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Assessed Biochar and *Moringa oleifera* extracts on barley growth and quality in a salty environment

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الملخص العربي

تقييم تأثير مستخلصات الفحم الحيوي و المورينجا على نمو الشعير وجودته في بيئة مالحة

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***المعهد العالي للتقنيات الزراعية بالخضراء- ترهونة- ليبيا**

أُجريت التجربة الحقلية في مزرعة المعهد- ترهونة- ليبيا خلال شتاء عامي 2022-2023 و2023-2024. هدف البحث إلى دراسة استجابة الشعير (جيزة 128) لمستخلصات المورينجا والفحم الحيوي من حيث النمو والجودة في ظروف الملوحة. استُخدمت ثلاث تكرارات لكل معاملة في تجربة تصميم القطاعات العشوائية الكاملة (RCBD). كانت معاملات التجربة هي: معاملة الكنترول، الفحم الحيوي (3، 6، 9%)، المورينجا (5، 10، 15 %). تم قياس صفات النمو الخضري (طول النبات، وعدد الفروع/ نبات، ومساحة الورقة، ومجموع الكلوروفيل)، والمحصول ومكوناته (طول السنبلة، وعدد السنابل/ م^2، وعدد السنيبلات/ السنبلة، ووزن 1000 حبة، ومحصول الحبوب، والمحصول البيولوجي (طن/هكتار)، مؤشر الحصاد (%)، التركيب الكيميائي (النيتروجين والفوسفور والبوتاسيوم والبروتين والكربوهيدرات %)، بالمقارنة مع الكنترول التي سجلت قيمًا أقل لهذه الصفات أظهرت النتائج أن زيادة مستخلص المورينجا إلى 15% أدت إلى ارتفاع مستويات جميع مؤشرات النمو الخضري المدروسة، بما في ذلك طول النبات، وعدد الأفرع/ نبات، والمساحة الورقية، ومحتوى الكلوروفيل الكلي. يليه مستخلص الفحم الحيوي بتركيز 9%. في المقابل، سجلت كل من طول السنبلة، وعدد السنابل/ م^2، عدد السنيبلات/ سنبلة، وزن الألف حبة، محصول الحبوب، المحصول البيولوجي (طن/هكتار) قيمًا أعلى عند زيادة مستخلص المورينجا إلى 15%، بينما أظهر الفحم الحيوي بنسبة 9% مؤشر حصاد أعلى مقارنةً بالمقارنة مع الكنترول ، التي سجلت قيمًا أقل لهذه الصفات. بالإضافة إلى ذلك، سجل مستخلص المورينجا بتركيز 15٪ قيمًا أعلى من نسب النيتروجين والفوسفور والبوتاسيوم والبروتين و الكربوهيدرات، يليه مستخلص الفحم الحيوي بنسبة تصل إلى 9٪. بالمقارنة مع معاملة الكنترول، التي سجلت قيمًا أقل لهذه الصفات . تشير نتائج الدراسة إلى أن الفحم الحيوي ومستخلص أوراق المورينجا يمكن أن يعززا نمو وإنتاجية محاصيل الحبوب العلفية المزروعة في ظروف قاسية. ننصح باستخدام الفحم الحيوي ومستخلص أوراق المورينجا بدلاً من الأسمدة غير العضوية المكلفة والضارة بالبيئة في المناطق الجافة التي ينتشر فيها الإجهاد الملحي.

الكلمات المفتاحية: الشعير ، الفحم الحيوي، مستخلص المورينجا ، النمو الخضري، المحصول ومكوناته، التركيب الكيميائي

ABSTRACT

The field experiment took place at Institute Farm - Tarhuna - Libya, in the winter of 2022–2023 and 2023–2024. The purpose of the research was to investigate how barley (Giza 128) responded to extracts from biochar and *Moringa oleifera* in terms of growth and quality in salt conditions. Three repetitions of each treatment were used in the randomizing complete block design (RCBD) experiment. The experimental treatments were, control, biochar at 3, 6, and 9%, and moringa at 5, 10, and 15% were used. Vegetative growth (plant height, number of tillers/ plant, leaf area, and total chlorophyll), yield and yield components (spike length, number of spike/m^2, number of spikelet/ spike, 1000-grain weight, grain yield, biological yield (ton/ha), and harvest index), and chemical composition (percentages of nitrogen, phosphorus, potassium, protein, and carbohydrates) are all examined. In comparison to the control treatment, which recorded lower values of these traits, the results showed that increasing *Moringa oleifera* extract up to 15% recorded higher levels of all vegetative growth studied, including plant height, number of tillers/plant, leaf area, and total chlorophyll. This was followed by biochar extract up to 9%. Conversely, spike length, number of spikes/m^2, number of spikelets/ spike, 1000-grain weight, grain yield, and biological yield (ton/ha) all showed higher values when *Moringa oleifera* extract was increased up to 15%, while biochar at 9% showed a higher harvest index when compared to the control treatment, which showed lower values of these traits. Additionally, compared to the control treatment, which recorded lower values of every chemical composition examined, *Moringa oleifera* extract up to 15% recorded higher values of nitrogen, phosphate, potassium, protein, and carbs percentages, followed by biochar extract up to 9%. The study's findings suggest that biochar and marina leaf extract can boost the growth and yield of cereal forages cultivated under stressful conditions. We advise using biochar and moringa leaf extract in place of costly, environmentally harmful inorganic fertilizers in dry regions where salt stress is prevalent.

