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Under Natural Field Conditions, Exogenous Application of Moringa Organ Water Extract Enhanced the Growth- and Yield-Related Traits of Barley Accessions

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Abstract: Barley (*Hordeum vulgare* L.) is the preferred crop in arid regions, particularly for farmers with limited agricultural resources and low income. Typically, it is utilized for human consumption, animal feed, and malting. The discovery of natural (organic) sources of biostimulants has attracted a great deal of interest for crop productivity enhancement. Using a randomized complete block design with three main blocks, it was our aim to investigate the effects of foliar moringa (*Moringa oleifera* L.) organ extract (MOE) on the growth and yield components of a collection of barley accessions grown in Iraq. As indicated by the obtained results, almost all traits associated with barley growth and yield productivity were significantly enhanced by MOE application, relative to the respective control condition. The majority of barley accessions responded positively to the MOE treatment based on all studied traits (with the exception of 1000-kernel weight). According to the results of principal component analysis (PCA), the distribution of accessions on the two components under the MOE application was distinct from the distribution of accessions under control conditions, indicating that accessions responded differently to the MOE application. In addition, the distribution pattern of traits under MOE treatment was comparable to the distribution pattern of traits under the control condition, with the exception of two traits: total yield and 1000-kernel weight. AC5 and AC18 responded positively to the MOE application by possessing the highest total yield and harvest index values. The total yield trait registered the highest increasing value index (37.55%) based on the trait response index, followed by the straw weight (22.29%), tillering number per plant (21.44%), and spike number per plant (21.36%), while the spike length trait registered the lowest increasing value index (0.45%), compared to the traits under control conditions. So far, the results indicate that foliar application of MOE can be utilized effectively as a natural growth promoter to increase the growth and yield productivity of grown barley accessions.

Keywords: bostimulation; plant extract; *Hordeum vulgare*; growth performance; production components

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1. Introduction

The greatest challenge facing modern agriculture science is maintaining food production, in order to meet the needs of a growing global population without jeopardizing future generations' access to natural resources. The current level of agricultural intensification has reached a tipping point, with far-reaching, irreversible effects on the global environment and a significant decline in the range of ecosystem services once provided by nature [1]. Barley (*Hordeum vulgare* L.) is the preferred crop in arid regions, particularly among farmers with limited agricultural resources and low income. It is commonly used for human consumption, animal feed, and malting [2]. As a result of their low glycemic index and high nutritional value, barley crops are currently the subject of worldwide interest [3]. In

comparison to other small grains such as wheat and rice, it is generally believed that barley yields are less susceptible to weather fluctuations [4]. In Iraq, barley is primarily grown in areas with limited precipitation and rain-fed conditions. As a result of climatic changes, crops such as wheat and rice are competing for a shrinking amount of arable land. Farmers believe that barley can replace some wheat cultivars, so they are cultivating it instead, particularly during this dry year [5]. In order to improve the yield and growth parameters of barley, agronomists, crop physiologists, and other researchers must urgently discover sustainable techniques and new innovations. Despite the fact that barley is considered to be stress-resistant [6], its productivity in harsh environmental conditions is negatively impacted by a number of factors, including water limitation, agronomic practices, heat stress, and so on [7].

Pesticides, nitrates (from nitrogen-rich fertilizers), and phosphorus are the most serious agricultural pollutants. Chemical fertilizers can certainly increase agricultural yield, and they are regarded as a crucial factor influencing the final quality of barley products [8]. Unfortunately, the use of this type of fertilizer comes at a terrible price, as it degrades the soil and pollutes the environment, in addition to being expensive. The greatest opportunity for expanding food production is to improve yields and quality through the strategic application of mineral and organic fertilizers, plant protection products, and water supply. It is critical that this process is carried out in a manner that is safe for both the environment and consumers [9]. In recent years, there has been a great deal of focus on identifying various natural (organic) sources of biostimulants for enhancing crop productivity and achieving sustainable agriculture [10,11]. There are numerous sources of biostimulants used frequently in agriculture, including humic acid [12], chitosan and chitin derivatives [13], seaweed extracts [14], and plant extracts [15].

Stimulants are beneficial, but they cannot replace chemical fertilizer in long-term agricultural output. Plant extracts of moringa can either inhibit (at high concentrations) or stimulate (at low concentrations) plant development and growth [16,17]. Moringa leaf extract (MLE) obtained from moringa (*Moringa oleifera*) is one of the most popular plant biostimulants that can be used as a substitute and natural source of mineral nutrition and fertilizer, because it contains stimulant compounds, such as cytokinins such as zeatin, antioxidants such as ascorbic acid, flavonoid, amino acids, vitamins C and A, and phenolics, and micro- and macronutrients [18]. Besides, Yasmeen et al. [19] showed that the leaf extraction of such a plant can also provide the balance among nutrients, phytohormones, and antioxidants. Zeatin is the main hormone detected in MLE, and, so far, its concentration is thousands of times higher compared to the most studied plants [20]. To improve the productivity and growth of many plants grown in normal conditions, this kind of natural biostimulant has been applied as a foliar application [21–23]. To our knowledge, few small-scale experiments have been conducted to investigate the effect of moringa mlant extract on barely crops for productivity [24]. At field scale, no study has been reported using a combined application of moringa (leaf, root, and seed) extract. Recently, an investigation into a collection of barley accessions grown in Iraq by our own research group stated different patterns of response at early stages, phenotypically, physiologically, and biochemically, for drought tolerance [25]. In this regard, the current investigation was planned to study the effects of moringa organ extract on the growth and yield of a collection of barley accessions.

