FAOSTAT, 2022) the current world area coverage of barley is about 51.6 million ha with a total production of 157 million tons with about mean productivity of 3.0 tons ha^{-1} (Figure 2). Although the production trend is fluctuating it showed an increasing pattern from 2018-2020. The shift could be the result of changing consumption patterns and land use to accommodate growing demands for food, living space, and livelihoods, which requires society to allocate intensively managed land uses in a much more strategic manner (Nelson *et al*., 2010). Moreover, FAOSTAT data of 2020 (FAOSTAT, 2022) indicated that the major barley production comes from Europe (60.1%) followed by Asia (16.2%), Americas (13.5%), Oceania (6.7%), and Africa (3.5%) which revealed Europe is producing more than half of world barley production (Figure 3). From the world's top ten largest barley-producing countries in 2020, some countries like Germany (6.5 t ha^{-1}) produced the highest productivity per unit area followed by the UK and Northern Ireland (5.8 t ha^{-1}), France (5.2 t ha^{-1}), Spain (4.2 t ha^{-1}) and Argentina (4.1 t ha^{-1}) which all are above the world average (FAOSTAT, 2022) (Figure 4). Therefore, as compared to these countries, the current barley productivity in Ethiopia is far behind requiring redesigning the breeding strategy.

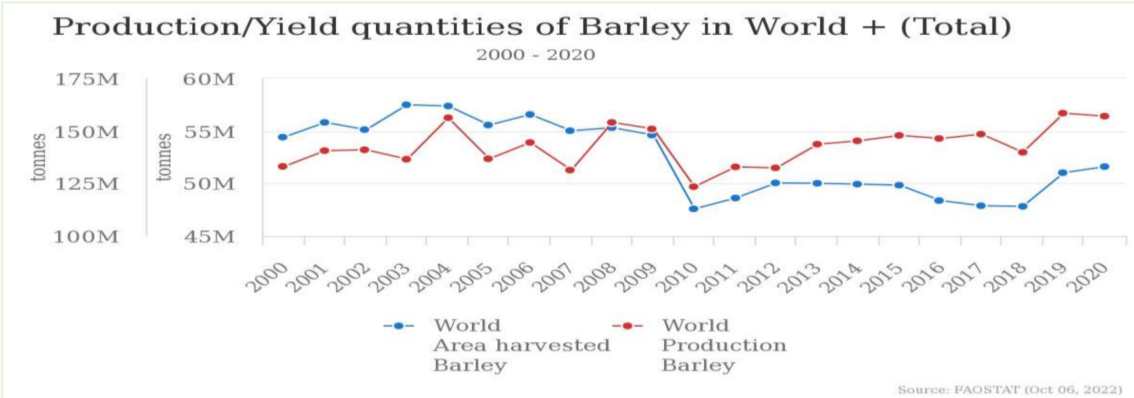

Figure 2. World barley production trend (2000-2020) (FAOSTAT, 2022)

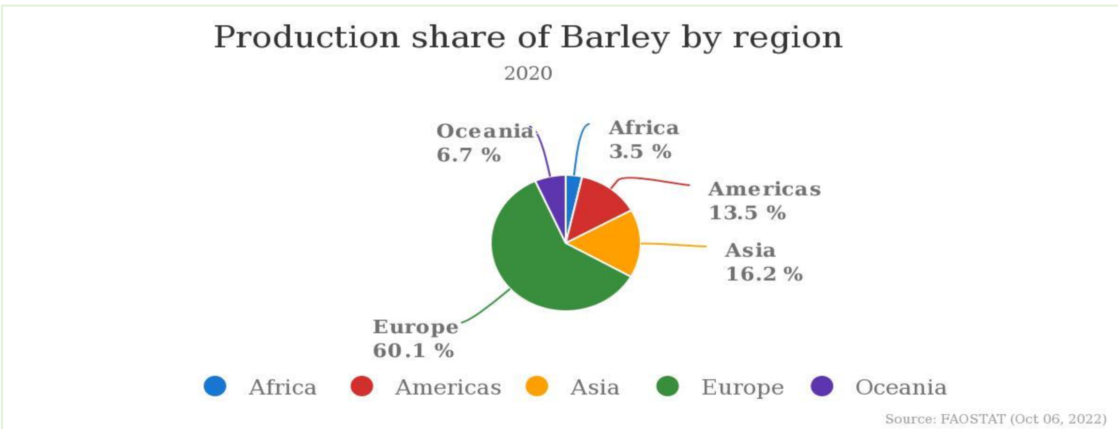

Figure 3. The distribution of barley production across different regions

Source: FAOSTAT (2022)

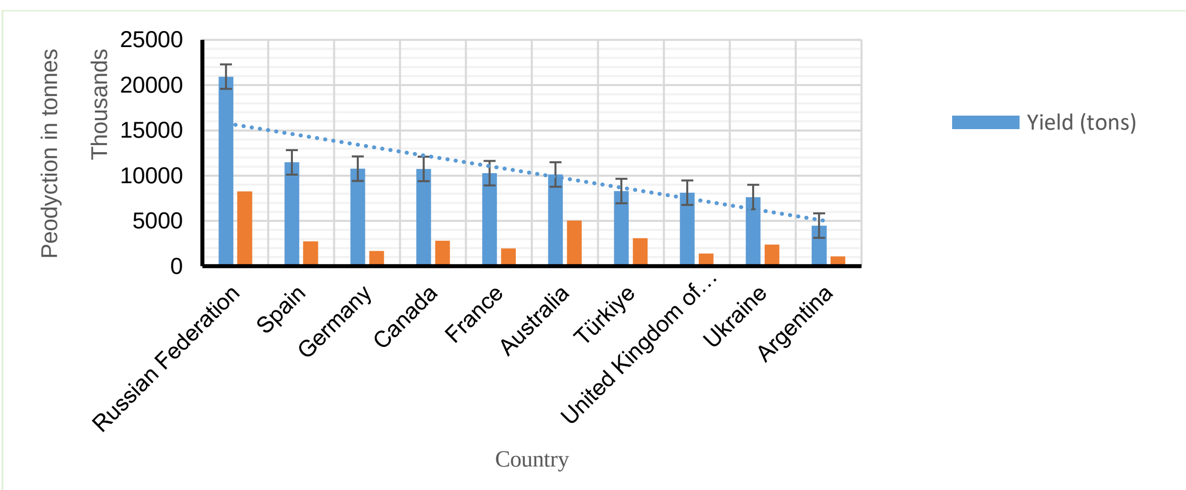

Figure 4. The leading ten countries globally in terms of barley production

Source: FAOSTAT (2022)