Keywords: Barley (*Hordeum vulgare* L.), biochar, *Moringa oleifera* extracts, vegetative growth, yield and yield components, chemical composition

INTRODUCTION

By 2050, there will be 9.6 billion people on the planet, which would require a significant increase in agricultural output to meet the growing demand for food. In order to guarantee food security and global sustainability, this calls for the use of creative and sustainable agriculture practices **(Fukase and Martin, 2020).** One of the longest-cultivated cereals in the world, barley (*Hordeum vulgare* L.) is a member of the Poaceae family and is crucial to food security. It is the fifth most popular crop in terms of planted area and a key component of European agriculture. Russia, Australia, France, and Germany are the top producers of barley grain **(FAO, 2023; Serrago *et al.*, 2023).**

After wheat, rice, and maize, barley is the fourth most significant cereal crop in the world. The majority of grain is used as flour to manufacture "Chapattis" or "Sattu" by roasting and grinding grains. Additionally, it is used to prepare malt for the production of beer, whisky, and other goods like vinegar and industrial alcohol. Additionally, the grain area is used to make powder and pearl goods, which are typically consumed by sick individuals. Grain surpluses are fed to cattle. Cattle are also fed straw **(Singh *et al.*, 2025).** In a variety of settings, barley is grown in low-input, high-production farming methods. It can be grown in both spring and winter forms **(Cammarano *et al.*, 2019).**

Barley is grown mostly for animal feed and to make barley malt, which is used in brewing, all over the world. Approximately 2–5% of the grain is meant for direct human consumption. Due to its high concentration of several essential nutrients and beta-glucan, barley is among the healthiest cereals in the human diet, according to numerous studies **(Langridge, 2018, Gong, 2019; Zeng *et al.*, 2020).** The main components of barley are whole grains, low fat, and high fiber, which make them perfect for individual consumption. Barley dishes are lovely additions to the diet. In addition to offering good nourishment, barley food contains other health-promoting qualities. Similar to oats, barley products have cholesterol-lowering qualities due to their beta glucon soluble fiber concentration. Data also point to benefits that go beyond lowering cholesterol, such as decreased insulin and post-prodigal blood glucose levels **(Prasad *et al.*, 2019).** Because barley is essential to the beverage industry's malt production, sustainable

methods are required to increase grain output and quality. Biofertilizers and fertility management improve soil health and nutrient availability, but their combined impacts on the quality of 1malt barley need more research **(Athnere *et al.*, 2024).**
Salinity stress has a detrimental effect on plant growth and productivity, making it a significant limiting factor for crop output worldwide **(Singh *et al.*, 2018).** It affects more than 20% of arable land and 7% of all land, resulting in major agricultural losses globally. Soil salinization might cause 50% of cultivable land to disappear by 2050 if current trends continue **(Flowers *et al.*, 2010).** In addition to desertification, land degradation, and a decreasing rate of precipitation, this issue's side consequences are increasingly restricting crop production in arid and semiarid climate zones, such Saudi Arabia **(Youssef, 2009).** Thus, improving crops' ability to withstand salt is essential for sustainable agriculture. Salinity inhibits many metabolic processes, decreases transpiration and photosynthesis, and interferes with the absorption of water and nutrients. Additionally, it contributes to oxidative stress by generating reactive oxygen species (ROS) **(DosSantos *et al.*, 2022).** This need is predicted to rise to between 30% and 62% when the effects of climate change are taken into consideration **(Van Dijk *et al.*, 2021).** Numerous biotic and abiotic stressors affect plants, and salt is becoming a major global hazard to sustainable food production. High-saline irrigation water, insufficient rainfall, rising temperatures, and subpar farming methods are the primary causes of soil salinity, a global problem. According to estimates, it affects 33% of agricultural irrigated fields and 20% of cultivated land **(Negacz *et al.*, 2022).** Salinity is predicted to damage more than half of the world's agricultural land by 2050 **(FAO, 2024; Shokri *et al.*, 2024,).**