2. Materials and Methods

2.1. Study Area and Experimental Layout

In this study, 59 barley accessions collected throughout Iraq were grown in the field under rain-fed conditions at the Faculty of Agricultural Sciences-University of Sulaimani Research Station (35°34′17.5″ N 45°22′01.0″ E) during the 2019–2020 growing season (Table 1). The annual precipitation was 417 mm, and average temperatures ranged from 1 to 35 °C during the growing season. The experiment was set up using a two-way analysis of variance and a randomized complete block design with two main groups. Group 1 was designated as the control or untreated group (WOM), while Group 2 represented the treated

group with MOE (WM). Each group was made up of three blocks, each with 30 plants. Plants and plots were separated by 30 and 50 cm, respectively. Seeds of the tested barley accessions were planted in early November. Each replicate was thinned to 21 plants, after the plants reached a reasonable growth stage at the start. In the field, standard agricultural practices were carried out, including hand weed control.

Table 1. Code, origin, and name of 59 barley accessions included in this study.

Accession Code	Origin	Accession Name	Accession Code	Origin	Accession Name
AC1	South of Iraq	Shoaa	AC31	Middle of Iraq	Scio/3
AC2	South of Iraq	Boraak	AC32	Middle of Iraq	Victoria
AC3	South of Iraq	Radical	AC33	Middle of Iraq	Black-Bhoos-B
AC4	South of Iraq	Arivat	AC34	Middle of Iraq	Irani
AC5	South of Iraq	16 HB	AC35	Middle of Iraq	A1
AC6	South of Iraq	Furat 9	AC36	Middle of Iraq	MORA
AC7	South of Iraq	Al-warka	AC37	Middle of Iraq	ABN
AC8	South of Iraq	Numar	AC38	Middle of Iraq	Arabi aswad
AC9	South of Iraq	Al-amal	AC39	Middle of Iraq	Clipper
AC10	South of Iraq	Rafidain-1	AC40	Middle of Iraq	Bhoos-H1
AC11	South of Iraq	Al-khayr	AC41	Middle of Iraq	BN2R
AC12	South of Iraq	BN6	AC42	Middle of Iraq	BA4
AC13	South of Iraq	IBAA-99	AC43	North of Iraq	Qala-1
AC14	North of Iraq	Saydsadiq	AC44	North of Iraq	Black-kalar
AC15	Middle of Iraq	Bhoos-244	AC45	North of Iraq	White-kalar
AC16	Middle of Iraq	IBAA-265	AC46	North of Iraq	Black-Akre
AC17	North of Iraq	White-Akre	AC47	North of Iraq	Black-Garmiyan
AC18	North of Iraq	Black-Bhoos Akre	AC48	North of Iraq	Black-Chiman
AC19	North of Iraq	Black-Zaxo	AC49	North of Iraq	Ukranian-Zarayan
AC20	North of Iraq	White-Zaxo	AC50	North of Iraq	White-Zarayan
AC21	South of Iraq	Bhoos-912	AC51	North of Iraq	Abrash
AC22	North of Iraq	White-Halabja	AC52	North of Iraq	Bujayl 1-Shaqlawa
AC23	South of Iraq	Samr	AC53	North of Iraq	Bujayl 2-Shaqlawa
AC24	South of Iraq	GOB	AC54	North of Iraq	Bujayl 3-Shaqlawa
AC25	South of Iraq	Abiad	AC55	South of Iraq	Rehaan
AC26	South of Iraq	CANELA	AC56	South of Iraq	Sameer
AC27	South of Iraq	MSEL	AC57	South of Iraq	Warka-B12
AC28	South of Iraq	Acsad strain	AC58	South of Iraq	Al-Hazzar
AC29	South of Iraq	Acsad-14	AC59	South of Iraq	IBAA-995
AC30	South of Iraq	Gk-Omega			

2.2. Soil Analysis

During growing seasons, the experimental site's soil texture was silty clay with electrical conductivity (EC) of 0.62 dS m^{-1}, pH 7.25, organic matter of 22.77 g Kg^{-1}, total nitrogen of 1.2 g Kg^{-1}, available phosphorus of 6.18 mg Kg^{-1}, organic matter of 23.0 g Kg^{-1}, and exchangeable potassium of 0.13 mmole L^{-1}.

2.3. Preparation of Moringa Organ Extract (MOE) and Its Application

Moringa (*Moringa oleifera* L.) plant parts (leaves, roots, and seeds) were harvested from young full-grown trees and planted in the nursery of the Faculty of Science, University of Sulaimani, courtesy of Jamal Saeed Rashid. MOE was made by drying a sample of moringa parts in shad and then grinding to a fine powder with a blender. Following grinding, the extract was made by combining 20 g of each part and macerating it in 1 L of distilled water. For 24 h, the mixture was shaken. The mixture was then centrifuged for 30 min at 8000× *g*. The supernatant was then filtered through Whatman filter paper to remove any residue. To achieve the required foliar spray concentrations, the supernatant was diluted 30 times with distilled water [26]. Before dusk, foliar sprays were done to promote the best penetration into leaf tissues and inhibit evaporation. During the stages of fully emerging leaves, flag

leaf growth, and seed filling, the foliar MOE treatments were sprayed. At the same time, distilled water was sprayed on control plants. No synthetic fertilizer was used.

2.4. Plant Measurements

Three weeks after the last foliar application, the total chlorophyll measurement (TCC in Spad) was achieved using a portable chlorophyll meter CCM-200 (SPAD meter: Minolta Camera Co., Osaka, Japan), on three fully developed leaves near the plant apex of five plants. Leaf area (LA in cm^2) was also recorded at the same time. The leaf area was determined by the following formula: leaf length × leaf width × constant (0.64) [27].

