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Review Article

Genetic Merits of Ethiopian Barley Landraces in Developing Variety for Moisture-Stressed Environments: A Review

Aliyi Robsa Shuro*

Kulumsa Agricultural Research Center (KARC), Ethiopia Institute of Agricultural Research (EIAR), Asela, Ethiopia

Abstract

Barley (*Hordeum vulgare L.*) is an important cereal crop grown in diverse agro-ecological zones worldwide, ranging from lowland (in regions facing moisture stress) to highland areas. Ethiopian barley landraces are known for their resilience to these stresses, and they possess valuable genetic traits that make them a potential resource for developing drought-tolerant varieties. This review highlights the genetic diversity of Ethiopian barley landraces and their role in improving barley's resilience to moisture stress, which is increasingly important in the face of climate change. The genetic traits of Ethiopian barley landraces, such as drought resistance, water-use efficiency, and yield stability under water-limited conditions, are central to their ability to thrive in challenging environments. These traits have evolved over centuries, allowing Ethiopian barley to adapt to the country's diverse agro-ecological zones. With Ethiopia recognized as a center of genetic diversity for barley, the local landraces represent a critical genetic reservoir for breeding drought-tolerant varieties that can withstand the unpredictable rainfall patterns associated with climate change. Conventional methods, such as hybridization and selection have shown success in improving drought tolerance by incorporating desirable traits from landraces into elite cultivars. Despite the considerable potential of Ethiopian barley landraces, several challenges hinder their full utilization. These include genetic erosion due to the widespread adoption of modern cultivars, the impacts of climate change on traditional growing conditions, and limited research infrastructure. Addressing these challenges will require collaborative efforts between farmers, researchers, and international organizations to conserve and exploit the genetic resources of Ethiopian barley. By doing so, Ethiopia can enhance the development of drought-resistant barley varieties that will contribute to global food security in the face of changing climate conditions.

Keywords

Barley Breeding, Drought Resistance, Drought Tolerance, Early Maturity, Ethiopian Barley, Food Security, Genetic Diversity, Landraces, Moisture Stress, Root Architecture

1. Introduction

Barley (*Hordeum vulgare L.*) is the fourth most important cereal crop in the world, after wheat, maize, and rice, in terms of area under cultivation [1]. It is grown in diverse environments, ranging from highlands to semi-arid regions, where it

*Corresponding author: aliyirobsa@gmail.com (Aliyi Robsa Shuro)

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plays an essential role in food security, livestock feed, and brewing industries. Barley is widely cultivated across Europe, North America, and Asia, with Russia being the leading producer in terms of total production. Meanwhile, France ranks highest in terms of yield per hectare [2].

Barley has deep historical and cultural significance in Ethiopia, with evidence of its cultivation dating back over 5,000 years. It is grown during two distinct seasons: the *'Meher'* season, which corresponds to the main rainy period from June to October, when a variety of genotypes are cultivated, and the 'Belg' season, a shorter rainy period from late February to early July, when mainly early-maturing varieties are planted. Today, barley ranks as the fifth most important cereal crop in Ethiopia, predominantly grown in the highland regions at altitudes ranging from 2,000 to 3,500 meters above sea level. These highland areas present challenging conditions, including soil erosion, acidity, occasional drought, and frost, which limit the viability of other crops [3]. The major barley-producing areas of Ethiopia are Shewa, Gojam, Arsi, Gonder, Wollo, and Bale, which collectively contribute to over 85% of the country's total barley production [4].

Barley (*Hordeum vulgare L.*) is one of the oldest domesticated cereals, with a long history of cultivation worldwide. It traces its origins to the wild species "*Hordeum spontaneum*", which is native to regions of Asia and North Africa. This early domestication has made barley a cornerstone of agriculture for more than 10,000 years [5].