According to **Amini *et al.* (2016),** there are an estimated 1128 Mha of salt-affected soils on Earth, which are widely dispersed over 75 countries on every continent. The buildup of salt in crop leaves will cause toxicity and early leaf senescence, which will significantly lower aboveground biomass **(Ali *et al.*, 2017).** Furthermore, a deficiency of soil organic matter (SOM) is frequently observed in salt-affected soil, which is detrimental to the preservation of soil structural integrity **(Akhtar *et al.*, 2015).**
In horticulture, plant biostimulants are frequently employed to improve crop quality and quantity as well as stress tolerance. According to **DeVasconcelos and Chaves (2019),** plant biostimulants can effectively encourage the synthesis of osmolytes, which helps the plant withstand the detrimental effects of salt stress and thus lowers output losses. One major component of environmental factors that impair crop development and production is salt stress. Fortunately, zeatin and *Moringa oleifera* leaf extract have a significant impact in reducing the detrimental effects of salt on crops **(El-Lethy *et al.*, 2024).**
Biochar is a naturally occurring substance that is produced by pyrolyzing organic waste, such animal dung and plant straw, at high temperatures (300–1000°C) with no oxygen. Because of its huge surface area and low density, biochar has an excellent adsorption capacity. Biochar efficiently lowers soil bulk density and raises soil pH, cation exchange capacity (CEC), soil structure, and water retention capacity when mixed with soil **(Fehmi *et al.*, 2020),** hence improving crop output and WUE. By binding ions and holding precipitation or irrigation water, biochar can reduce irrigation requirements during drought stress conditions, guaranteeing crops a consistent supply of water and nutrients **(Qian *et al.*, 2020; Zhao and Hu, 2021).** Because of its exceptional ability to enhance soil conditions and encourage plant development under drought stress, biochar is frequently used as a soil improvement additive in field applications. 283 pairs of biochar amendment (BA) treatments and non-BA controls under drought stress were examined in a meta-analysis **(Zhang *et al.*, 2024).** As a negatively charged, C-enriched substance with a large specific surface area (SSA) and high porosity, biochar can lower the availability of hazardous metals in soil **(Su *et al.*, 2024).** Because of its positive effects and ecological safety when no PHA, polycyclic aromatic hydrocarbons, or other contaminants are adsorbed to it, biochar is attracting a lot of attention as a soil additive on a global scale.

Biochar has been shown by **Gusiatin and Rouhani (2023)** to be able to bind pollutants, trap carbon, and reduce greenhouse gasses (GHGs), all of which can help control climate change. Additionally, by reducing Pb^{2+} buildup and fostering plant growth, biochar has shown promise in mitigating Pb^{2+} toxicity and drought stress in barley **(Mansoor *et al.*, 2021; Liu *et al.*, 2022; Mehrabi *et al.*, 2024).** Thus, allantoin gives soil conveniently accessible nitrogen, whereas biochar enhances soil structure, microbial activity, and water retention. When combined, they have been shown to improve nutrient uptake, reduce the bioavailability of hazardous metals, and support general plant health **(Ravichandran, 2024).** Biofertilizers and biochar are examples of amendments that help reduce the bioavailability of heavy metals in soil and promote the creation of less accessible compounds **(Yadav and Ramakrishna, 2023).** By altering the metabolism of glucose, fatty acids, and amino acids, the application of biochar in barley influences growth **(Ghouili *et al.*, 2023).** By releasing significant amounts of proline from the root system, it improves resistance to environmental stressors **(Sadak *et al.*, 2024).** After wheat, rice, and maize, barley is the fourth-largest grain crop in the world. Barley is commonly used in breads, soups, stews, and health-related products **(Badea and Wijekoon, 2021).**

The deciduous, perennial moringa tree (*Moringa oleifera*) is primarily found in tropical and subtropical areas **(Dhakad *et al.*, 2019).** Because practically all plant tissues, including leaves, flowers, bark, seeds, and roots, are edible and have pharmacological qualities, it has been widely used in traditional phytomedicine and offers vital nutrients against malnutrition **(Saa *et al.*, 2019; Arora and Arora 2021; Yang *et al.*, 2023).** With the world's population growing at a rate that threatens hunger waves, the use of Moringa leaf extracts as a potential plant enhancer can offer a reasonably accessible, inexpensive, and environmentally friendly way to increase crop yields to meet the growing demand for food worldwide. For almost any crop, extracts from fresh Moringa leaves could be used to create an efficient plant growth promoter that increases production by 25–30% **(Price, 2007).**

Recent years have seen a rise in research on Moringa's potential uses as a food supplement, medicinal herb, and plant growth enhancer under biotic and abiotic stressors **(Abdelhameed *et al.*, 2025).** For example, the most common species in the Moringa genus is Moringa, also known as the "tree of life." It has antimicrobial properties and is a source of several phytochemicals, such as glucosinolates **(Mgbeahuruike *et al.*, 2017).** Triterpenoids, alkaloids, tannins, flavonoids, and saponins with antibacterial qualities are among the many active components present in *M. oleifera* **(Ahmed *et al.*, 2023). Furthermore**, other metabolites in *M. oleifera*, including zeatin, cytokinin, potassium, calcium, protein, ascorbate, vitamin A, and vitamin C, are essential for fostering plant growth and shielding it from environmental stressors **(Abdel Latef *et al.*, 2017).** Because of its dual function, it has been found that employing plant biostimulants *M. oleifera* extract in particular holds significant promise for sustainable agriculture. It helps manage a variety of plant diseases as a natural antibacterial agent, which lessens the need for artificial pesticides. With its abundance of phytohormones, antioxidants, and minerals, it simultaneously functions as a powerful biostimulant, boosting plant growth, strengthening stress tolerance, and increasing total agricultural output **(Arif *et al.*, 2023).**