The majority of Ethiopia's barley is produced between 2000 and 3000 meters above sea level (Berhane *et al*., 1996) and used in Ethiopia for human consumption, malting, and feed (Birhanu *et al*., 2005). Barley is among the major staple crops grown on about one million ha and producing an estimated annual production of more than two million tons of yield with a national average of about 2.5 t ha^{-1} (CSA, 2020). Barley production in Ethiopia is in an increasing trend from 1998 to 2020 as shown in FAOSTAT (2022) data (Figure 5) which may be largely contributed to farmers' adoption of barley technological packages. Ethiopian Central Statistical Agency data for 2018 to 2020 revealed that after important crops like tef, maize, sorghum, and wheat, barley is the sixth crop in terms of area covered and production. In production, maize is the highest followed by tef, sorghum, and wheat (CSA, 2018, 2019, 2020; Figure 7), and all these five major staple crops are in an increasing trend and constitute 95% of the area of cereals and 77% of all grain crops (cereals, pulse and oil crops) and 95.5% of cereal production and 88.5% of out of about 33.5 million tons of grain crops (CSA, 2020). Furthermore, the average productivity of all the five major crops of the three years indicated that maize (4.0 t ha^{-1}) followed by wheat (2.8 t ha^{-1}) and sorghum (2.8 t ha^{-1}), barley (2.3% t ha^{-1}) and tef (1.8 t ha^{-1}) (CSA, 2020; Figure 7). Therefore, the data reveals that the production and productivity of major cereal crops in Ethiopia are in an increasing trend which shows high competition for resources and technology.

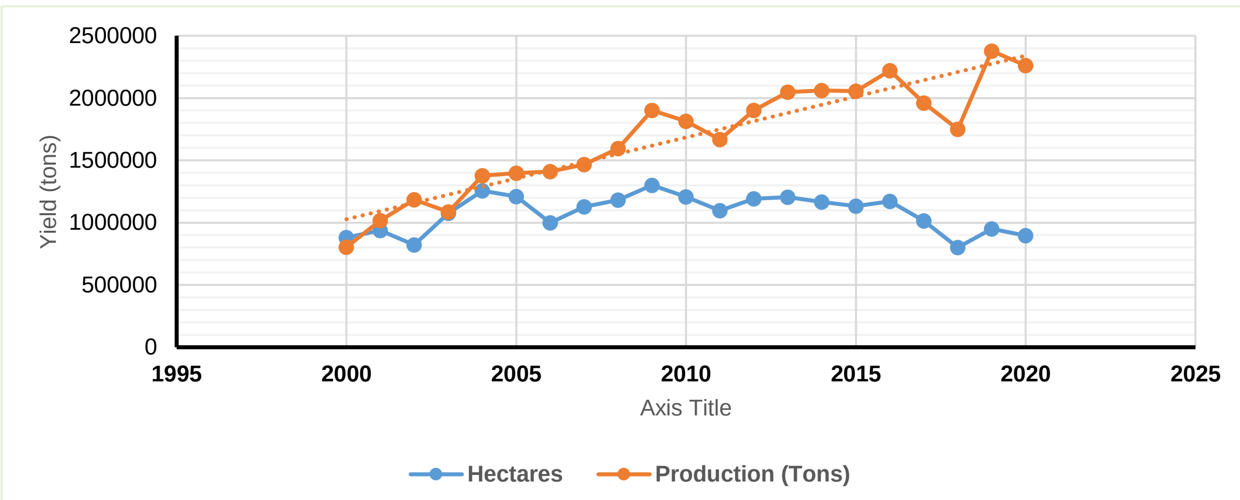

Figure 5. Barley area cultivation and production trends in Ethiopia from 2000 to 2020

Source: Ethiopian Central Statistical Authority (CSA) (CSA, 2020)