Barley plants in each treated and untreated group were harvested at the end of the growing season, and parameters such as plant height (PH in cm), leaf area (LA in cm^2), total chlorophyll content (TCC in SPAD), number of the tillers per plant (TNP), number of the spikes per plant (SNP), spike length (SL in cm), awan length (AL in cm), spike weight (SW in cm), number of seeds per spike (SNS), seed weight per spike (SWS in g), 1000-kernel weight (1000-KW in g), total yield per plot (TY in g), and straw weight per plot (STW in g) were recorded.

2.5. Statistical Analysis

All of the recorded growth and yield parameters were statistically analyzed and assessed using the XLSTAT version 2020.3.1 and JMP version 14 statistical packages. A Duncan's Multiple-Range Test ($p \leq 0.05$) was used to compare mean values across treatments using the XLSTAT version 2020.3.1 statistical package. The dendrogram was created using JMP version 14 software. The principal component analysis (PCA) was calculated based on the mean data by using the XLSTAT version 2020.3.1 statistical package. Correlation analysis was performed by Q Research software. The radar, bar, and pie charts were created using Microsoft Excel version 2019. The percentage of trait index (PTI) was computed using the following formula:

$$\text{PTI (\%)} = [(\text{treated plants with MOE} - \text{untreated plants})/\text{untreated plants}] \times 100.$$

3. Results

3.1. Performance of Growth Traits under the Application of MOE

The results of a two-way analysis of variance indicate that accessions, foliar MOE application, and their interaction contribute significantly ($p \leq 0.01$) to all growth and yield component traits studied, with the exception of spike length in the foliar MOE treatment. A maximum F-value was observed for foliar MOE application (3933.46) and accessions (3177.67) based on seeds per spike (SNS), followed by 2162.29 for foliar MOE application and 877.77 for accessions based on straw weight (STW) (Table 2). The individual outcomes are displayed as follows.

The analysis of variance and mean pairwise comparison (Duncan) of all studied traits revealed statistically significant differences between treated (WM) and untreated (WOM) plants (Tables 2–4 and Table S1 in Supplementary Materials). The plants with the greatest height (90.95 cm) were those treated with moringa organ extract (WM) (Table 3). In addition, mean pairwise comparison analysis revealed significant variation among accessions for all studied traits (Table 4). AC57 recorded the greatest length at 110.03 cm, followed by AC56 at 109.30 cm and AC55 at 104.03 cm. In contrast, the barley accessions AC1, AC6, and AC5 were considered the shortest barley accessions, with respective values of 52.17, 62.93, and 65.90 cm. The plant height was positively affected by the exogenous application of moringa plant parts, as shown by the mean analysis and pairwise comparison in Table S1, which represents the interaction between MOE treatment and accessions. The AC57 accession recorded the greatest length (117 cm) under foliar application of MOE (AC57 * WM), followed by AC29 under foliar application of MOE (AC29 * WM), with a value of 113.53 cm. The barley accession AC1 under the control conditions (AC1 * WOM) is the shortest of the 59 barley accessions, with a length of 51.27 cm.

Table 2. Summary of analysis of variance of different studied traits.

	Accessions		Foliar MOE Application		Replications		Accessions * Foliar MOE Application	
Traits	**F**	**Pr > F**	**F**	**Pr > F**	**F**	**Pr > F**	**F**	**Pr > F**
PH (cm)	275.81 **	<0.0001	734.81 **	<0.0001	6.14 **	0.00	49.32 **	<0.0001
LA (cm^2)	31.17 **	<0.0001	298.34 **	<0.0001	1.14 ^{ns}	0.32	7.16 **	<0.0001
TCC (SPAD)	10.45 **	<0.0001	18.73 **	<0.0001	0.69 ^{ns}	0.50	4.02 **	<0.0001
TNP	14.38 **	<0.0001	28.57 **	<0.0001	3.76 ^{ns}	0.02	2.96 **	<0.0001
SNP	12.08 **	<0.0001	19.73 **	<0.0001	2.89 ^{ns}	0.06	2.75 **	<0.0001
SL (cm)	24.03 **	<0.0001	2.25 ^{ns}	0.13	3.45 *	0.03	3.59 **	<0.0001
AL (cm)	28.35 **	<0.0001	47.22 **	<0.0001	0.19 ^{ns}	0.83	9.28 **	<0.0001
SW (g)	143.52 **	<0.0001	70.28 **	<0.0001	30.78 **	<0.0001	12.39 **	<0.0001
SNS	3177.67 **	<0.0001	3933.46 **	<0.0001	39.11 **	<0.0001	183.40 **	<0.0001
SWS (g)	775.22 **	<0.0001	501.80 **	<0.0001	28.52 **	<0.0001	61.80 **	<0.0001
1000-KW (g)	57.82 **	<0.0001	71.49 **	<0.0001	57.73 **	<0.0001	10.59 **	<0.0001
TY (g)	20.62 **	<0.0001	49.56 **	<0.0001	0.04 *	0.96	1.78 **	0.00
STW (g)	869.77 **	<0.0001	2162.29 **	<0.0001	0.04 *	0.96	79.23 **	<0.0001

PH: plant height, LA: leaf area, TCC: total chlorophyll content, TNP: number of the tillers per plant, SNP: number of the spikes per plant, SL: spike length, AL: awan length, SW: spike weight, SNS: number of seeds per spike, SWS: seed weight per spike, 1000-KW: 1000-kernel weight, TY: total yield per plot, and STW: straw weight per plot. *: indicates a significant difference at the 0.05 level, **: indicates a highly significant variation at the 0.01 level. NS: denotes a non-significant variation.

Table 3. Pairwise comparisons (Duncan) of different studied characteristics under treatment with MOE (WM) versus control conditions (WOM).