Under both favorable and unfavorable circumstances, MLAE as a foliar spray or seed amendment improves seed germination and seedling vigor, promotes root development, and increases photosynthetic efficiency **(Imran *et al.*, 2013).** The administration of MLAE reduces the impacts of heat, salt, drought, and heavy metal stressors by boosting antioxidant enzyme activity and increasing the content of phenols, flavonols, sugars, and osmolytes. Reactive oxygen species (ROS), electrolyte leakage, and lipid peroxidation are all reduced as a result **(Arif *et al.*, 2023).**

Thus, the primary goal of this study was to ascertain how biochar and extracts from *Moringa oleifera* affected the development and quality of barley in a salted environment.

MATERIALS AND METHODS

The field experiment was carried out in Farm, Libya, in the winter of 2022–2023 and 2023–2024. The purpose of the research was to investigate how barley (Giza 128) responded to extracts from *Moringa oleifera* and biochar in terms of growth and quality in salt conditions. Three repetitions of each treatment were used in the randomizing complete block design (RCBD) experiment.

The following is a description of the experimental treatments:

- Control (untreated)
- Biochar at 3%
- Biochar at 6%
- Biochar at 9%
- MLE at 5%
- MLE at 10%
- MLE at 15%

Table (1): Characteristics and elemental makeup of biochar

Components	value
Porosity %	81
pH	8.34
C%	87.4
N %	0.4
% H	2.8
$N\text{-}NO_3$, mg kg^{-1}	12
$N\text{-}NH_4$, mg kg^{-1}	7.3
P mg kg^{-1}	10.7
K, mg kg^{-1}	74
Ca, mg kg^{-1}	3655
Mg, mg kg^{-1}	958
Fe, mg kg^{-1}	50
Cu, mg kg^{-1}	16.8
Zn, mg kg^{-1}	116.4

Table (2): *Moringa oleifera's* nutritional makeup

***Moringa oleifera*/ 100 g**	**value**
Energy (kcal)	64
Protein (g)	9.4 g
Fat (g)	1.4 g
Vit. A (IU)	6739
Vit. B	4.33
Vit. C	220
Carbohydrate (g)	8.3 g
Fiber (g)	2
K, mg kg^{-1}	337
Mg, mg kg^{-1}	147
Ca, ^{1}	200
Fe mg kg^{-1}	3.7

Data recorded

One square meter was randomly selected from each sub-sub plot at harvest in order to ascertain:

A) Vegetative growth:

- Plant height (cm)
- Number of tillers/plant.
- **Leaf area index (cm^2):** Ten leaves were measured using a portable leaf area meter (AM350), and the mean was computed.
- **Total chlorophyll (SPAD)**: The amount of foliage in a plant was measured using the Minolta SPAD Chlorophyll Meter (Minolta Camera Co., Osaka, Japan). The SPAD-502 chlorophyll meter measures the absorbance of chlorophyll in the red and near-infrared bands to create a digital SPAD value that is proportionate to the amount of chlorophyll present in the leaf **(Minolta, 1989).**

B) Yield and yield components:

- Spike length (cm).
- Number of spike/m^2.
- Number of Spikelet/ spike: Grain counts were made from the spikes of particular plants.
- 1000 grain weight (g): 1000 grains were weighed and tallied for the test weight. It was stated in g.
- Grain yield (ton/ha): The grain yield was calculated by harvesting a single square meter of the experimental plot. The unit of measurement was kg/ha.
  Biological yield (ton/ha): Biological yield= Grain yield + straw yield
- Harvest index (%): The harvest index was estimated from the following formula,

  Harvest index = (Grain yield / biological yield) x 100

C) Chemical composition:

- Nitrogen (%)
- Phosphorus (%)
- Potassium (%)
- Protein (%)
- Carbohydrates (%): According to **Smith *et al.* (1964),** total accessible carbohydrates were extracted, and **Montgomery (1961)** described the phenol-sulphuric acid method for calorimetric estimation.

- **Statistical analysis**:

According to **Snedecor and Cochran (1990),** the results of the measured parameters were subjected to computerized statistical analysis using SAS statistical software version 9.0 for analysis of variance (ANOVA) and means of treatments were compared using LSD at 0.05.

RESULTS AND DISCUSSION

A) Vegetative growth

The findings in **Table (3) and Fig. (1)** demonstrated that during the 2022–2023 and 2023–2024 seasons, Biochar and *Moringa oleifera* extracts had a substantial impact on vegetative development (plant height, number of tillers/plant, total chlorophyll, and leaf area index). In contrast to the control treatment, which recorded lower values of plant height (76.06 cm), number of tillers/plant (2.94), total chlorophyll (39.32 SPAD), and leaf area index (38.16 cm2), the results showed that increasing *Moringa oleifera* extract up to 15% recorded higher values of plant height (98.11 cm), number of tillers/plant (4.03), total chlorophyll (50.35 SPAD), and leaf area index (52.52 cm2). Biochar extract up to 9%.