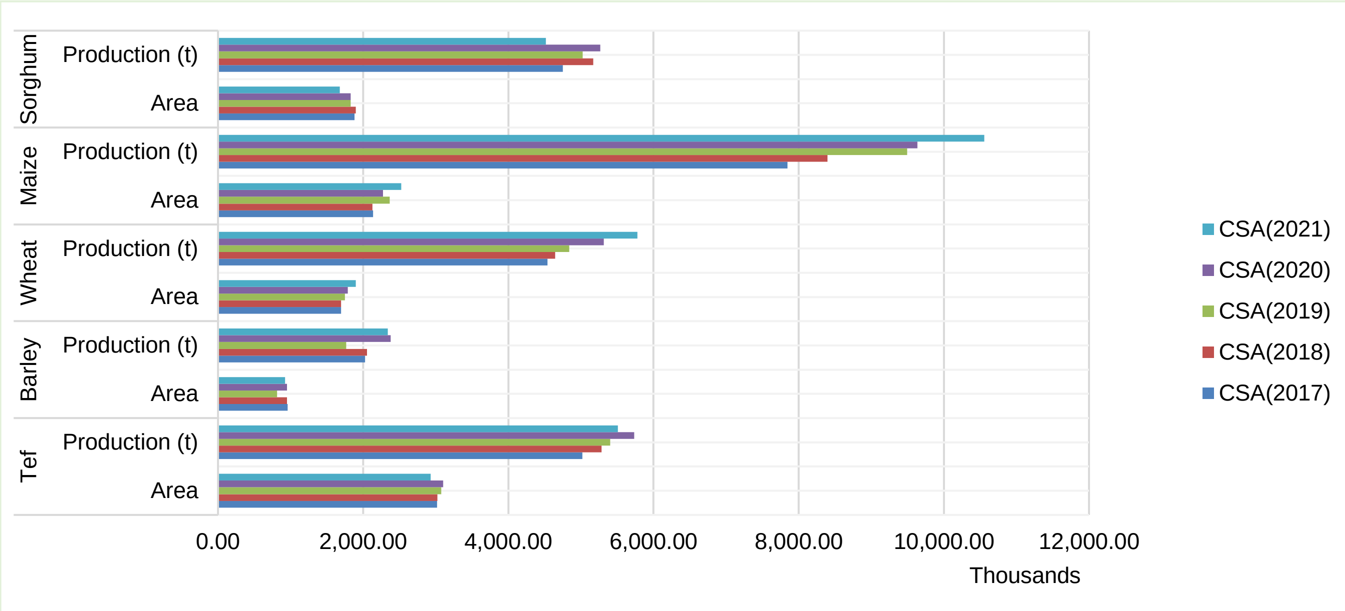

Figure 6. Hectare-based area coverage and tonnage of major cereal crops in Ethiopia for the years 2018 to 2021

Source: CSA (2018-2020)

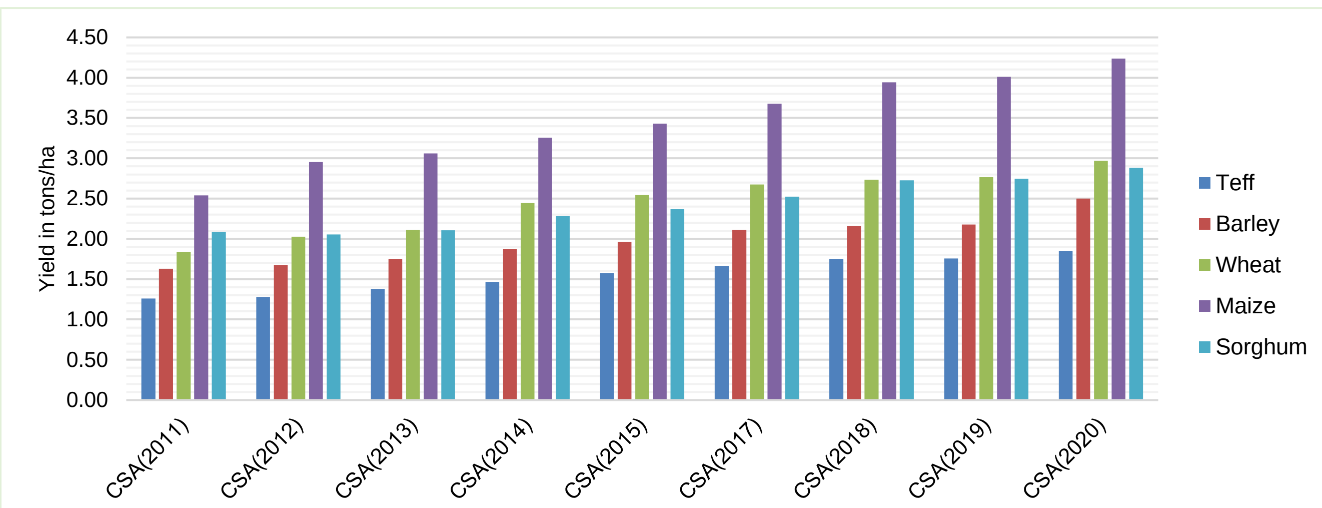

Figure 7. Yield productivity (tons/ha) of main cereals in Ethiopia

Source: CSA (2011-2020

Barley breeding efforts and achievements

Though barley research began in 1955 at Debre Zeit Agricultural Research Center, however, more structured barley research began in 1966 with the founding of Holetta Agricultural Research Centre (HARC) which coordinated the national barley improvement from 1967 to 2005. In 1969, a more detailed breeding plan was set up emphasizing the introduction and evaluation of exotic germplasm including hybridization and selection from large collections of local and exotic germplasm. The research approach from the mid-1980s onwards was based on teamwork while in the 1990s a participatory and multidisciplinary approach was followed that facilitated the development and diffusion of more barley technologies (Bayeh and Berhane, 2011).

From 1966 to 1993, several entries were evaluated but most of the exotic lines were found highly susceptible to scald, net, spot blotches, and barley shoot fly, and had poor plant vigor and small grains. Some outstanding cultivars such as C63 and AHOR 880/61 were released and some other lines were advanced as sources of desirable genes in national crossing programs (Birhanu *et al*., 2005). A more thorough research strategy was established in 1969, and numerous research projects, including hybridization and selection from sizable collections of indigenous and foreign germplasm, were being carried out at Holetta. Additionally, the research methodology from the middle of the 1980s onward was centered on cooperation, while a participative and multidisciplinary methodology was used in the 1990s, which more effectively supported the creation and spread of new barley technologies (Bayeh and Berhane, 2011).

Barley landrace enhancement

Early in the 1970s, when alien cultivars seemed to have limited adaptation and were more vulnerable to diseases and pests, barley research focused on assessing and choosing local landraces. As a result, excellent producing cultivars like IAR/H/485 and ARDU 12-60B were discovered in the 1980s (Berhane *et al.*, 1996). At Holetta and other locations, selections were advanced using the pedigree and mass approaches. Additionally, the program was expanded in 1974 and 1978, and over the years, the pedigree approach was used to examine roughly 378 hybrids. As a result, excellent choices including HB-7, HB-15, HB-26, HB-42, and HB-100 were found. Also released were excellent producing cultivars such as Composite 29, IAR/H/485, AHOR 880/61, HB-42, and ARDU 12-60B (Berhane *et al*., 1996; Hailu *et al*., 1996; Bayeh and Berhane, 2011). In addition, some local landraces have poor yield potential despite demonstrating good adaptation, tolerance, or resistance to diseases and insect pests (Hailu *et al*., 1996; Birhanu *et al*., 2005) and several Yellow Dwarf Virus (BYDV) resistance gene sources were reported from landraces evaluations, while, Line 3296-15 selection was found tolerant to Russian Wheat Aphid (RWA) (Bayeh and Berhane, 2011). In the barley landrace improvement program, 20 varieties were released from regional and national research centers between 1993-2007 (Table 1).