Ethiopia is recognized as a center of genetic diversity for barley, with its landraces exhibiting distinct genetic traits compared to other barley populations globally. The rich genetic diversity of Ethiopian barley is likely due to the country's varied topography, elevation, climate, soil types, and farming systems.

Over thousands of years, barley thrive in a wide range of environmental conditions and has the ability to grow in a diverse environmental condition, securing its place as a vital crop in both ancient and modern agricultural systems. Its resilience makes it particularly valuable in regions with harsh climates or poor soils, where other crops may not survive [3]. Barley's adaptability has enabled it to flourish in areas facing challenges like water scarcity, low soil fertility, and extreme temperatures, thus supporting food security and livelihoods in many parts of the world. On other hand, barley thrives in cooler highland climates, which makes it an essential crop in Ethiopia's agricultural systems. Its versatility has allowed for its cultivation in over 100 countries, with Ethiopia being one of the key regions where barley plays a crucial role in both food security and agriculture [6, 2]. Beyond food production, barley is also critical for animal feed and the malting industry, making significant contributions to rural livelihoods and the broader economy. Despite its widespread cultivation, barley yields in Ethiopia average approximately 2.1 tons per hectare, which is lower than the global average of 3.1 tons per hectare [4]. This yield gap can be attributed to a combination of abiotic stresses, such as soil acidity and frost, as well as biotic stresses, including diseases, pests, and weeds, which significantly hinder barley productivity in the country.

Many studies have highlighted the high genetic diversity present among barley genotypes, which is valuable for identifying and combining favorable alleles to enhance desirable agronomic traits. This diversity is essential for modern plant breeding, as it provides a reservoir of novel traits that can help improve the crop's resilience to various stresses. Such genetic variation is crucial for developing barley varieties with enhanced tolerance to challenges like drought, disease, and poor soil conditions [7, 8].

Moisture stress is a major abiotic factor that significantly impacts crop production in many regions, particularly in areas with irregular or insufficient rainfall. This stress can result in reduced germination rates, poor seedling establishment, stunted growth, premature flowering, and, ultimately, lower crop yields [7]. In Ethiopia, where agriculture is heavily dependent on rainfall, addressing moisture stress is essential for ensuring food security. The development of drought-tolerant barley varieties is a key strategy for mitigating the effects of water scarcity, particularly in light of climate change, which is expected to intensify rainfall variability and exacerbate water shortages [8]. Ethiopian barley landraces, having evolved over centuries under local environmental pressures, demonstrate a significant degree of genetic diversity, making them a valuable resource for breeding drought-tolerant varieties. These landraces are particularly well-suited to the moisture-limited conditions of the Ethiopian highlands, where they exhibit traits related to drought resistance, water-use efficiency, and yield stability, which are essential for enhancing agricultural resilience in the face of climate change.

Barley improvement relies heavily on genetic diversity, which is essential for the success of breeding programs. The genetic diversity of barley can be traced back to a small number of farmer varieties, which serve as the primary sources of genetic material for breeding efforts [17]. The selection of parent varieties for breeding is a key factor in crop improvement, and categorizing accessions into morphologically related clusters plays an important role in this process [18]. Thus, understanding the existing morphological diversity in barley germplasm is an important step in enhancing the selection of breeding materials with varied genetic backgrounds and efficient management of crop genetic resources [27, 28].

Therefore, the objective of this review is to examine the genetic diversity of Ethiopian barley landraces, explore their potential for developing drought-tolerant varieties, and highlight their role in improving barley breeding programs. This review also aims to provide insights into the adaptation of these landraces to the diverse agro-ecological zones of Ethiopia, and to discuss the significance of preserving these landraces for future crop improvement in the face of climate change and other environmental stresses.