According to earlier research, using biochar improved plant growth performance **(Naeem *et al.*, 2017).** According to **Major *et al.* (2010) and Abdipour *et al.* (2019),** utilizing biochar can have both direct and indirect benefits (nutrients in the biomass and enhancement of the

physical, chemical, and biological aspects of the soil). As a result, it is anticipated to have a good impact on the growth characteristics of plant height, stem diameter, and leaf count. Growth hormones, particularly zeatin, which has been shown to boost crop output by 10 to 45%, are abundant in moringa leaf juice **(Muhammad, 2014).**
Additionally, a range of crops, from cereals to oil crops, from fiber to sugar crops, and from forages to tuber crops, benefit from the micronutrients included in moringa leaf juice in appropriate levels and proportions (**Muhamman *et al.,* 2013).** Increased soil nutrient availability and better growth circumstances, which lead to greater yield, are responsible for the increased fresh and dry weights of shoots brought about by the application of biochar.
The amount of photosynthetic pigments in treated plants is reduced by salinity **(Taffouo *et al.,* 2010).** These results are consistent with **Manuchehri and Salehi's (2014)** findings. Increased degradation and inhibition of that pigment's synthesis led to a decrease in the amount of chlorophyll in plants growing under saline environments **(Garcı aSánchez *et al.,* 2002).** Because of the potent antioxidant qualities of some pigments like carotenoids and chlorophyll, MLE may have a stimulating effect **(Owusu, 2008).** Moreover, MLE includes a variety of macro-elements, such as Mg, which is a part of Chlo **(Yameogo *et al.,* 2011).** Furthermore, zeatin may improve photosynthetic pigments by delaying the breakdown of chlorophyll by inhibiting the chlorophyllase enzyme **(Chernyad 2000).**
The various growth metrics under study were significantly improved by MLE. The Giza124 barley genotype typically showed the strongest stimulation compared to the Giza129 genotype. The results of photosynthetic pigments supported the growth data from before. Increased leaf area and more photosynthetic pigments may result from the applied moringa extract's ability to promote earlier cytokinin production and prevent premature leaf senescence **(Ali *et al.,* 2011).** Therefore, it is possible to draw the conclusion that elevated cytokinin levels in MLE may have been linked to the rise in chlorophylls and many growth traits of barley genotypes **(Rady *et al.,* 2013).** The amount of photosynthetic pigments in treated plants is reduced by salinity **(Taffouo *et al.,* 2010).** These results are consistent with **Manuchehri and Salehi's (2014)** findings. Increased degradation and inhibition of that pigment's synthesis led to a decrease in the amount of chlorophyll in plants growing under saline environments (**Garcı aSánchez *et al.,* 2002).**

Table (3): Biochar and *Moringa oleifera* extracts' effects on barley crop height, tiller count per plant, total chlorophyll, and leaf area in the 2022–2023 and 2023–2024 growing seasons.

Treatments	Plant height (cm)	No. of tillers/ Plant	Total chlorophyll (SPAD)	Leaf area (cm^2)
Control	76.06	2.94	39.32	38.16
Biochar at 3%	82.29	3.04	38.67	42.98
Biochar at 6%	87.88	3.57	42.80	44.25
Biochar at 9%	93.55	3.90	48.46	49.82
MLE at 5%	91.43	3.70	44.05	46.57
MLE at 10%	94.10	3.81	46.74	47.67
MLE at 15%	98.11	4.03	50.35	52.52
$LSD_{(0.05)}$	**5.08**	**0.44**	**41.66**	**10.68**

