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Agronomic performance of 105 varieties of barley for malting purposes under field conditions using a sustainable approach

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Abstract. Barley is widely recognized as one of the four major crops, along with wheat, maize, and rice. Nowadays, these characteristics are as desirable as ever under the sustainable crop production wing. As such, research regarding alternatives for increasing yield and quality production has led to different trends where Genetically Modified Organisms (GMO), variety breeding, and the mapping of desirable genetic trends are probably among the main goals within cereal research. Considering the aforementioned, this research aimed to study the main agricultural characteristics of 105 different varieties of barley growing under field conditions following a sustainable agricultural practice protocol, including their resistance against some of the most common threats to this crop (yellow rust, leaf rust, and barley yellow dwarf virus). This included varieties from different regions, and the most commonly used ones by local producers. Results from this study showed that 10.9% of the tested varieties were able to fully grow. More importantly, these included 2 out of 4 locally grown varieties. Regarding plants' resistance to diseases, all germinated varieties showed similar traits. However, when looking at the seed proximate analysis, five of these varieties were shown to be unsuitable for malting purposes. Overall results showed that a small percentage of varieties (7.61%) meet both disease resistance and malting standards under a sustainable agricultural practice. These results allow for the identification of the strengths of locally produced crops under commonly used agricultural practices as a viable alternative to the use of agrochemicals.

Key words: cereal, varieties, disease resistance, sustainable crop production, environmental conditions

INTRODUCTION

Barley (*Hordeum vulgare* L.) has historically been recognized as a reliable crop for both human consumption and feedstock production. Nowadays, it is considered amongst the most important crops in the world alongside maize, rice, and wheat (El-Hashash & El-Absy, 2019). As such, research on different aspects of this plant species has consistently been developed, aiming to address most of its major limitations (Jiang et al., 2025). Among these, diseases, adaptation towards environmental conditions, and climate change represent some of the numerous challenges that barley production will face to remain a viable crop. Knowing this, research regarding the development of different strategies to improve both the quantity and quality of barley has remained as the main interest among scientists and engineers (Verstegen et al., 2014; Jiang et al., 2025). As pointed out by Jiang et al. (2025), barley is probably one of the most studied crop species, being a staple for different research trends such as the development of hybrid breeding, mapping of genetic traits, and the production of genetically modified organisms (GMOs).

More importantly, tropical and sub-tropical regions of the world tend to highly depend on agricultural activities to thrive economically. This is mainly due to relatively favorable environmental conditions throughout the year. However, although the tropical regions of the world are often associated with a temperate climate and enough precipitation to ensure crop viability, they also tend to face some specific traits that could lead a reduced crop production as well as being more susceptible to pests and diseases (Albino & Callado, 2012; Vázquez-Luna et al., 2019). Consequently, several areas of the tropics pose certain contrasting characteristics that might compromise proper agricultural production (Guerra Sierra et al., 2021). In addition, soil from this region of the world is characterized by a range of traits that might compromise nutrient availability and ultimately limit plant nutrition (Fageria & Moreira, 2011). Combined, these conditions tend to increase farmers' dependence on certain soil enhancers such as fertilizers and pesticides. Even though these can offer significantly important advantages to farmers, today's market has consistently shown a tendency towards a chemical-free production, making it especially important to develop new technologies in this field. Consequently, research regarding this subject has developed within a wide range of areas, including the improvement of soil desirable traits such as nutrient and water availability (Kang et al., 2022), pests and disease control (Jaiswal et al., 2022), as well as improvement within seed, seedling, and plant development (Fiodor et al., 2023), to name some.