Table 1. Food barley varieties released from the landrace enhancement program by national and regional research centers from 1993-2007.

No.	Variety	Pedigree	Year of release	Releasing center	Developed by
1	Agegnehu	218950-08	2007	Sirinka	Sirinka
2	Guta	3260-18	2007	Sinana	Sinana
3	Gabula	231222/MS	2007	Awassa	Awassa
4	Yedogit	BI95 IN198	2005	Sirinka	Sirinka
5	Dafo	Aruso (42) 4 (Sn99G)	2005	Sinana	Sinana
6	Biftu	Shasho#22GO-1(Sn98B)	2005	Sinana	Sinana
7	Shire	3297-06	2005	Kulumsa	Holeta
8	Dinsho	Wadago-4	2004	Sinana	Sinana
9	Estayish	218963-4	2004	Sirinka	Sirinka
10	Trit	215235-2	2004	Sirinka	Sirinka
11	Mulu	3371-03	2004	Adet	Holeta
12	Setegn	3369-17	2004	Adet	Holeta
13	Harbu	Aruso Bale#10-1	2004	Sinana	Sinana
14	Baso	4731-7	2004	Debre Berhan	Debre Berhan
15	Mezezo	4748-16	2004	Debre Berhan	Debre Berhan
16	Shedho	3381-01	2003	Sirinka	Holeta
17	Dimtu	3369-19	2001	Holetta	Holetta
18	Misrach	Kulumsa1/88	1998	Debre Berhan	Holetta
19	Abay	3357-10	1998	Adet	Holetta
20	Shege	3336-20	1995	Holetta	Holetta

Source: Berhane and Alemayehu (2011).

The six-row and irregular barley types had comparable spike lengths of 3–10 cm and 5–10 cm, respectively, with a mean of nearly 7 cm. The six-row types retained on average 45 seeds per spike, compared with 21 for two-rowed and 24 seeds for irregular types. Similarly, grain yields per spike for the six-row, irregular, and two-row types were on average 2.19, 1.83, and 1.18 g, respectively (Berhane and Alemayehu, 2011). The hull-less cultivars had lower kernel weight and were more susceptible to diseases than the hulled cultivars, according to a study on hull-less barley conducted in the early 1970s. The best hull-less barley (entry 4-73) produced 2.6 t ha^{-1} of grain as opposed to 4.2 t ha^{-1} of Composite 29 (the standard hulled barley) (Hailu *et al*., 1996) showing unsuccessful which signifies the need for research attention for its improvement. Generally, considerable genetic progress was attained from the past barley breeding efforts. Thus, regression of mean analysis on grain yield vs the number of years elapsed since 1970/1973 to 2006 revealed yield gain has risen at an average rate of 44.24 kg ha^{-1} (1.34%) and 42.96 kg ha^{-1} (1.19%) per year of release, respectively, in Ethiopia and the study showed absence of yield plateau indicating the potential for further progress in grain yield in food barley (Fekadu *et al*., 2011).

Malt barley improvement

Malting barley production has a fairly little history and is mostly related to Ethiopian beer production, which began in the early 1920s with the creation of the St. George Brewery **(**Fekadu *et al*., 2013**)** and malt barley research started in Ethiopia to investigate the possibility of local malt barley production by introducing and developing appropriate malt barley technologies to save the foreign exchange incurred from the import of malt (Alemu *et al.,* 2014). According to recent statistics, since 1979 malting barley varieties have shown considerable improvements in quality and yield potential, increasing at an average yearly rate of 28.95 kg ha^{-1} (0.88%) $year^{-1}$. Additionally, kernel plumpness was much enhanced due to the large improvement in kernel size (0.27%) in year ^{1} and the huge decrease in non-standard seed size (2.2 mm) **(**Fekadu *et al*., 2013). In Ethiopia, significant achievements have been made in malt barley productivity and production in the last decade due to the use of improved crop technologies developed by the federal and regional agricultural research institutes. It has been reported that the farmers' demand for IBON 174/03 malt barley variety (ICARDA origin) is ever-increasing due to its high and stable yield, early maturity, and broad adaptation in almost all production sites in the country (Bishaw *et al*., 2020). In another malt barley performance report, the mean grain yield of malting barley varieties ranged from 1853 kg ha^{-1} for Holker to IBON174/03, (3351 kg $ha^{-1.}$ Malt barley varieties, EH1847 and IBON174/03 yielded the highest grain yield of 3340 kg ha^{-1} and 3351 kg ha^{-1}, respectively, followed by Bahati (3240 kg ha^{-1}) including other quality parameters (Assefa *et al*., 2021).

From 1973 to 2012, fifteen malt barley varieties were released from the national agricultural research system in Ethiopia. Import of malt has risen tremendously from about 3.0 thousand tons in 2000 to over 40 thousand tons in 2012 registering 13-fold increases. In 2012, malt imports reached 40.0 thousand tons covering 62% of the total annual demand and costing the country about 27.8 million USD (Alemu *et al.,* 2014**)**.

Major constraints of barley production in Ethiopia

Genetic erosion

Genetic erosion is the loss of genes or alleles, or more broadly, it is the loss of varieties (FAO, 2010). A survey report (Firdissa *et al*., 2010) from central Ethiopia (in Dandi and Jeldu districts, west Showa) showed that there is an increasing loss of genetic diversity of barley landraces. The study indicated that from 14 existing known barley landraces, only four of them are recently under cultivation in the area which might be triggered by an increased use of improved varieties in the area. Girma (2014) also reported an estimated genetic loss of barley in north Showa of Ethiopia accounting for 65%. In the southeastern part of Ethiopia, as documented by Gadisa *et al*. (2021b), cultivation data revealed that out of the 25 distinct barley landraces originally cultivated in the region, only 14 are currently under cultivation. This signifies the elimination of 11 landraces from the district(s), representing a substantial 56.0% combined genetic erosion. This loss poses a significant challenge, as it indicates the disappearance of crucial agronomic traits, thereby becoming a major bottleneck for future improvement and conservation initiatives. The main factors contributing to gene loss include the replacement of local varieties with improved ones, the displacement of local varieties by alternative crops, market-driven agricultural practices, and the impact of pests and diseases, as highlighted in various sources such as FAO (2010) and IBC (2012).