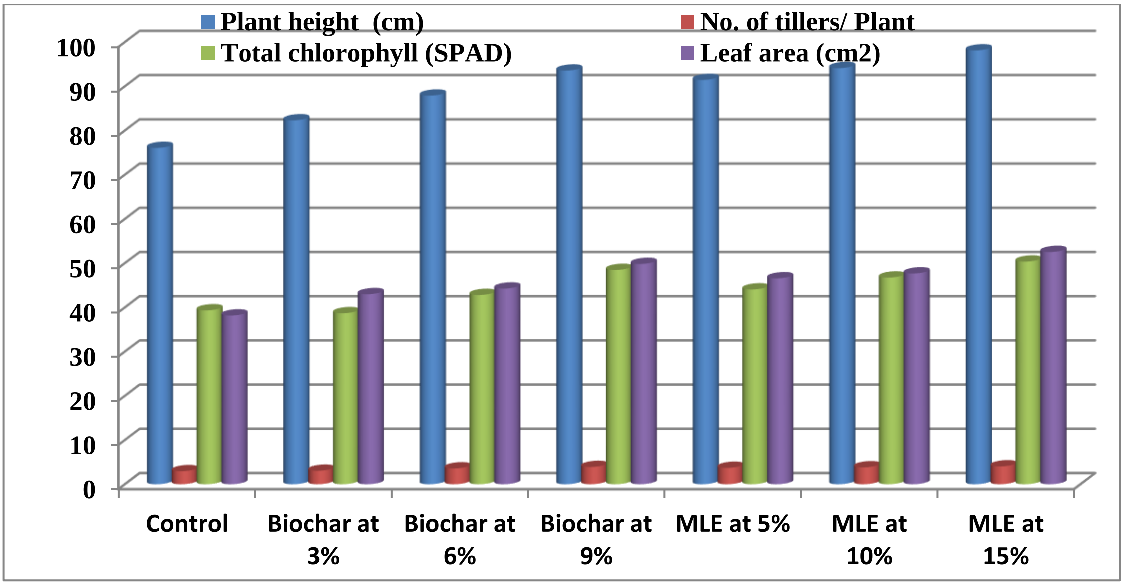

Fig. (3): Biochar and *Moringa oleifera* extracts' effects on barley crop height, tiller count per plant, total chlorophyll, and leaf area in the 2022–2023 and 2023–2024 growing seasons.

B) Yield and yield components:

The findings in **Table (4) and Fig. (2)** demonstrated that during the 2022/2023 and 2023/2024 seasons, Biochar and *Moringa oleifera* extracts had a significant impact on yield and yield components (spike length, No. of spike/m^2, no. of spikelet/spike, 1000-grain weight, grain yield, biological yield, and harvest index). In contrast to the control treatment, which recorded lower spike length (6.73 cm), no. of spike/m^2 (679 spike/m^2), no. of spikelet/spike (15.8), 1000-grain weight (34.46 g), grain yield (2.71 t/ha), and biological yield (6.65), the results showed that increasing *Moringa oleifera* extract up to 15% recorded higher values of spike length (76.50 g), no. of spikelet/spike (49.50 t/ha), and biological yield (11.22 t/ha). A significant increase in osmolyte accumulation, antioxidant activities, nutrient uptake, and a decrease in ROS and MDA formation may be the cause of BC's beneficial effect on growth under flooding stress **(Sun *et al.*, 2017).** In the current study, BC improves the length and growth of the roots, which may enhance the soil water status and boost plant water consumption. The root is a crucial channel that controls the above-growing plant growth. In addition, BC improved soil structure, permeability, water-holding capacity, and nutrient availability, all of which led to a notable boost in plant growth under stress **(Edeh *et al.*, 2020; Gliniak *et al.*, 2020; Ghorbani *et al.*, 2022).** Applying BC boosted the production of chlorophyll, which was associated with enhanced water absorption, antioxidant activity, and decreased oxidative damage **(Habibi, 2012).** Under both normal and flooding situations, BC also shown a notable rise in leaf water status. According to **Abd El-Mageed *et al.* (2019) and Liao *et al.* (2019),** biochar holds water and enhances root growth and root osmotic potential, which promotes an increase in water intake and ultimately maintains superior leaf water levels under stressful conditions.

MLE foliar treatment has demonstrated its significance in improving yield-contributing factors such spike length, number of grains per spike, and 1000-grain weight. When compared to the other treatments, exogenously given MLE alone as a foliar spray significantly increased the spike length, grains per spike, and 1000-grain weight. Because of the "stay green phenomena," using MLE as a foliar spray greatly boosted 1000 gain weight, grain yield, and biological yield during the grain filling stage. Grain filling photoassimilation translation, which eventually increased grain weight, may be associated with the use of MLE spray. **Khan *et al.* (2017b)** also reported similar results.

Table (4): Biochar and *Moringa oleifera* extracts' effects on barley crop spike length, number of spikes/m^2, number of spikelets/spike, 1000-grain weight, grain yield, biological yield, and harvest index in the 2022–2023 and 2023–2024 seasons.

Treatments	Spike length (cm)	No. of spike/m^2	No. of Spikelet/ spike	1000-grains weight (g)	Grain yield (t/ha)	Biological yield (t/ha)	Harvest index (%)
Control	6.73	679	15.8	34.46	2.71	6.65	40.75
Biochar at 3%	7.01	688	16.8	36.26	3.22	7.16	44.97
Biochar at 6%	7.18	694	17.3	38.44	3.87	8.09	47.84
Biochar at 9%	7.26	713	17.7	40.00	4.08	9.06	45.03
MLE at 5%	6.85	719	17.9	43.94	4.19	9.62	43.56
MLE at 10%	7.25	737	18.1	44.35	4.37	10.72	40.76
MLE at 15%	7.65	767	18.6	49.50	4.80	11.22	42.78
$LSD_{(0.05)}$	**0.69**	**0.97**	**0.05**	**38.01**	**0.11**	**0.82**	**2.07**