Characteristics	Foliar Application	Mean ± Standard Error
PH (cm)	WOM	86.30 b ± 0.89
	WM	90.95 a ± 0.89
LA (cm^2)	WOM	10.62 b ± 0.18
	WM	12.31 a ± 0.18
TCC (SPAD)	WOM	11.12 b ± 0.31
	WM	12.21 a ± 0.31
TNP	WOM	15.71 b ± 0.55
	WM	17.94 a ± 0.56
SNP	WOM	12.29 b ± 0.41
	WM	13.78 a ± 0.42
SL (cm)	WOM	5.88 b ± 0.08
	WM	5.97 a ± 0.11
AL (cm)	WOM	11.15 b ± 0.14
	WM	11.62 a ± 0.11
SW (g)	WOM	1.89 b ± 0.05
	WM	2.01 a ± 0.05
SNS	WOM	33.50 b ± 0.99
	WM	37.06 a ± 0.89
SWS (g)	WOM	1.57 b ± 0.05
	WM	1.68 a ± 0.04
1000-KW (g)	WOM	47.52 a ± 0.47
	WM	45.82 b ± 0.52
TY (g)	WOM	111.61 b ± 6.16
	WM	138.83 a ± 5.21
STW (g)	WOM	352.99 b ± 11.78
	WM	412.92 a ± 11.05

PH: plant height, LA: leaf area, TCC: total chlorophyll content, TNP: number of the tillers per plant, SNP: number of the spikes per plant, SL: spike length, AL: awan length, SW: spike weight, SNS: number of seeds per spike, SWS: seed weight per spike, 1000-KW: 1000-kernel weight, TY: total yield per plot, STW: straw weight per plot. WOM: control (without application of moringa organ extract), WM: with application of moringa organ extract. Any values of means with the same letter in the same column are not significant according to Duncan's multiple range test at $p \leq 0.05$.

Table 4. Mean pairwise comparison between 59 barley accessions for three growth traits under treatment with MOE and control condition.

Accessions	PH (cm)	LA (cm^2)	TCC (SPAD)	Accessions	PH (cm)	LA (cm^2)	TCC (SPAD)
AC1	52.17 ae ± 0.46	14.42 cde ± 0.62	15.17 c–h ± 1.29	AC31	89.13 p–s ± 1.21	11.55 l–r ± 1.15	14.67 d–i ± 0.87
AC2	78.60 y ± 4.07	10.78 p–u ± 0.62	15.47 c–e ± 1.36	AC32	94.13 i–l ± 0.47	10.53 q–v ± 0.75	12.12 g–p ± 1.26
AC3	74.90 z ± 2.61	11.15 m–t ± 0.31	10.58 l–t ± 1.14	AC33	94.13 jkl ± 0.40	9.93 t–w ± 0.44	8.62 q–v ± 0.82
AC4	81.30 wx ± 3.36	12.15 i–o ± 0.78	10.40 l–t ± 0.65	AC34	96.23 ghi ± 2.07	10.02 s–w ± 0.55	8.88 p–v ± 0.79
AC5	65.90 ac ± 2.41	12.18 i–n ± 0.47	10.75 k–t ± 1.91	AC35	90.70 n–q ± 1.86	10.41 r–v ± 1.27	17.80 abc ± 0.90
AC6	62.93 ad ± 4.68	12.30 i–m ± 0.51	13.48 d–l ± 1.41	AC36	87.57 stu ± 0.60	6.91 z ± 0.93	9.25 o–v ± 0.69
AC7	93.67 jkl ± 3.95	15.07 cd ± 0.50	13.10 d–m ± 1.09	AC37	89.50 p–s ± 0.50	8.38 xy ± 0.27	8.63 q–v ± 1.32
AC8	67.83 ab ± 0.28	12.89 f–k ± 0.70	12.45 f–o ± 0.96	AC38	93.03 klm ± 1.65	11.04 m–t ± 0.61	7.40 tuv ± 0.67
AC9	88.40 rst ± 1.62	10.90 n–t ± 0.70	12.02 g–p ± 1.09	AC39	79.97 xy ± 2.91	12.30 i–m ± 0.48	16.23 bcd ± 4.45
AC10	80.27 xy ± 3.97	11.77 k–q ± 0.58	11.22 j–r ± 0.62	AC40	89.23 p–s ± 0.66	9.58 uvw ± 0.36	12.05 g–p ± 1.26
AC11	89.13 p–s ± 6.12	16.18 ab ± 0.69	11.90 h–q ± 1.11	AC41	72.73 aa ± 1.74	13.61 e–h ± 0.26	12.03 g–p ± 0.79
AC12	89.60 p–s ± 1.44	10.14 s–w ± 0.28	11.33 i–q ± 0.73	AC42	74.40 zaa ± 2.10	12.84 g–k ± 0.49	8.97 p–v ± 0.48
AC13	92.63 lmn ± 0.31	10.86 o–t ± 0.41	11.13 k–r ± 0.89	AC43	89.57 p–s ± 1.96	9.57 uvw ± 0.36	19.80 a ± 2.75
AC14	92.90 klm ± 0.65	11.26 m–s ± 0.65	12.93 e–m ± 0.97	AC44	91.13 m–p ± 1.89	8.34 xy ± 0.23	10.67 i–t ± 1.16
AC15	98.43 ef ± 1.69	15.36 bc ± 0.97	11.15 k–r ± 0.73	AC45	94.93 ijk ± 1.73	9.29 vwx ± 0.26	9.37 n–v ± 1.26
AC16	100.10 de ± 2.41	14.91 cd ± 1.12	12.87 e–m ± 1.66	AC46	82.83 w ± 2.02	11.16 m–t ± 0.78	10.90 k–s ± 0.94
AC17	95.77 g–j ± 0.57	11.28 m–s ± 0.95	15.37 c–g ± 1.51	AC47	88.50 rst ± 2.17	10.25 s–w ± 0.89	7.85 r–v ± 0.63
AC18	85.27 v ± 3.63	10.93 n–t ± 0.26	7.47 tuv ± 0.80	AC48	92.50 l–o ± 2.90	12.13 i–o ± 0.70	8.62 q–v ± 0.67
AC19	74.40 zaa ± 0.40	14.09 def ± 0.54	10.27 l–u ± 0.55	AC49	92.17 o ± 2.28	11.14 m–t ± 0.27	8.63 q–v ± 1.25
AC20	75.00 z ± 0.64	10.50 q–v ± 0.55	7.62 s–v ± 1.20	AC50	99.43 e ± 1.59	9.07 wx ± 0.82	12.13 g–p ± 0.81
AC21	102.60 bc ± 3.23	12.64 h–l ± 0.66	13.12 d–m ± 0.46	AC51	97.20 fgh ± 3.46	16.61 a ± 0.93	14.12 d–k ± 1.20
AC22	86.60 tuv ± 0.70	11.86 j–p ± 0.53	12.68 f–n ± 1.06	AC52	92.23 l–o ± 0.73	11.17 m–t ± 0.45	12.07 g–p ± 0.86
AC23	82.37 w ± 3.57	8.22 xy ± 0.25	7.60 s–v ± 0.64	AC53	86.03 uv ± 0.61	10.54 q–v ± 0.59	8.85 p–v ± 1.16
AC24	95.43 g–j ± 0.32	7.80 yz ± 0.35	7.02 uv ± 1.13	AC54	88.90 qrs ± 0.52	7.59 yz ± 0.21	8.60 q–v ± 0.21
AC25	100.00 de ± 0.81	11.90 j–p ± 0.91	11.43 i–q ± 1.62	AC55	104.03 b ± 0.35	9.39 vwx ± 0.41	16.10 b–e ± 0.56
AC26	86.57 tuv ± 1.36	9.92 t–w ± 1.33	9.77 m–v ± 1.23	AC56	109.30 a ± 0.53	13.33 e–i ± 0.31	14.53 d–j ± 1.69
AC27	89.20 p–s ± 2.81	10.78 p–u ± 0.59	6.67 v ± 0.43	AC57	110.03 a ± 4.36	13.96 d–g ± 0.37	12.42 f–o ± 1.26
AC28	97.30 fg ± 2.67	12.01 j–p ± 1.59	20.27 a ± 1.84	AC58	90.47 o–r ± 1.98	13.53 e–h ± 0.38	9.78 m–v ± 0.68
AC29	101.60 cd ± 5.34	11.73 k–q ± 0.45	10.53 l–t ± 1.01	AC59	92.87 klm ± 1.47	13.09 f–j ± 0.12	12.57 f–o ± 0.44
AC30	95.17 hij ± 0.62	13.31 e–I ± 0.98	18.78 ab ± 1.34				