2. Genetic Diversity of Ethiopian Barley Landraces

Ethiopian barley landraces are celebrated for their rich genetic diversity, shaped by centuries of adaptation to the country's diverse agro-ecological zones. This genetic pool encompasses varieties with distinctive traits, such as early maturity, deep root systems, and efficient water use. The diversity within these landraces can be broadly categorized into two main groups: highland landraces, which are suited to cool and moist environments, and lowland landraces, which have adapted to the harsher, arid, and semi-arid conditions found in lower altitudes. The introduction of modern barley cultivars to Ethiopia started in the 20th century [9]. However, the Ethiopian barley cultivation system still depend on several unique landraces [10-14]. Barley landraces are widely cultivated in Ethiopia and considered to be an important source of genes for stability traits.

The study by [15] demonstrated that a phylogenetic analysis of Ethiopian barley landraces shows a clear genetic difference between Ethiopian and non-Ethiopian populations. Such genetic variation underscores the presence of distinct landrace groups, with Ethiopian barley landraces being specially adapted to the traditional farming systems and varied landscape conditions found across the country [16]. Ethiopia is globally recognized as a center of genetic diversity for barley [19, 20], with its genetic variation primarily shaped by a combination of factors such as soil types, climate, altitude, topography, and diverse farming systems, as well as the country's long periods of geographical isolation [23, 22]. Ethiopian barley landraces are particularly notable for their high potential for drought tolerance. Landraces collected from various regions of the country exhibit distinct traits, such as differences in earliness [24], and demonstrate higher yield stability compared to improved cultivars, often with a greater grain yield gain [25, 21]. This suggests that Ethiopian barley landraces may employ multiple mechanisms of drought tolerance to cope with varying degrees of water stress. Study of Genome wide association [26] on 239 Ethiopian barley landraces and 21 breeding pipelines for terminal drought stress tolerance under field and climate chamber conditions revealed the tolerance of Ethiopian landraces to different levels of drought stress as well as their potential to be considered in future barley improvement programs.

3. Genetic Merits for Moisture Stress Tolerance

Several studies have identified key traits in Ethiopian barley landraces that contribute to drought tolerance. These traits can be broadly categorized into morphological, physiological, and biochemical characteristics:

1. Morphological Traits

Studying morphological diversity is a crucial initial step before applying more advanced tools such as molecular and genomic techniques. Understanding the existing morphological diversity in barley germplasm is essential for improving the selection of breeding materials with diverse genetic backgrounds and for effective management of crop genetic resources [27, 28]. Previous research has highlighted significant morphological variation in Ethiopian barley germplasm. For instance, studies on 22 accessions for nine qualitative traits [33], on 44 landraces for four qualitative traits (Assefa & Labuschagne, 2004), on 106 landraces for eight qualitative traits [35], on 43 landraces for eight qualitative traits [34] on 102 accessions for six qualitative traits [22], on 36 landraces for 11 qualitative traits [29], and on 120 landraces for seven qualitative traits [31] showed significant morphological variation in Ethiopian barley germplasm. These studies provide valuable baseline data for distinguishing genetic resources from diverse geographic areas, which is essential for efficient germplasm collection and utilization in barley breeding [22, 32].

1) *Early Maturity*: Many Ethiopian barley landraces have a shorter growth cycle, which allows them to escape drought stress during the reproductive stages by completing their life cycle before the onset of severe water scarcity. Early maturity is a critical adaptive trait in moisture-stressed environments.
2) *Root Architecture*: Some landraces exhibit deeper or more extensive root systems, which enable them to access water from deeper soil layers. These landraces are more drought-tolerant because they can maintain better water uptake during dry periods.
3) *Leaf Characteristics*: Landraces with smaller leaves or reduced leaf area may exhibit lower transpiration rates, thereby conserving water during periods of drought. Leaf pubescence (hairiness) is another trait that can reduce water loss by reflecting sunlight and reducing evaporation.

2. Physiological Traits

Water Use Efficiency (*WUE*): WUE is an important trait in drought-prone environments, as it reflects the plant's ability to convert water into biomass or yield. Barley landraces that exhibit higher WUE can maintain productivity despite water deficits.