Further to this, in addition to the constraints that crops might have to overcome due to environmental conditions, varieties from the same species have commonly shown significant differences regarding tolerance to stressors. For instance, landraces are often recognized as highly tolerant against hostile environmental conditions when compared to other genotypes (Yumurtaci, 2015; D'Souza et al., 2025). Moreover, recent research has emphasized the relevance of further looking at the differences between modern varieties of several species against these landraces (Katsileros et al., 2025; Martin et al., 2025). For instance, authors over the years have consistently pointed out the importance of using crops that are capable of properly developing under a site's specific conditions, as well as the implications that these will have within different aspects (Newton et al., 2010; Fradgley et al., 2019). Among these, one field that has gained major relevance in recent years is sustainable crop production (Newton et al., 2010; Adhikari et al., 2022). Even though sustainability is a commonly used word, the relevance that this concept can have in everyone's life is often underestimated. When talking about sustainable food systems, the ability to produce enough resources to meet dietary needs is one of the main goals for the modern world (Andersson et al., 2024). In this regard, research focused on comparisons between landraces and modern species has been previously performed (Newton et al., 2010). Similarly, efforts are made to identify the viability of seeds from different varieties of the same species. This is mainly due to the interest in introducing plant varieties capable of producing a larger and better yield. Such studies have been reported for different grains, such as rice (Barus et al., 2023) or wheat (Ghimire et al., 2023). However, these studies are scarce, yet typically acknowledged as necessary to ensure sufficient production with minimal resource use. Bearing this in mind, the present study aimed to assess the seed viability and further development of 105 different lines under field conditions. Moreover, the resistance of germinated seeds was evaluated against some of the most common diseases. Results from this study represent a significant insight into the most resistant lines of barley capable of properly germinating and developing within a chemical-free environment as an ecologically and economically viable crop in a tropical climate.

MATERIALS AND METHODS

Soil characterization and preparation

An experimental field located in the Tulancingo Municipality in the Institute for Agricultural Science of the Universidad Autónoma del Estado de Hidalgo (UAEH) (Hidalgo, Mexico) was selected as the study area. This farmland has a history of usage for growing different crops while mainly using extensive agricultural practices. Soil was further characterized to varying depths in order to identify any possible significant differences amongst horizons. For this, chemical characteristics of the soil were assessed: soil pH (H_20 and KCl), organic matter (%), total cation exchange capacity (cmol K^{-1}), exchangeable bases (K, Ca, and Mg), and saturation bases. Moreover, physical traits were also evaluated: density (real and bulk) (mg/m^3), porosity, color, and texture. Overall methodology followed standard methods and local and international regulations regarding soil characterization (Diario Oficial de la Federación, 2002; Burt, 2014).

Sowing assays

Seeds from 101 different varieties of barley were sown and grown. Seeds were obtained from the personal collection of Dr. Sanjaya Rajaram. Dr. Rajaram was the winner of the 2014 World Food Prize and was fully committed to the study of high-yielding and disease-resistant varieties of wheat and barley. Studied varieties included seeds from around the world, including the most commonly used ones in Mexico. Alongside these seeds, 4 locally grown varieties were also included in the study (Supplementary Information). For this, seeds were sown using a randomized block design ($n = 3$) at a 100 kg ha^{-1} seed rate. Further to this, experimental units were arranged using beds (5 m long) and left under field conditions for the entirety of the experiment. Soil fertilization was performed according to local agricultural practices, which consisted of adding dried cattle manure as reported by Santillán et al. (2014).

During this period, different morphological characteristics and vulnerability against the most common diseases were evaluated. Morphological characteristics were assessed through the recording of overall height, leaf blight (*Xanthomonas translucens*), and flowering. These traits were selected based on the main stages of phenological development of plants (Prysiazhniuk et al., 2022). On the other hand, vulnerability against diseases was assessed through the evaluation of yellow rust (*Puccinia striiformis* Westend.), leaf rust (*Puccinia hordei* G.H. Otth), and barley yellow dwarf virus (BYDV) (Peterson et al., 1948; Schaller & Qualset, 1980; Sharma, 2023). Full flowering and seed development were followed over a period of up to 90 days.