Low-yielding potential varieties

Although several improved barley varieties have been released in Ethiopia, however, still there are large gaps in productivity as compared to the global average (~3.0 t ha^{-1}) and top world barley producers like Germany (6.5 t ha^{-1} and UK and Northern Ireland (5.8 t ha^{-1}) (FAOSTAT, 2022). The presence of low-yielding potential varieties has been reported for its low yield (Bayeh and Berhane, 2011). Samuel (2016) also indicated a shortage of supply of disease-resistant and high-yield varieties as a major constraint. Another report indicated that Ethiopia has been significantly deficient in meeting the ever-increasing malt barley demand of local breweries from domestic production where the net import bill for malt barley continues to increase and projected to reach as high as US $420 million by 2025 (Bishaw and Molla, 2021). This is due to low awareness, limited access, and adoption of improved malt varieties (Bishaw *et al*., 2020). The climate changes are expected to affect the quality and quantity of the harvested grain and it is already a challenge to mitigate the unpredictable seasonal and annual variations in temperature and precipitation under elevated CO_2 by breeding (Meng *et al*., 2023).

Foliar diseases

Research showed that there is a high yield loss due to barley leaf diseases. Worldwide studies on scald showed that under high epidemics 100% losses in susceptible cultivars have been reported (Yahyaoui, 2004). In Australia, barley yield loss can occur between 23 to 44% due to net blotch (Jayasena *et al.*, 2007) and the amount of barley grain produced can also be impacted by net blotch disease, and in the case of severe epidemics, the yield loss due to disease in sensitive cultivars can reach up to 100% (Worku, 2021). Net blotch is also one of the most significant barley diseases in all of the world's major barley-growing countries, with yield losses ranging from 10% to 40% during outbreaks (Mathre, 1997; Zhan *et al*., 2008). According to earlier accounts, there were over 40 different barley diseases in Ethiopia; nevertheless, the three main and most prevalent ones are leaf scald, net blotch, and rust (Yitbarek *et al*., 1996). In addition to this, studies were done in testing the host resistance on 150 barley entries consisting of landraces and varieties at eight locations, Moreover, Bayeh and Berhane (2011) showed scald, net blotch, spot blotch, and rusts causing yield reduction reaching 67% in Ethiopia. Over the past few decades, in many areas of America and Europe, a wide range of virus-disease-resistant barley cultivars has been developed through a hybridization program (Friedt *et al*., 2011).

Insect pest:

Aphids and barley shoot fly pests were reported to cause yield losses of 79% and 56%, respectively, in Ethiopia. (Bayeh and Berhane (2011). The barley shoot fly is a pest that is known to exist in the Bale region and is particularly harmful to barley crops there. Two additional species of shoot flies, one from wheat and the other from barley were discovered in 2003 at Sinana, Bale area, adding to the previous record (Tafa and Tadesse, 2005). *D. arambourgi* and *D. flavibasis*, (*viz* in Bale's high- and mid-altitude regions) two species of shoot fly that are known to attack barley were present in Ethiopia. A survey conducted in the highlands and mid-highlands of Bale revealed that there were significant differences in *D. flavibasis* infestation in every district. As a result of this, improved barley varieties showed poor adaptation in Bale due to heavy shoot fly infestation, except of the local *Aruso'* variety. Depending on infestation and tolerance (crop recovery growth), resistant genotypes were found in barley landrace screening (Tafa and Bayeh, 2011).

The Sinana barley breeding program has made progress in developing food barley varieties with shoot fly resistance such as *Guta* (Acc.3260-18), *Biftu*, *Dafo*, *Dinsho*, and *Harbu* especially from *Aruso* landrace improvement in Bale highlands (Ayalneh *et al*., 2009) and in 2011 another shoot fly resistant variety named *Abdane* (EH956/F2-8H—6-4SNRFBC99G0003-21) was released (Zerihun *et al*., 2011). Besides this, recently a new malt barley variety named *Singitan* was released for production in Bale areas where shoot fly and foliar diseases are affecting barley. This new variety gave 2.5 t ha^{-1} yield, good protein content, good physical grain quality, moderate resistance to common leaf diseases and scald, moderate tolerance to barley shoot fly, and lodging resistance (Mideksa *et al*., 2016). The development of a *Singitan* variety in the Bale region of Ethiopia is a significant achievement in malt barley breeding by Sinana Research Center where shoot fly pests can cause yield losses of up to 100% during shorter rainy seasons (Tafa and Bayeh, 2011).

Lodging:

Ethiopian barleys show sensitivity to lodging (Berhane *et al*., 1996**)** and there has been little research attempt done in Ethiopia. One of the reasons may be the lack of gene sources for dwarf and stiff stems. A study indicated that lodging in barley at heading and by 24% twenty days after heading reduced grain production by around 34% (Pinthus, 1973). However, some lodging can be avoided through genetic resistance, and the majority of the genes for lodging resistance are associated with lower plant stature (Kandemir, 2004) and choosing plants with optimum plant height that are more resistant to lodging can boost grain output in barley (Mirosavljevic *et al*., 2015). Another report revealed that lodging-resistant semi-dwarf barley cultivars have been effectively used in many regions of the world, including China, where they achieved a yield gain of roughly five times that of older cultivars and landraces (Zhang and Zhang, 2003.) and are widely used in USA, Canada, most European countries, Japan and Korea (Hellewell *et al*., 2000). Thus, the improvement of lodging resistance in Ethiopian barley must be encouraged to minimize yield and quality reduction due to lodging.

Breeding for low soil moisture areas

For production in low moisture locations and *Belg* growing season regions of Ethiopia, three varieties, Desta (EMBSN 5th 2/95-3-3-3), Bentu (EMBSN 5th46/95-9-9-5), and Deribe (7thEMBSN 19/98), were released in 2006 and 2008 (Tesfahun *et al*., 2012). In general, for achievement in barley improvement including about resistance to biotic and abiotic stresses, it is also important to integrate the marker-assisted selection. The application of molecular markers in various fields of plant science has demonstrated that molecular technology is a powerful and reliable tool for the genetic manipulation of desirable agronomical traits in crop plants (Jiang, 2013). Molecular markers are not environmentally regulated and are unaffected by the conditions in which the plants are grown and are detectable in all stages of plant growth (Francia *et al*., 2005).