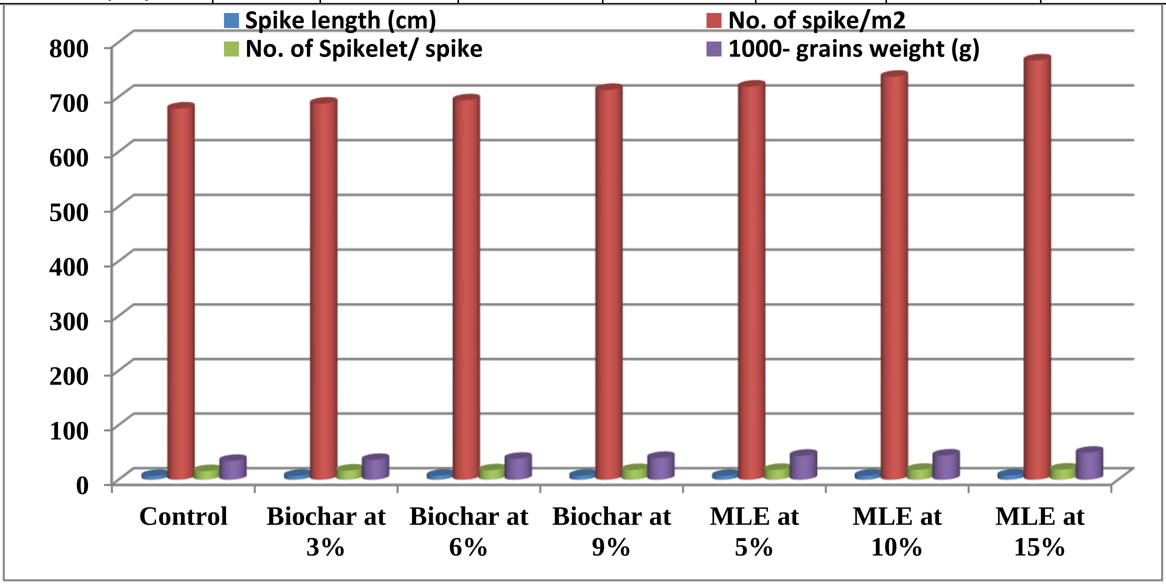

Fig. (4): Biochar and *Moringa oleifera* extracts' effects on barley crop spike length, number of spikes/m^2, number of spikelets/spike, 1000-grain weight, grain yield, biological yield, and harvest index in the 2022–2023 and 2023–2024 seasons.

C) Chemical composition:

The findings in **Table (5) and Fig. (3)** demonstrated that throughout the 2022–2023 and 2023–2024 seasons, Biochar and *Moringa oleifera* extracts had a substantial impact on yield and yield components (nitrogen, phosphorus, potassium, protein, and carbs). In contrast to the control treatment, which recorded lower values of nitrogen (1.43%), phosphorus (0.25%), potassium (1.92%), protein (8.94%), and carbohydrates (48.25%), the results showed that increasing *Moringa oleifera* extract up to 15% recorded higher values of nitrogen (2.65%), phosphorus (0.68%), potassium (2.85%), protein (16.56%), and carbohydrates (65.98%), followed by Biochar at 9%.

These findings showed that adding biochar to the calcareous sandy soil improved the barley plants' agronomic efficiency of the applied N and P. It is explained by the biochar's capacity to keep nutrients from leaking into the soil and its role as a source of nutrients, which enhances the efficiency of nutrient usage. In order to increase essential nutrient intake, biochar may improve soil conditions and encourage root elongation **(Qi *et al.*, 2024).** As a soil additive, biochar enhances the availability and retention of nutrients. Because of its increased CEC (cation exchange capacity), it can sustain levels of essential nutrients like N, P, and K, increasing their availability for plants **(Turan, 2020). Kamal *et al.* (2024)** shown that biochar improves nutrient availability, leading to increased levels of photosynthetic pigment, which is consistent with our trial series. The high concentration of K in the biochar ash may be the reason for the rise in K absorption in soils treated with biochar. Because it enhances soil structure, water-holding capacity, and supplies substrates for decomposition microorganisms, biochar is essential to the soil ecology **(Abiven *et al.*, 2009).** Additionally, adding biochar to the culture medium enhances the physical and chemical characteristics of the soil, maintains soil organic matter, increases nutrient availability, and ultimately boosts crop output **(Abdipour *et al.*, 2019).**

These findings showed that adding biochar to the calcareous sandy soil improved the barley plants' agronomic efficiency of the applied N and P. It is explained by the biochar's capacity to keep nutrients from leaking into the soil and its role as a source of nutrients, which enhances the efficiency of nutrient usage. The Giza124 barley genotype has significantly greater total protein levels in both the root and the shoot than the Giza129 genotype. In the various organs of the two barley genotypes under study, moringa extract considerably increased the soluble and total carbohydrate levels as well as the protein contents. MLE can control the expression of genes involved in defense and metabolism, as well as aid in osmotic adjustment **(Hebers and Sonnewald, 1998).** The barley genotype Giza124 has greater K^+, Ca^{+2}, and Mg^{+2} levels than Giza129. MLE increased the K^+, Ca^{+2}, and Mg^{+2} contents of the roots and shoots of barley genotypes with minimal stimulation of the Mg^{+2} content. This was consistent with the findings of **Yasmeen *et al.* (2013),** who discovered that applying MLE increased the mineral contents (K, Ca, and Mg) to improve the tolerance in wheat plants in saline circumstances. Zeatin, calcium, potassium, magnesium, and other growth components are abundant in MLE, making it an ideal growth stimulant for crop cultivation **(Yasmeen *et al.*, 2012a; Nouman *et al.*, 2012a).** Under the MLE treatment, both barley genotypes showed a direct rise in the K^+ content of the shoots, which in turn increased the uptake of K^+ during stomatal conductance **(Cakmak, 2005).** The uptake and buildup of certain minerals, such as K, Na, Ca, and Mg, as a result of organic fertilization was examined **(Sivakumar and Ponnusami, 2011).** Protein, β-carotene, vitamin C, calcium, potassium, and natural antioxidants are all abundant in moringa leaves **(Siddhuraju and Becker, 2003).**