Seed chemical and physical characterization

To assess not only germination but also seed quality, a proximate analysis of seeds from the germinated plants was performed by evaluating protein, humidity, ash, crude fiber, and fat content (%). Further to this, the total content of CHO and the amount of malting barley (%) were also evaluated. Methods for this were in accordance with the recommendations made by López et al. (2007). Additionally, the physical characteristics of the seeds were estimated, taking into account relevant production traits. For this, the percent of germination, hardness, damaged grains, and naked and/or broken grains were also quantified in accordance with the methods used by López et al. (2005), and recommended by local regulations through the norm NMX-FF-043-SCFI-2003 (Secretariat of Economy, 2003). Further to this, the obtained data were compared against local regulations regarding barley for human consumption as a cereal and for malting purposes (Secretariat of Economy, 2003).

RESULTS AND DISCUSSION

Soil characterisation

Soil showed similar characteristics across different depths ($p > 0.05$), as shown in Table 1.

Although barley is a ubiquitously distributed cereal, certain soil and environmental characteristics must be met. In the case of soil properties, these are the result of complex interactions between the different paedogenic factors (Ayoubi & Sahrawat, 2011). Further to this, different plant species will require certain specific characteristics from the soil and ultimately thrive under these conditions. In the case of barley, a strong relationship has been reported between barley biomass and production and soil electrical conductivity, pH, total nitrogen, available phosphorus,and soil organic matter (Ayoubi & Sahrawat, 2011). This is in accordance with the report made by

Table 1. Overall physical and chemical characteristics of the soil. Values represent the mean ± standard error of the mean

Characteristic		Value
pH (H_2O)		6.34 ± 0.09
pH (KCl, 1:5)		5.27 ± 0.11
SOM (%)		3.16 ± 1.20
C (%)		1.83 ± 0.70
CEC (cmol kg^{-1})		22.77 ± 3.09
Saturation base		26.39 ± 2.66
Bulk density		0.91 ± 0.04
Real density		2.41 ± 0.08
Exchageable bases	Na	0.53 ± 0.03
(cmol(+) kg^{-1})	K	1.20 ± 0.20
	Ca	3.83 ± 1.52
	Mg	0.99 ± 0.21

Lovarelli et al. (2020), who also observed a significantly higher barley production when slurry was used as a soil conditioner instead of inorganic fertilizers. This might be given that animal slurry not only provides a source of bioavailable nutrients but also acts as an enhancer of soil structure and input of organic matter. As for the case of the present study, as expected, soil organic matter (SOM) in the first 15 cm of soil was observed to be the highest within soil horizons. More importantly, as root depth for this species typically does not tend to exceed 30 cm below ground level (Reid, 2015), SOM among the rhizosphere ranged from 10.21% (0-15 cm depth) down to 4.05% (25-35 cm depth).

Although it is not easy to establish a direct relationship between SOM and yield production, some indicators have been developed to evaluate how this parameter can be associated with crops. In the case of barley, for instance, Quiroga et al. (2006) have shown a significant relationship between the ratio of SOM to clay + silt and grain production. This has been historically attributed to various factors, such as sorption-desorption processes that directly intervene in the fate and behaviour of nutrients (Quiroga et al., 2006), or the soil's water-holding capacity (Bashir et al., 2021). Above all, soil characteristics will be the result of the interaction between both biotic and abiotic factors. This is especially important in tropical regions of the world, where climatic conditions will tend to pose a larger pressure on certain characteristics, such as an accelerated nutrient and SOM cycling (Nair et al., 2021), and therefore produce a low availability of nutrients. The aforementioned behaviour has been considered by some as one of the bigger threats to food production and ultimately self-sufficiency in a vast majority of countries distributed across the tropical and subtropical regions of the world (Gallup & Sachs, 2000; Albino & Callado, 2012; Rahman et al., 2022). Therefore, the relevance of finding varieties of crops capable of thriving under these circumstances has constantly arisen as a global concern. As for the case of this study, soil characteristics coupled with environmental and climatic conditions favour the germination and further development of 12% of the tested varieties. Significantly, these varieties were able to fully grow and produce grains under what nowadays is known as a sustainable agricultural practice (Rehman et al., 2022), but historically used within tropical and subtropical regions of the world (Mcclung De Tapia, 2016).