CONCLUSION AND RECOMMENDATIONS

Globally barley production in recent years indicated fluctuation while in Ethiopia the production showed a steady increment. The large barley collections at the Ethiopian gene bank provide prospects for barley improvement in the search for desirable sources of genes. Significant achievements were obtained in the past breeding efforts in the development of several food and malt barley varieties. To attain further success in the barley improvement in Ethiopia, the following points require research attention: (1) Prioritizing the development of high-yielding potential varieties with a broad spectrum of resistance to diseases and pests (2) Development of lodging-resistant barley plants. (3) Crossbreeding of introduced malting barley lines with the barley landraces can improve malting barley adaptation and resistance to pests (4) Integrating the use of marker-assisted selection in crop improvement can improve the precision and efficiency of variety development and utilization of barley genetic sources (5) The current trend of genetic erosion in barley requires its conservation and sustainable use.

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Competing interest

The author declares that there is no competing interest.

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REFERENCES

Alemayehu, F. (1995). Genetic variation between and within Ethiopian barley landraces with emphasis on durable disease resistance. PhD Thesis, Wageningen University, Netherlands. Pp.95.

Alemu, D., Kelemu, K. & Lakew, B. (2014). Value Chain Analysis of Malt Barley in Arsi and West Arsi Zones of Oromia Region, Self Help Africa -Ethiopia, Addis Ababa, Ethiopia.Pp.28.

Allo, A. D., Dawit T. D., Ermias A., Krishna, M. S. R., Singh, B. J. K., Kassahun T. (2021). Spatial and temporal genetic variation in Ethiopian barley (*Hordeum vulgare* L.) landraces as revealed by simple sequence repeat (SSR) markers. *Journal of Agriculture & Food Security* (10)56, 14pp. https://doi.org/10.1186/s40066-021-00336-3

Anderson, B., Zue, Q., Newman, R. & Newman, W. (1991). Serum lipid concentrations of chickens fed diets with flour or red dog from different types of glacier barley. Barley Genetics VI: 461-465.

Assefa, A., Girmay, G., Alemayehu, T. & Lakew, L. (2021). Performance evaluation of malt barley (*Hordeum vulgare* L.) varieties for yield and quality traits in Eastern Amhara Regional State, Ethiopia. *Advances in Agriculture*, Volume 2021, Article ID 5566381, 5 pages. https://doi.org/10.1155/2021/5566381

Ayalneh, T., Zerihun, J. & Amare, B. (2009). Registration of Guta barley (*Hordeum vulgare* L.) variety for Bale highlands. *East African Journal of Sciences* 3(1)108-110.

Bayeh, M. & Berhane, L. (2011). Barley research and development in Ethiopia – an overview. In: M. Bayeh and S. Grando (eds.), Barley Research and Development in Ethiopia, Proceedings of the 2nd National Barley Research and Development Review Workshop, 28–30 November 2006, Holetta, Ethiopia. pp. 1-18.

Berhane, L. & Alemayehu, A. (2011). Advances and experiences in barley landrace improvement in Ethiopia. In M. Bayeh and S. Grando (eds.), Barley research and development in Ethiopia, Proceedings of the 2nd national barley research and development review workshop, 28–30 November 2006, Holetta, Ethiopia. pp. 31-46,

Berhane, L., Hailu, G. & Fekadu, A. (1996). Barley production and research. In: Hailu Gebre and J.van Leur (eds.), Barley Research in Ethiopia: Past work and prospects, Proceedings of the First Barley Research Review Workshop, 16-19 October 1993, Addis Abeba: IAR/ICARDA. Addis Abeba, Ethiopia. pp. 1-8.

Bishaw, Z., Molla, A., Kemal, S.A., Silim, S., Nigussie, D., Yitayeh, M. & Kassie, G.T. (2020). Achievements of seed production and scaling up malt barley technologies in the highlands of Ethiopia. In: Z. Beshaw and A. Molla (eds.), Deployment of malt barley technologies in Ethiopia: Achievements and lessons learned. ICARDA, Pp.238.

Bishaw, Z. & Molla, A.T. (2021). Deployment of malt barley technologies in Ethiopia achievements and lessons learned. International Center for Agricultural Research in the Dry Areas (ICARDA).

Birhanu, B., Fekadu, A. & Berhane, L. (2005). Food barley in Ethiopia. In: S. Grando and H.G\. Macpherson (eds.), Food Barley: Importance, uses and local knowledge, Proceedings of the International workshop on food barley improvement, 14-17 January 2002, Hammamet, Tunisia. ICARDA, Aleppo, Syria. Pp. 53-82.

CSA (Central Statistical Agency). (2018). Agricultural sample survey, 2017/18 (2010E.C). Volume I: Report on area and production of major crops (Private peasant holdings, *Meher* season), Statistical Bulletin 586, Addis Ababa. Pp 53.

CSA (Central Statistical Agency). (2019). Agricultural Sample Survey, 2018/19 (2011 E.C). Volume I: Report On area and production of major crops (Private peasant holdings, *Meher* season), Statistical Bulletin 589, Addis Ababa. Pp. 54.

CSA (Central Statistical Agency). (2020). Agricultural Sample Survey, 2019/20 (2012 E.C). Volume I: Report On Area and Production of Major Crops (Private peasant holdings, *Meher* season), Statistical Bulletin 587, Addis Ababa. pp 133.