PH: plant height, LA: leaf area, TCC: total chlorophyll content. According to Duncan's multiple range test at $p \leq 0.05$, any mean values with a common letter in the same column are not considered significant. The values are represented by the mean ± standard error.

Analysis of variance and mean comparisons between the WM and WOM groups revealed that the WM group had the greatest leaf area (12.31 cm^2) (Table 3). The barley accessions with the highest measurement of this trait were AC51, with a value of 16.61 cm^2, AC11, with a value of 16.18 cm^2, and AC15, with a value of 15.36 cm^2. AC36 was the least productive barley accession (6.91 cm^2), followed by AC54 (7.59 cm^2) and AC24 (7.80 cm^2). In the presence of foliar application of moringa, the interaction results revealed that AC51 under MOE application (AC51 * WM) produced the highest measurement (18.48 cm^2), followed by AC11 and AC15 under MOE treatment (AC11 * WM and AC15 * WM), with values of 17.43 and 17.40 cm^2, respectively, while AC36 under control conditions (AC36 * WOM) produced the lowest measurement (4.85 cm^2) for this trait (Table S1).

The SPAD meter CCM-200 was used to measure the total chlorophyll content (TCC) of barley flag leaves in our study. Significant differences were observed for this trait between WM and WOM (Table 2). The value of TCC was greatest at the WM plant (12.21 SPAD). The mean pairwise comparison analysis of significant variation among barley accessions, as expressed in Table 3, revealed that barley accession AC28 had the highest TCC value (20.27 SPAD) compared to the other barley accessions studied, whereas barley accession AC27 had the lowest TCC value (6.67 SPAD) (Table 4). As shown in Table S1, significant interaction effects were observed for the investigated trait between the treatment applications of moringa and barley accessions. This trait contributed significantly more to the interaction of AC39 under MOE application (AC39 * WM, 26.0 SPAD) than AC20 under control conditions (AC20 * WOM, 5.07 SPAD).

3.2. Contributing Yield Traits' Performance in the Presence of Moringa Organ Extract

In our experiment regarding the foliar effect of moringa plant extract (MOE), significant differences were observed between the untreated and treated groups for all yield-related traits except for the 1000-kernel weight (1000-KW) trait (Table 2, Table 3 and Table 6, and Supplementary Materials). The highest value (17.94) of the number of tillers per plant (TNP) was stated by the plants treated by the MOE (Table 3). Furthermore, the mean pairwise comparison between barley accessions revealed significant variation for all studied characteristics (Table 5). The results demonstrated that the barley accession AC47 had the greatest number of tillers (30.83). In contrast, barley accession AC7 had the lowest number of tillers per plant (5.67). According to Table S2 in Supplementary Materials, the mean pairwise comparison for the interaction of accession and MOE treatment revealed that AC47 had the highest tiller number per plant (37.33) in the presence of moringa application (AC47 * WM). In contrast, the AC7 accession recorded the lowest value (5.33), when the same treatment was not applied (AC7 * WOM).