4. Conventional Breeding for Moisture Stress Tolerance

The rich genetic diversity of Ethiopian barley landraces offers significant potential for conventional breeding programs aimed at improving drought tolerance. Traditional breeding approaches, such as selection for early maturity, hybridization of drought-tolerant landraces, and backcrossing, have been successfully employed to develop drought-tolerant barley varieties. Crosses between drought-resistant landraces and improved varieties have been used to introduce desirable traits such as deep rooting, early flowering, and water use efficiency into elite barley cultivars.

Marker-assisted selection (*MAS*) is a promising tool in conventional breeding, enabling breeders to identify and select for specific drought tolerance traits at the molecular level. By leveraging molecular markers associated with traits like early maturity, root architecture, and osmotic adjustment, MAS can expedite the development of barley varieties with enhanced moisture stress tolerance.

5. Modern Biotechnology Approaches

Modern biotechnological techniques, such as genomic selection, CRISPR/Cas9 gene editing, and transgenics, offer additional avenues for improving drought tolerance in barley. The availability of high-quality barley genome sequences and the identification of drought-responsive genes opens up the possibility of fine-tuning these genes through gene editing or transgenic approaches. For example, the overexpression of genes involved in ABA biosynthesis or drought stress signaling could enhance the plant's ability to withstand moisture stress.

Moreover, transgenic barley carrying genes from other drought-tolerant species has shown promise in laboratory and field trials. However, concerns over the environmental and socio-economic impacts of genetically modified organisms (GMOs) must be addressed to ensure the safe adoption of such technologies in Ethiopia.

6. Challenges and Opportunities

Despite the promising genetic diversity of Ethiopian barley landraces, several challenges remain in the effective utilization of these resources for breeding drought-tolerant varieties. These challenges include:

1) *Genetic Erosion*: Landrace populations are often at risk of genetic erosion due to the adoption of modern cultivars and changing farming practices. Efforts to conserve these landraces through in situ and ex situ conservation methods are essential to preserve their genetic potential.
2) *Climate Change*: As climate change exacerbates water scarcity in some parts of Ethiopia, the environmental conditions that barley landraces have adapted to are likely to change, making it challenging to predict which traits will be most beneficial in the future.
3) *Limited Research and Infrastructure*: While there is a growing body of research on the genetic merits of Ethiopian barley landraces, further studies are needed to understand the genetic basis of drought tolerance in these landraces and to develop breeding programs that can efficiently incorporate these traits into improved varieties.

Despite these challenges, there are numerous opportunities for advancing drought-tolerant barley breeding in Ethiopia. Collaborative efforts between local farmers, research institutions, and international organizations can help maximize the genetic potential of Ethiopian barley landraces and develop resilient varieties suited to the changing climate.

7. Conclusion

Ethiopian barley landraces represent a rich genetic resource that holds great promise for improving drought tolerance and other agronomic traits in barley. These landraces, shaped by centuries of adaptation to the country's diverse agro-ecological conditions, exhibit traits that can contribute to higher yield stability, improved water-use efficiency, and greater resilience to climate-induced stresses. Although challenges like genetic erosion and climate change complicate the preservation and utilization of these genetic resources, there is ample opportunity for integrating these landraces into modern breeding programs. Continued research, including the use of advanced biotechnological tools and breeding methods, will be critical in harnessing the full potential of Ethiopian barley germplasm. Preserving and effectively utilizing these landraces will play a pivotal role in ensuring food security and agricultural resilience in Ethiopia, particularly in the face of an increasingly uncertain climate.

Abbreviations

KARC	Kulumsa Agricultural Research Center
EIAR	Ethiopia Institute of Agricultural Research
WUE	Water Use Efficiency
GMOs	Genetically Modified Organisms
MAS	Marker-assisted Selection

Author Contributions

Aliyi Robsa Shuro is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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