CSA (Central Statistical Agency). (2021). Agricultural Sample Survey, 2020/21 (2013 E.C). Volume I: Report on area and production of major crops (Private peasant holdings, *Meher* season), Statistical Bulletin 590, Addis Ababa.Pp.139. https://www.statsethiopia.gov.et/work-with-us/

Dido, A.A., Degefu, D.T., Assefa, E., Krishna, M. S. R., Singh, B. J. K. & Tesfaye, K. (2021a). Spatial and temporal genetic variation in Ethiopian barley (*Hordeum vulgare* L.) landraces as revealed by simple sequence repeat (SSR) markers. A*griculture and Food Security,* 10:56. https://doi.org/10.1186/s40066-021-00336-3

Dido, A.A., Tesfaye, K., Krishna, M. S. R., Degefu, D.T. & Singh, B. J. K. (2021b). Diversity within and among Ethiopian barley (*Hordeum vulgare* L.) landraces in resistance to barley net blotch (*Pyrenophora teres F.teres* (Ptt)). *Australasian Plant Pathology,* 50:217-227. https://doi.org/10.1007/s13313-020-00764-y

Dwivedi, S.L, Salvatore, C., Blair, M. W., Upadhyaya, H. D., Are, A. K., & Ortiz, R. (2016). Landrace germplasm for improving yield and abiotic stress adaptation. *Trends in Plant Science*, 21:31-42. doi: 10.1016/j.tplants.2015.10.012

Fekadu, G., Meskerem, A., and Berhane, W. (2021). Assessment on the Current State of On-Farm Diversity and Genetic Erosion in Barley (*Hordeum vulgare* L.) Landraces from Bale Highlands, Southeast Ethiopia**.** *BioMed Research International* ID 6677363, 12 pp. https://doi.org/10.1155/2021/6677363

Fekadu, W., Zelekle, H. & Ayana, A. (2011). Genetic improvement in grain yield potential and associated traits of food barley (*Hordeum vulgare* L.) in Ethiopia. *Ethiopian Journal of Applied Science and Technology*, 2(2): 39-57.

Firdissa, E., Woldeyesus, S. & Heinrich, G. (2010). On-farm Diversity and Characterization of Barley (*Hordeum vulgare* L.) Landraces in the Highlands of West Shewa, Ethiopia. Ethnobotany Research and Applications, pp.1-34. DOI: 10.17348/era.8.0.25-34

Gadisa, F., Abebe, M. & Bekele, T. (2021a). Agro-morphological traits-based genetic diversity assessment in Ethiopian barley (*Hordeum vulgare* L.) landrace collections from Bale highlands, Southeast Ethiopia. Agr*iculture & Food Security*, 10:58. https://doi.org/10.1186/s40066-021-00335-4

Gadisa, F., Abebe, M. & Bekele, T. (2021b). Assessment on the current state of on-farm diversity and genetic erosion in barley (*Hordeum vulgare* L.) landraces from Bale highlands, southeast Ethiopia. *BioMed Research International*, Volume 2021, Article ID 6677363, 12 pages. https://doi.org/10.1155/2021/6677363

Gamst F.C. (1969). The Qemant: A Pagan-Hebraic Peasantry of Ethiopia. Homewood, IL: Waveland Press.

Girma, M. (2014). Genetic erosion of barley in north Shewa Zone of Oromiya region, Ethiopia. *International Journal of Biodiversity and Conservation*, 6(3):280-289, DOI: 10.5897/IJBC2013.0673

FAO. (2010). The second report on the State of the World's Plant Genetic Resources for Food and Agriculture. Rome.pp370.

FAO. (2012). Synthetic account of the second global plan of action for Plant Genetic Resources for Food and Agriculture, Rome, Italy.

FAOSTAT. (2022). Food and Agriculture Organization of United Nations: Food and agriculture data (https://www.fao.org/faostat/en/#data/QCL/visualize, accessed in September, 2022.

Fekadu, W., Ayana, A. & Zelekle, H. (2013). Improvement in grain yield and malting quality of barley (*Hordeum vulgare* L.) in Ethiopia. *Journal of Applied Science and Technology*, 4(2), 37-62.

Francia, E., Tacconi, G., Crosatti, C., Barabaschi, D., Bulgarelli,D., Dall'Aglio, E. & Vale G. (2005). Marker assisted selection in crop plants. *Plant Cell, Tissue and Organ Culture,* 82: 317–342. DOI 10.1007/s11240-005-2387-z

Friedt W., David Poulsen, D. Richard D. Horsley, Reg C.M. Lance (2011). Barley breeding history, progress, objectives, and technology. barley: production, improvement, and uses. Pp. 158-218. DOI: 10.1002/9780470958636.ch8.

Hailu, G., Berhane L., Fekadu F., Berhanu B., Alemayehu A. & Tesfaye G.. (1996). Food barley breeding. in: Hailu Gebre and Joop van Leur, (eds.), Barley research in Ethiopia: Past work and prospects, Proceedings of the First Barley Research Review Workshop, 16-19 October 1993, Addis Abeba: IAR/ICARDA. Addis Abeba, Ethiopia. pp. 9-23.

Harlan, J.R. (2008). Evolution of Crop Plants. New York. N.W Simmonds (eds.), University of Illinois Urbana Iii USA, Longman.

Hellewell, K.B., Rasmusson, D.C. Gallo-Meagher, M. (2000). Enhancing Yield of Semidwarf Barley. *Crop Science, 40(2), 352–.* doi:10.2135/cropsci2000.402352x

IBC (Institute of Biodiversity Conservation). (2008). Ethiopia: Second Country Report on the State of PGRFA to FAO, January, 2008.Addis Ababa. Pp 45. http://www.fao.org/pgrfa-gpa-archive/eth/Reports/Second_Report.pdf

IBC (Institute of Biodiversity Conservation). (2012). Ethiopia: Third country report on the state of plant genetic resources for food and agriculture, Addis Ababa, October, 2012.pp 105.

Jayasena, K. W., A. Van Burgel, K. Tanaka, J. M. & Loughman, R. (2007). Yield reduction in barley in relation to spot-type net blotch. *Australasian Plant Pathology*, 36, 429–433.DOI: 10.1071/AP0704

Jiang, G.L. (2013). Molecular markers and marker-assisted breeding in plants, In: S.B. Anderson (ed.), Plant breeding from laboratories to fields, InTech. Croatia. Pp.45–83.