Table 5. Mean pairwise comparison between 59 barley accessions for number of the tillers per plant, number of the spikes per plant, spike length, awan length, and spike weight traits after application of moringa plant extract.

Accessions	TNP	SNP	SL (cm)	AL (cm)	SW (g)
AC1	7.67 x–ab ± 0.33	5.67 r–u ± 0.49	4.42 v–y ± 0.20	10.86 n–u ± 0.19	1.94 jk ± 0.09
AC2	6.83 z–ab ± 0.31	6.00 r–u ± 0.58	6.85 d–i ± 0.27	12.62 d–g ± 0.50	2.30 e ± 0.37
AC3	6.17 aaab ± 0.75	4.00 u ± 0.52	3.79 y ± 0.07	12.43 d–h ± 0.45	1.84 l ± 0.12
AC4	9.50 w–ab ± 1.06	6.67 q–u ± 1.20	6.22 h–n ± 0.31	12.19 e–j ± 0.71	2.30 e ± 0.07
AC5	7.00 z–ab ± 0.68	5.17 stu ± 0.79	4.69 t–x ± 0.36	13.14bcd ± 0.45	1.61 rs ± 0.09
AC6	7.50 y–ab ± 0.67	5.33 stu ± 0.76	4.89 s–w ± 0.20	13.13bcd ± 0.65	1.64 qr ± 0.07
AC7	5.67 ab ± 0.71	4.33 tu ± 0.49	5.69 m–r ± 0.52	10.19 r–x ± 0.40	1.53 t ± 0.11
AC8	11.33 r–aa ± 2.04	9.17 n–s ± 2.18	4.78 t–x ± 0.18	12.37 d–i ± 0.53	1.67 pq ± 0.08
AC9	10.00 u–ab ± 1.29	7.83 p–u ± 1.40	4.26 wxy ± 0.12	12.10 e–k ± 0.26	2.07 i ± 0.07
AC10	10.67 t–ab ± 0.80	7.83 p–u ± 0.60	5.85 l–r ± 0.46	11.02 m–r ± 0.07	2.15 g ± 0.23
AC11	9.83 v–ab ± 1.54	7.33 p–u ± 1.48	4.90 s–w ± 0.17	12.67 d–g ± 0.41	1.83 lm ± 0.07
AC12	11.00 s–ab ± 1.00	8.33 o–t ± 0.71	5.13 q–v ± 0.23	11.11 l–q ± 0.25	1.78 mn ± 0.06
AC13	12.17 o–z ± 2.24	10.50 l–q ± 1.82	4.72 t–x ± 0.09	12.28 d–j ± 0.39	2.63 c ± 0.08
AC14	11.33 r–aa ± 1.09	8.33 o–t ± 1.26	4.91 s–w ± 0.11	12.43 d–h ± 0.18	2.21 f ± 0.06
AC15	14.33 l–w ± 1.28	11.67 h–p ± 1.05	5.29 p–u ± 0.51	14.10 a ± 0.88	1.96 jk ± 0.17
AC16	12.67 n–y ± 1.28	11.33 i–p ± 1.17	5.70 m–r ± 0.24	13.87 ab ± 0.36	2.11 hi ± 0.06
AC17	17.67 h–o ± 1.78	15.33 c–i ± 1.82	4.65 t–x ± 0.24	11.70 h–n ± 0.19	2.04 j ± 0.07
AC18	16.33 i–s ± 1.67	10.50 i–q ± 0.56	4.18 wxy ± 0.17	9.54 x–ab ± 0.20	1.85 l ± 0.17
AC19	13.00 m–x ± 2.21	9.83 m–r ± 1.62	4.58 u–x ± 0.17	10.99 m–s ± 0.16	1.98 jk ± 0.06
AC20	16.67 h–r ± 2.40	12.50 g–o ± 1.84	6.63 f–l ± 0.22	11.81 g–m ± 0.28	1.07 yz ± 0.06
AC21	11.67 q–z ± 1.71	10.83 j–q ± 1.72	7.51 bcd ± 0.24	14.49 a ± 0.27	2.71 b ± 0.08
AC22	11.67 q–z ± 0.71	8.83 o–s ± 0.87	4.09 xy ± 0.08	12.20 e–j ± 0.16	1.94 jk ± 0.09
AC23	18.17 g–n ± 1.14	13.17 f–n ± 1.25	7.28 c–f ± 0.28	9.33 y–ab ± 0.11	1.03 z ± 0.06
AC24	16.17 i–s ± 1.74	12.67 g–o ± 0.99	6.66 f–k ± 0.22	9.92 w–aa ± 0.27	1.17 x ± 0.06
AC25	20.83 d–j ± 2.07	16.00 b–h ± 1.84	7.35 b–f ± 0.31	13.94 a ± 0.86	1.44 u ± 0.08
AC26	19.83 d–l ± 1.17	13.83 d–m ± 1.45	6.44 g–m ± 0.19	10.93 n–t ± 0.58	1.04 yz ± 0.06
AC27	24.83 bcd ± 2.87	17.67 b–f ± 2.46	6.34 g–n ± 0.20	11.66 h–n ± 0.36	1.21 wx ± 0.06
AC28	21.67 c–i ± 3.56	19.17 abc ± 3.38	6.22 h–h ± 0.16	12.11 e–k ± 1.00	1.43 u ± 0.07
AC29	20.17 d–k ± 1.66	15.17 c–j ± 1.45	7.36 b–f ± 0.36	12.79 def ± 0.78	1.56 st ± 0.17
AC30	17.17 h–q ± 2.30	15.17 c–j ± 1.85	8.50 a ± 0.06	13.72 abc ± 0.55	1.63 qr ± 0.07
AC31	16.00 j–t ± 1.39	13.83 d–m ± 1.35	5.87 k–q ± 0.13	11.41 j–o ± 0.62	1.32 v ± 0.06
AC32	17.00 h–q ± 1.39	15.00 c–k ± 0.93	8.03 ab ± 0.21	10.45 p–w ± 0.43	1.25 w ± 0.08
AC33	19.50 d–l ± 1.26	15.17 c–j ± 1.08	6.28 g–n ± 0.14	9.96 v–aa ± 0.27	0.89 ab ± 0.06
AC34	26.33 abc ± 3.66	15.67 c–i ± 2.40	7.96 abc ± 0.16	10.07 t–z ± 0.48	1.09 y ± 0.06
AC35	17.50 h–p ± 2.40	14.33 d–l ± 1.23	6.03 j–p ± 0.35	10.46 p–w ± 0.92	2.14 g ± 0.10
AC36	19.67 d–l ± 3.76	17.50 b–f ± 2.97	5.79 m–r ± 0.15	10.40 q–x ± 0.35	1.44 u ± 0.07
AC37	24.00 b–f ± 3.01	20.17 ab ± 2.18	6.35 g–n ± 0.25	10.71 o–w ± 0.17	1.22 wx ± 0.12
AC38	26.17 abc ± 2.20	22.33 a ± 1.41	6.39 g–n ± 0.31	10.01 u–aa ± 0.21	1.10 y ± 0.10
AC39	20.00 d–l ± 1.15	18.00 b–e ± 0.89	6.13 i–o ± 0.03	11.95 f–l ± 0.42	1.22 wx ± 0.06