Plant development and susceptibility to diseases

Of all 105 different varieties of barley, 13 were able to develop under field conditions (Table 2). Of these, 11 varieties originated from seeds in the personal collection of Dr. Sanjaya Rajaram, and two from locally grown barley varieties. Height, maturity, and agronomic evaluation ranged among varieties with a mean height of 83.84 ± 2.72 cm (mean ± sem). Furthermore, only one of the varieties showed an early development, taking 70 days to full maturity. More importantly, although these varieties were able to fully grow and further produce grains, they exhibited a range of characteristics and resistance against diseases (Table 2). As for the case of Yellow Rust, the entirety of the varieties showed to be highly resistant. Regarding leaf rust, pustules covered from 5 to 90% of the leaf with a severity ranging from susceptible to moderately susceptible. It is important to note that none of the plants were observed to be highly resistant to leaf rust.

Table 2. Varieties of barley capable of developing under field conditions

Code	Cross and pedigree	YR	LR	BYDV	LB	Heigth	Maturity
2	Chamico CMB89.324-D-1Y-1M-1Y-0B	TR	90S	3	4	80	M
7	LEGACY/4/TOCTE//GOB/HUMAI10/3/ ATAH92/ALELI CBSS00B00201S-25GH-1M-2Y-3FGR-2Y-0M	TR	50S	4	4	75	M
8	LEGACY/4/TOCTE//GOB/HUMAI10/3/ ATAH92/ALELI CBSS00B00201S-25GH-1M-2Y-3FGR-4Y-0M	TR	50MS	6	5	90	M
9	LEGACY/4/TOCTE//GOB/HUMAI10/3/ ATAH92/ALELI CBSS00B00201S-25GH-1M-2Y-3FGR-7Y-OM	TR	20MS	4	5	90	M
10	LEGACY/4/TOCTE//GOB/HUMAI10/3/ ATAH92/ALELI CBSS00B00201S-25GH-1 M-2Y-3FGR-8Y-0M	TR	10MS	4	5	90	M
19	LEGACY/4/TOCTE//GOB/HUMAI10/3/ ATAH92/ALELI CBSS00B00201S-25GH-1M-2Y-5FGR-7Y-0M	TR	20MS	4	7	90	M
20	LEGACY/4/TOCTE//GOB/HUMAI10/3/ ATAH92/ALELI CBSS00B00201S-25GH-1M-2Y-5FGR-8Y-0M	TR	20MS	4	5	95	M
83	LEGACY/CHAMICO CBSSOOB00207S-95GH-1M-1Y-1FGR-4Y-OM	TR	70S	3	3	85	M
86	LEGACY/CHAMICO CBSS00B00207S-95GH-1M-1Y-3FGR-9Y-0M	TR	70S	4	4	90	M
87	LEGACY/CHAMICO CBSS00B00207S-95GH-1M-1Y-3FGR-10Y-0M	TR	70S	4	4	90	M
100	6B89.2027/CHAMICO CBSSOOB00210S-50GH-1M-2Y-4FGR-9Y-OM	TR	70S	4	4	85	M
102	ESMERALDA	TR	5MR	6	6	65	E
106	ORCA	TR	30MS	4	4	65	M

YR: Yellow rust; LR: Leaf rust; BYDV: barley yellow dwarf virus; LB: Leaf blight; Maturity: M/Mid, E/Early.

On the other hand, when looking at the prevalence and resistance of barley yellow dwarf virus (BYDV), plants were also observed to have different degrees of susceptibility, with most of the plants being in between highly resistant (1) and highly susceptible (10). A similar response was observed concerning leaf blight, with most of the varieties presenting a moderate resistance towards the disease.