Table (5): Impact of Biochar and *Moringa oleifera* extracts on barley crop nitrogen, phosphorous, potassium, protein, and carbs in the 2022–2023 and 2023–2024 growing seasons.

Treatments	N (%)	P (%)	K (%)	Protein (%)	Carbohydrate (%)
Control	1.43	0.25	1.92	8.94	48.25
Biochar at 3%	1.95	0.32	2.26	12.19	52.13
Biochar at 6%	2.13	0.48	2.66	13.31	56.98
Biochar at 9%	2.18	0.65	2.81	13.63	59.98
MLE at 5%	2.05	0.43	2.39	12.81	60.21
MLE at 10%	2.32	0.59	2.57	14.50	62.54
MLE at 15%	2.65	0.68	2.85	16.56	65.38
$LSD_{(0.05)}$	**0.10**	**0.04**	**0.01**	**0.21**	**1.45**

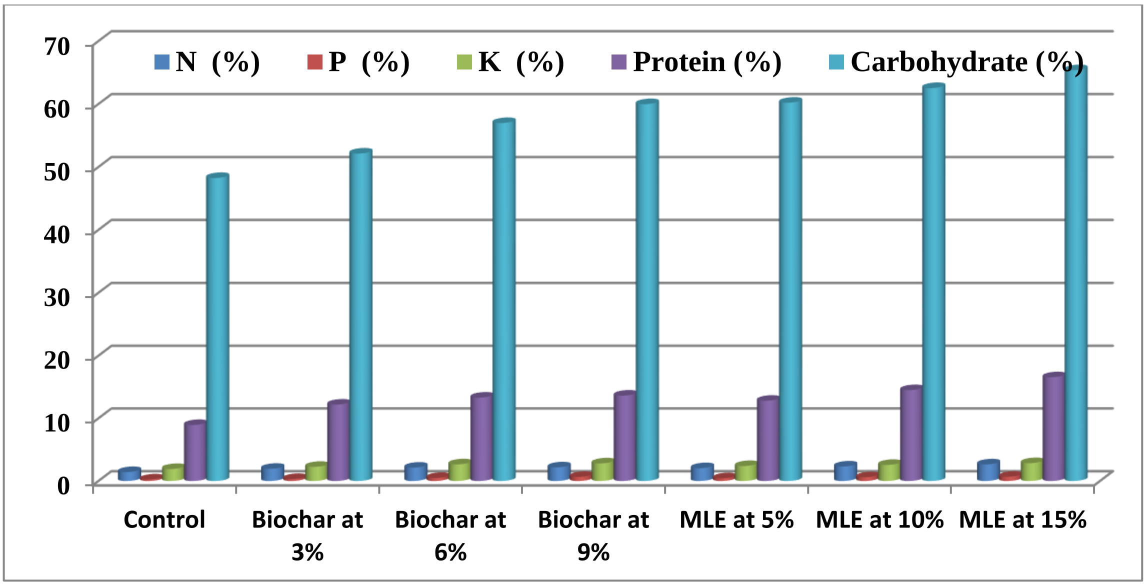

Fig. (5): Impact of Biochar and *Moringa oleifera* extracts on barley crop nitrogen, phosphorous, potassium, protein, and carbs in the 2022–2023 and 2023–2024 growing seasons.

Conclusions:

The use of biochar improved the soil's characteristics, increasing the soil's and the plants' access to nitrogen, phosphate, and potassium. The agronomic efficiency of applied nitrogen, phosphorus, and photosynthetic pigments were enhanced by the addition of biochar. This study shows that barley plants grown on sandy soils treated with biochar can be irrigated with marginal water. Thus, this study validates the role that biochars play in water saving and agricultural sustainability. MLE has shown promise as a natural plant growth enhancer that can help barley crops become drought-resistant. During this investigation, increased barley mineral concentrations and enhanced enzymatic and non-enzymatic antioxidant activities were also noted. The use of biochar improved the soil's characteristics, increasing the soil's and the plants' access to nitrogen, phosphate, and potassium. MLE has shown promise as a natural plant growth enhancer that can help wheat crops become drought-resistant. The use of biochar improved the soil's characteristics, increasing the soil's and the plants' access to nitrogen, phosphate, and potassium. We advise using both biochar and moringa leaf extract in place of costly, environmentally harmful inorganic fertilizers in dry regions where salt stress is prevalent.

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