Table 5. *Cont.*

Accessions	TNP	SNP	SL (cm)	AL (cm)	SW (g)
AC40	15.17 k–v ± 1.96	13.67 e–m ± 1.56	6.41 g–n ± 0.08	12.43 d–h ± 0.36	1.33 v ± 0.06
AC41	19.83 d–l ± 2.50	16.33 b–g ± 1.82	7.42 b–e ± 0.40	11.31 k–p ± 0.48	1.05 yz ± 0.09
AC42	19.33 e–l ± 1.74	15.83 b–h ± 1.49	7.03 d–g ± 0.26	10.85 n–v ± 0.23	1.32 v ± 0.07
AC43	17.00 h–q ± 1.73	15.67 c–i ± 1.17	4.20 wxy ± 0.13	10.17 r–y ± 0.21	2.18 fg ± 0.06
AC44	28.00 ab ± 2.89	18.33 a–d ± 1.80	6.14 h–o ± 0.16	9.19 aaab ± 0.10	0.85 ab–ac ± 0.06
AC45	18.33 g–m ± 1.36	13.83 d–m ± 1.17	7.04 d–g ± 0.21	9.29 z–ab ± 0.23	1.19 wx ± 0.08
AC46	28.17 ab ± 1.70	19.17 abc ± 1.47	6.91 d–h ± 0.23	10.73 o–w ± 0.49	0.96 aa ± 0.10
AC47	28.50 ab ± 4.70	20.17 ab ± 2.87	5.09 r–v ± 0.14	9.29 z–ab ± 0.29	0.66 a–d ± 0.06
AC48	30.83 a ± 1.89	18.33 a–d ± 0.92	5.62 n–s ± 0.12	10.75 o–w ± 0.74	0.70 a–d ± 0.06
AC49	15.00 k–v ± 1.63	10.67 k–q ± 0.92	4.19 wxy ± 0.06	10.73 o–w ± 0.25	2.12 gh ± 0.06
AC50	19.17 e–l ± 1.80	15.00 c–k ± 1.91	5.19 q–u ± 0.12	10.46 p–w ± 0.54	1.70 op ± 0.06
AC51	12.00 p–z ± 1.15	8.50 o–t ± 0.62	6.04 j–p ± 0.27	12.59 d ± 0.25	1.91 k ± 0.11
AC52	24.33 b–d ± 2.70	16.50 b–g ± 1.06	6.73 e–j ± 0.33	9.46 y–ab ± 0.24	0.91 aaab ± 0.07
AC53	23.33 b–g ± 2.30	16.67 b–g ± 1.15	5.77 m–r ± 0.20	9.92 w–aa ± 0.28	0.82 ac ± 0.10
AC54	18.83 f–l ± 1.82	14.83 c–l ± 1.14	7.86 abc ± 0.54	10.12 s–z ± 0.12	1.31 v ± 0.10
AC55	17.00 h–q ± 1.06	14.33 d–l ± 0.88	6.08 i–o ± 1.09	11.50 i–o ± 0.32	2.45 d ± 0.20
AC56	22.00 c–h ± 1.63	17.00 b–g ± 1.93	5.63 n–s ± 0.38	10.99 m–s ± 0.15	1.76 no ± 0.12
AC57	15.33 j–u ± 0.88	12.50 g–o ± 0.76	6.38 g–n ± 0.12	8.95 ab ± 0.17	1.97 jk ± 0.14
AC58	16.67 h–r ± 1.84	14.50 d–l ± 1.65	5.77 m–r ± 0.09	12.87 de ± 0.24	2.31 e ± 0.06
AC59	18.17 g–n ± 2.61	15.17 c–j ± 1.96	5.36 o–t ± 0.15	12.98 cde ± 0.16	3.22 a ± 0.14

TNP: number of the tillers per plant, SNP: number of the spikes per plant, SL: spike length, AL: awan length, SW: spike weight. Any values of means containing the same letter in the same column are insignificant. The values are depicted by the mean ± standard error.