Seed chemical and physical characterization

Seed proximate analysis (Fig. 1, (a, b and c) revealed that, although differences can be observed among seed varieties, an overall homogeneity of the data is evident. Thiscan be further demonstrated by descriptive statistics, which show that only the seed germination and percentage of grains within malting size have standard errors of the mean (sem) larger than 1. This trend shows an overall homogeneity of the data regardless of seed variety.

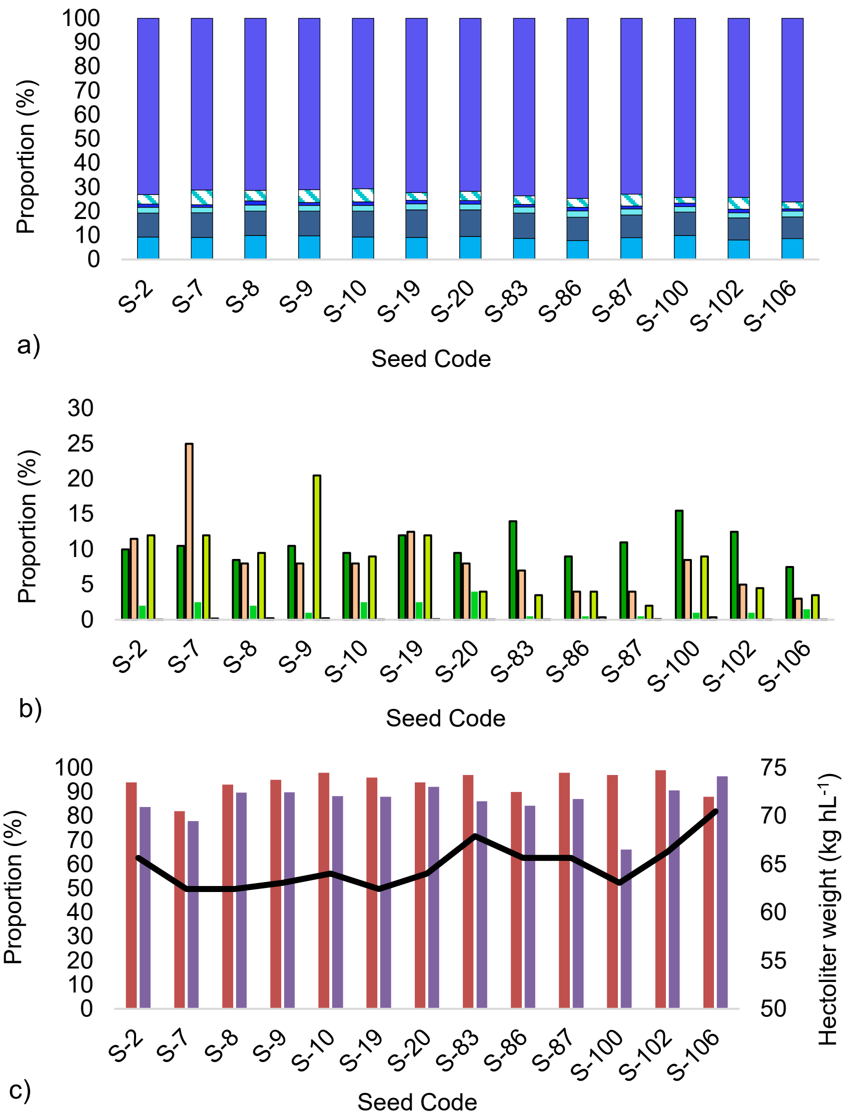

Figure 1. Seed quality.

a) Protein, Humidity, Ash, Fats, Raw Fiber, Total CHO; b) Hardness, Damaged grains, Broken grains, Flotation index, Impurities; c) Germination, Malting size, Hectoliter weight.