Kandemir, N. (2004). Search for high yielding, lodging resistant barley cultivars with satisfactory straw yields for a fertile production area of Turkey. *Pakistan Journal of Biological Science* 7(6):971-976. DOI**:** 10.3923/pjbs.2004.971.976

Mathre, D.E. (1997). Compendium of barley diseases, 2nd ed. American Phytopathological Society, St. Paul, MN. https://www.apsnet.org/publications/apspress/BarleyCompCollab/Shared%20Documents/Previous%20edition%20Word%20files/FrontMat.doc

Meng, G., Rasmussen, S.K., Christensen, C.S.L., Fan, W. & Torp, A.M. (2023), Molecular breeding of barley for quality traits and resilience to climate change. *Frontiers in Genetics,* 13:1039996. doi: 10.3389/fgene.2022. 1039996

Mideksa, T., Tadese, K and Sabsibe, H. (2016). Registration of "Singitan" a newly released malt barley (*Hordeum vulgare* L.) variety for highland areas of Bale. *Academic Research Journal of Agricultural Science and Research*, 4(6): 241-244. DOI: 10.14662/ARJASR2016 .028

Mirosavljevic, M., Przulj, N., Canak, P., Momcilovic, V., Aćin, V., Jockovic, B., Hristov, N. & Mladenov, N. (2015). Relationship between grain yield and agronomic traits in winter barley. *Ratarstvo i povrtarstvo / Field and Vegetable Crops Research* 52 (2):74-79.

Nelson, E, Sander, H, Hawthorne, P, Conte, M, Ennaanay, D, Wolny, S, Manson, S. & Polasky, S. (2010) Projecting Global Land-Use Change and Its Effect on Ecosystem Service Provision and Biodiversity with Simple Models. *PLoS ONE* 5(12): e14327.doi: 10.1371/journal.pone.0014 327

Nevo, E. (1992). Origin, evolution, population genetic and resources for breeding of wild barley, *Hordeum spontaneum,* in the Fertile Crescent. In: P.R. Shewry (ed.), Barley: genetics, biochemistry, molecular biology and biotechnology, CAB International, Wallingford, Oxon. pp. 19-43.

Pinthus, M.J. (1973). Lodging in wheat, barley and oats: the phenomenon, its causes, and preventive measures. *Advances in Agronomy* 25:210-256. http://agris.fao.org/agris-search/search.

Samuel, W.J. (2016). Review on Barley Production and Marketing in Ethiopia. *Journal of Economics and Sustainable Development*, 7(.9): 91-100.

Tafa, J. & Tadesse, G. (2005). *Delia steiniella* Emden: newly recorded pest of wheat (*Triticum aestivum*) and its infestation level at Sinana, Ethiopia. *Pest Management Journal of Ethiopia,* 9: 83–85.

Tafa, J. & Bayeh, M. (2011). Research achievements in barley shoot fly in Ethiopia. In: Bayeh Mulatu and S. Grando (eds.), Barley research and development in Ethiopia, Proceedings of the 2nd National barley research and development review workshop, Holetta Agricultural Research Centre, Ethiopia 28–30 November 2006, HARC, Holetta, Ethiopia. pp. 157-172.

Teklemariam, S.S., Bayissa, K.N., Matros, A., Pillen, K., Ordon, F. & Wehner, G. (2022). The genetic diversity of Ethiopian barley genotypes in relation to their geographical origin. *PLoS ONE,* 17(5): e0260422. https://doi.org/10.1371/journal. pone.0260422

Tesfahun, A., Sentayehu, D., Shemeles, G., & Al-Yassin, A. *(*2012). ICARDA and EIAR Success of Joint Barley-Breeding Program in developing food barley varieties for the Ethiopian low-moisture areas. *International Journal of Water Resources and Arid Environments,*2(1):24-30. https://www.journals.uchicago.edu/doi/10.1093/bjps/III.11.279-a

von Bothmer, R., Sato, K., Komatsuda, T., Yasuda, S. & Fischbeck, G. (2003). The domestication of cultivated barley. In: R. von Bothmer, T.V. Hintum, H. Knu¨pffer., K. Sato (eds.), Diversity in barley (*Hordeum vulgare*), pp. 9–27.

von Bothmer, R., Jacobsen, N.., Baden, C., Jørgensen, R.B. & Linde-Laursen. I. (1991). An ecogeographical study of the genus *Hordeum*. International Board for Plant Genetic Resources, Rome. Pp 127.

Yahyaoui, A.H. (2004). Occurrence of barley leaf blights in Central Western Asia and North Africa. In: A.H. Yahyaoui, I. Brader, A. Tekauz, H. Wallwork., B. Steffenson (eds.), Meeting the challenges of barley blights, Proceedings of the Second International workshop on barley leaf blights, 7–11, April 2002, ICARDA, Aleppo, Syria. pp. 13–18.

Yitbarek, S., Bekele, H., Getaneh, W. & Dereje, T. (1996). Disease survey and loss assessment studies on barley. In: Hailu Gebre and J.van Leur (eds.), Barley Research in Ethiopia: Past work and future prospects, Proceedings of the first barley research review workshop, 16-19 October 1993, IAR/ICARDA, Addis Ababa.pp. 105-115.

Zemede, A. (2000). The barleys of Ethiopia. In*:* S.B. Brush (ed.), Genes in the Field: On farm Conservation of crop diversity, IDRC and IPGRI, Rome, Italia. pp. 77-107.https://www.idrc.ca/en/book/genes-field-farm-conservation-crop-diversity.

Zerihun, J., Amsalu, A. &. Fekadu, F. (2011). Assessment of yield stability and disease response of in Ethiopian barley (*Hordeum vulgare* L.) landraces and crosses. *International Journal of Agricultural Research*, 6(11):754-768. DOI.10.3923/hjar.2011.754.768.

Zhan, J., Fitt, B.D.L, Pinnschmidt H.O., Oxley S.J.P. & Newton, A.C. (2008). Resistance, epidemiology and sustainable management of *Rhynchosporium secalis* population on barley. *Plant Pathology* 57: 1–14.

Zhang, J. & Zhang, W. (2003). Tracing sources of dwarfing genes in barley breeding in China. *Euphytica*, 131:285–293.

Worku, A. (2021). Barley net blotch disease management: A Review. *International Journal of Environmental and Agriculture Research*, 07(3):69-81.