Even though overall environmental traits will condition the kind of biota that can develop in a certain area, data have shown that this effect is not as straightforward as it has been historically believed. For instance, Lovarelli et al., (2020) reported that the interaction of conditions can influence the general impact on barley production. In this study, results allowed the authors to conclude that while the use of inorganic fertilizers enhanced yield production, it was ultimately the interaction of agricultural practices and environmental conditions that defined the overall impact and production of barley. Therefore, from a sustainability point of view, the interaction between biotic and abiotic factors will allow producers (at different scales) the specific agronomic practices that will enhance their specific yield production. This last approach has already been highlighted by (Walters et al., 2012) as a key factor in achieving sustainability while reducing dependence on chemical soil enhancers. Most importantly, soil characteristics do not appear to have a limiting factor within plant development. This is confirmed by reports such as those published by Gangwar et al. (2019), who summed the high resistance of barley towards tropical and sub-tropical conditions, 3 commonly characterized as low in nutrients and organic matter.

Barley production is known as one of the most important crops in the world. The recognition of this characteristic, as well as the breeding of this species, has played a significant role in modern agriculture (Abay & Bjørnstad, 2009). More importantly, although breeding has resulted in varieties with more desirable traits, such as rapid growth, higher yield (Abay & Bjørnstad, 2009), or resistance against environmental factors or diseases (Singh et al., 2019), not all varieties will thrive in different areas of the world. Similarly, results from this study showed that from 105 different varieties of barley, only 13 were found to be adequate for their growth within the climate and soil characteristics in which the experimental field was located. This represents only 12% of the total tested varieties of barley.

Even though plant breeding has represented an extremely resourceful tool within modern crop production, it is not uncommon to find reports where the benefits from these strategies tend to be marginal. For instance, Abay & Bjørnstad, 2009) attributed this to the genotype by environment interaction (GEI). This process can be shortly defined as the specific response that genotypes might have within a range of environments (Van Sanford, 2005; Radic et al., 2024). Furthermore, the described response that a specific genotype can have when exposed to different abiotic factors can significantly define the agricultural vocation of a region. Among the most meaningful conditions that can cause GEI, authors have observed the relevance of both climate and soil conditions to be responsible for this effect. Among the different conditions, it has been reported that the significant influence of soil total nitrogen (Abay & Bjørnstad, 2009), soil salinity (Elakhdar et al., 2017), among others.

Interestingly, as climate change arises more as a reality than as a theory, the influence of abiotic factors on crop production requires a deeper understanding of how specific genotypes can be capable of overcoming these changes. Moreover, bearing this in mind, authors have recently looked into newer technologies to accurately predict the behavior of different cereal lines within a range of environments (Maho et al., 2022). Although not an aim of the present study, one significant approach is the use of DNA markers. For instance, (Ankamah-Yeboah et al., 2020) observed that information from this kind of tool can provide stronger information than pedigree-based information and even showed that GEI did not produce a significant improvement in the prediction of the response of barley. This has further developed into what has been launched as 'cereal breeding programs'. These have been recognized as a powerful tool that relies not only on the use of specific genetic material but also on the interaction that a specific breed will have with the environment (Loskutov, 2021). More importantly, when looking at the tested varieties separately, the development of locally grown seeds showed a 50% success rate against a 10.9% observed from those from the seed collection. This could be one of the effects derived from the GEI process, leading to better production due to adaptation of the variety to local environmental conditions, considering abiotic and biotic factors, as it has already been observed for other crops such as wheat (Mao et al., 2023).

Susceptibility to diseases

Despite barley being one of the most important crops worldwide, diseases have remained one of the most relevant challenges when looking at the production of this cereal (Walters et al., 2012). This study focused on the evaluation of the most prevalent diseases that barley is often exposed to in North America. In the case of yellow rust (YR) and leaf rust (LR), it is caused by a fungus (Brown et al., 2001). Interestingly, and as it has been previously reported by authors such as Brown et al. (2001) and Park et al. (2015) several varieties of barley have developed different levels of resistance and further being commercialized to avoid further complications due to this fungus. Therefore, the identification of varieties of barley capable of resisting the consequences of the infection by this fungus is an extremely desirable attribute for crop producers. In the case of the present study, while 100% of the grown varieties were shown to be highly resistant against YR, a contrasting response was observed when looking at the leaf rust (LR). In this case, only one of the varieties showed to be moderately resistant, with only 5% of the leaf surface being affected. More importantly, this response was observed in one of the locally grown varieties of barley. This response could be an indicator of the previously reported by authors such as Brown et al. (2001) and Park et al. (2015), where locally grown varieties tend to adapt and further thrive under these conditions. This has been further confirmed by (Walters et al., 2012), who pointed out that as sustainable agriculture will tend to grow in both interest and resources, barley and other crop diseases will have to be approached from a holistic perspective. More importantly, one of the strategies to achieve this has already been identified as the use of varieties able to properly develop without the need for further enhancers such as pesticides and other chemical methods for pest control (Walters et al., 2012; Meng et al., 2023).

Similar to the infections due to fungus, barley agronomic development is also threatened by viruses (Kapan et al., 2023). Even though there is a wide range of viruses that are known to affect barley, the barley yellow dwarf virus (BYDV) has been recognized as a widespread and significantly adverse pathogen by reducing overall quality and yield production (Kumari et al., 2024). Therefore, the resistance against this virus has been the object of attention over the past few decades. Aphids carry the BYDV virus; consequently, most efforts to combat the disease have focused on controlling these insects through pesticides (Shang et al., 2026). Alternatively, as in the case of LF and YR, specific resistance of certain varieties is still under study as one of the most promising alternatives for a sustainable agronomic practice for the production of barley (Gangwar et al., 2019; Shang et al., 2026). In the case of the present study, mean BYDV resistance ranged from 3 to 6, where 1 was related to highly resistant, while 9 to highly susceptible (Schaller & Qualset, 1980). Bearing this in mind, results showing most of the varieties falling on number 4 showed a mid-resistance towards this virus, hence representing a relatively common threat towards yield and overall grain quality. As modern agricultural practices arise, scientists have pointed out that one of the biggest challenges regarding this area is to improve communication between them and farmers (Walls et al., 2019). This might be mainly due to the increasing recognition of the relevance of locally generated strategies that involve an array of alternatives from biological pest control to reduce the persistence of the vectors up to mixed-cropping practices, and the breeding of highly resistant varieties. In the case of the results of the present study, interestingly, one of the local varieties showed to be susceptible to the virus (code 102), while the other one presented an average behavior (code 106) against the virus. These results could suggest an ongoing resistance development against the virus under the sustainable practices, keeping in mind that no fertilizers or pesticides were used in the development of the present investigation.

Seed proximate analysis and its use for malting purposes

Further to this, the uses of barley in modern industry have evolved since the beginning of its farming (Raj et al., 2023). Although barley can have various uses, including both human and animal feed, authors have recognized that malting for the production of beer and other alcoholic beverages is a far more lucrative sector than the aforementioned (Flavin et al., 2023). Bearing this in mind, the use of varieties capable of producing desirable traits within the beer and other alcoholic beverages industry should be a goal for barley producers. In the case of this study, these characteristics were evaluated through a proximate analysis and further assessed using local regulations regarding specifications and test methods for non-industrialized malting barley products (Secretariat of Economy, 2003). According to this, and based on the NMX-FF-043-SCFI-2003 (Secretariat of Economy, 2003), most of the evaluated varieties meet the requirements of malting barley for its commercialization in Mexico. Further to this, these regulations aim to set quality standards for barley (*Hordeum vulgare* L.) for the production of malt. Through this, specific characteristics are set, aiming to establish a minimum quality within producers as well as to promote higher prices for better quality grains through the application of incentives based on a point system. According to this, 4 out of the 13 varieties of barley (codes 2, 7, 86, and 97) do not meet the requirements for malting barley according to the local specifications. Furthermore, the totality of locally grown varieties that were able to develop were found to be suitable for the malting industry according to this same standard (Secretariat of Economy, 2003). It is important to note that most of the defining traits were the proportion of malting size grains, damaged grains, and the flotation index. On the other hand, the proportion of broken and naked grains, as well as the presence of impurities, was below the maximum amounts set by the previously mentioned norm, showing an overall high quality of the varieties.

More importantly, this norm is not established based only on the local agricultural practices, but is also in accordance with international regulations such as the U.S. Standards for barley (USDA, 2018). Based on these standards, results from this study showed that, from all the tested varieties, even though overall plant development was observed, not all produced grains capable of meeting these standards. Of these, 64% of the plants from seeds obtained through a seed collection from around the world produced malting-grade grains. On the other hand, 100% of their counterpart from locally grown varieties met these criteria. Interestingly, these locally grown species showed to have similar or even better characteristics than the selected varieties. For instance, the 'Esmeralda' (Seed code 102), one of the most commonly grown varieties, exhibited a 99% germination success, while the 'Orca' (Seed code 106) had a milting size proportion of trains of 96.49%, in both cases being the highest values for both characteristics.

As for the case of the grains' chemical characteristics, variables such as the content of protein, fibre, fat, ash, and overall moisture have been recognized as relevant attributes to define the viability of specific varieties of barley for malting and distillery uses. For instance, Castillo et al. (2019) reported a proximate characterization of five different varieties of malting barley from Mexico. From this, authors were able to conclude that the 'Esmeralda' variety showed the highest protein content, with reported values of 13.29 % (Castillo et al., 2019). This result is slightly higher than the one observed in the present study. However, this report aids in identifying the relevance of the 'Esmeralda' variety among one of the most prominently used within the region, as well as its potential for crop production.

With regard to the chemical characteristics of the seeds, certain attributes have been previously linked to a better performance within the malting industry. For instance, Prieto Méndez et al. (2013) and Rani & Bhardwaj (2021) have reported that the maximum water content should not exceed 14% of the total weight of the seeds. Further to this, ideal fibre content should fall between 4 and 5%. This is especially important for brewing, as fibre could inhibit the formation of alcohol due to the presence of components such as pectin, hence promoting the formation of gels (Prieto Méndez et al., 2013). In the case of the present study, results from the proximate analysis showed that none of the seeds were able to meet these standards, except for one of the varieties (code 7), which exceeded the recommended amount of fibre. Apart from this, the rest of the tested varieties were observed to have the desirable characteristics for malting and brewing purposes. Similarly, protein content can play a relevant role in the brewing process, as this can limit significant processes such as the breakdown of starch. However, even though high levels of protein can enhance foam stability, being a desirable attribute, this value should not exceed 12% as this could further lead to the formation of haze (Rani & Bhardwaj, 2021). This indicator allows us to identify that the entirety of the tested seeds meet this criterion, as the highest observed value remained under this limit (10.02 %). Under the aforementioned criteria, out of the 13 tested varieties, 5 are considered unsuitable for malting purposes (codes 94, 82, 95, 86, and 100). Further to this, seeds from local varieties meet the different standards, therefore being suitable for the production of malt.

CONCLUSIONS

In conclusion, under local agricultural practices, characterized by the absence of fertilizers and pesticides, locally grown varieties showed better development than those obtained from around the world. More importantly, although 10.9% of the tested varieties were able to fully develop, none of them showed disease resistance while meeting the standards for the malting industry. Overall, 8 varieties of barley (one commonly used for local producers) were able to grow and produce high-quality grains without the use of agrochemicals. This alone represents an outstanding finding supporting the necessity of mutual collaboration between academia and local producers in order to develop sustainable alternatives for both direct and indirect human and animal consumption.

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