The number of spikes per plant (SNP) in this experiment varied between 12.29 (WOM) and 13.78 (WM) (Table 3). The SNP for barley accessions AC38 and AC3 was 22.33 and 4, respectively (Table 5). On the other hand, the same method of mean pairwise comparison was used to observe the effect of moringa treatment and determine its interaction with the examined barley accessions (Table S1). The barley accession AC28 had a higher SNP (25.33) under MOE treatment (AC28 * WM) than AC3, which had only three spikes per plant under control conditions (AC3 * WOM).

The maximum value (5.97 cm) of the spike length (SL) was recorded under the application of MOE (WM), as determined by a mean comparison between the levels of foliar treatment (Table 3). The mean comparison of the evaluated barley accessions revealed that AC30, with a length of 8.50 cm, had the highest SL, followed by AC32 and AC34, with lengths of 8.03 cm and 7.96 cm, respectively. In contrast, AC3, AC22, and AC18 are the shortest barley accessions for the SL trait, with respective values of 3.79, 4.09, and 4.18 cm (Table 5). The mean pairwise comparison of the SL between foliar application of moringa and accessions revealed a significant improvement in their interactions (Table S2). The barley accession with the best performance was AC54 under control conditions (AC54 * WOM), with a length of 8.97 cm, followed by AC30 under MOE application (AC30 * WM), with a length of 8.53 cm. As shown in Table S2, barley accession AC3 had the shortest SL in both levels (with and without MOE treatment), with values of 3.78 and 3.81 cm, respectively.

According to our analysis, the greatest awn length (AL) was found when MOE was applied (Table 3). In terms of AL, accessions AC21 (14.49 cm), AC15 (14.10 cm), and AC25 (13.94 cm) performed better than the remaining examined accessions. AC57 had the shortest length measurement (8.95 cm), followed by AC44 (9.19 cm), AC45, and AC47, with the same value (9.29 cm) (Table 5). Similarly, the mean pairwise comparison of the interaction between barley accessions and treatment status revealed that accessions AC15, AC25, and AC21 exhibited the highest levels of AL under MOE application, with values of 15.94, 15.76, and 15.02 cm, respectively. In the absence of moringa application, AC35 had the shortest AL, followed by AC57 and AC47, with values of 8.46, 8.71, and 8.81 cm, respectively (Table S2).

The application of moringa organ extract (WM) increased spike weight by 2.01 g in comparison to the control group (WOM), which is another significant finding of this study

(Table 3). AC59, with a value of 3.74 g, had the heaviest spikes, followed by AC13 (3.27 g) and AC21 (3.27 g). The mean pairwise comparison between the studied barley accessions for this investigated trait, as presented in (Table 5), exhibited that AC13 (3.27 g) and AC21 (3.27 g) had the lowest spike weight. In contrast, the three barley accessions AC47, AC48, and AC53 performed the worst in terms of spike weight, with respective values of 0.77, 0.81, and 0.97 g. As documented in Table S2, the mean pairwise comparison for detecting the influence of MOE applications and their interaction with the studied barley accessions revealed significant impacts. Barley accession AC59 (4.03 g) with moringa application (WM) performed the best, followed by AC2 (3.57 g) and AC55 (4.03 g) (3.45 g). In contrast, the absence of MOE application (WOM) significantly decreased the weight of this trait. For instance, AC47, AC53, and AC48, with respective values of 0.77, 0.79, and 0.81g, had the lowest spike weights.

The application of MOE had a substantial influence on the number of seeds per spike (SNS). The WM group demonstrated the greatest statistical significance for SNS (37.06) (Table 3). The mean pairwise comparison between barley accessions varied considerably, as demonstrated in Table 6. Barley accessions AC59, AC21, and AC13 had greater seed numbers, with values of 65.72, 56.83, and 54.83, compared to barley accessions AC47, AC52, and AC48, which all had lower grain per spike, with values of 18.22, 19.78, and 19.98, respectively. As shown in Table S2, when the data for this trait were analyzed to observe the interaction between foliar application and barley accessions, significant differences were discovered. In both conditions (WOM and WM), the AC59 produced the most seeds per spike, with values of 72.11 and 59.33, respectively. In addition to AC59, the barley accession AC13 with foliar treatment displayed a high seed number per spike, of 57.78. In contrast, the absence of MOE treatment significantly reduced the number of seeds per spike, as shown in Table 6 for barley accessions AC53, AC47, and AC48, with values of 17.22, 17.78, and 19.22, respectively.

Table 6. Mean pairwise comparison between 59 barley accessions for number of seeds per spike, seed weight per spike, 1000-kernel weight, total yield per plot, and straw weight per plot traits after application of moringa plant extract based on Duncan's multiple range test at $p \leq 0.05$.

Accessions	SNS	SWS (g)	1000-KW (g)	TY (g)	STW (g)
AC1	38.28 r ± 1.68	2.60 ef ± 0.08	50.60 f–i ± 0.68	45.73 u–z ± 7.26	160.26 ae ± 11.94
AC2	40.83 p ± 5.64	2.75 de ± 0.27	57.30 b ± 1.56	72.64 q–y ± 6.93	232.70 ab–ac ± 6.71
AC3	42.72 n ± 0.66	2.05 k–n ± 0.03	43.17 t–w ± 0.52	15.83 z ± 1.49	72.52 ag ± 12.04
AC4	51.89 e ± 0.68	2.84 d ± 0.06	44.30 q–u ± 0.65	55.97 s–z ± 7.50	191.55 ad ± 5.95
AC5	36.06 s ± 3.61	2.17 jk ± 0.13	45.13 o–t ± 1.18	27.30 yz ± 6.85	136.53 af ± 9.53
AC6	40.06 q ± 2.17	1.97 l–o ± 0.03	41.44 v–y ± 1.83	37.68 v–z ± 5.08	127.74 af ± 3.03
AC7	41.89 o ± 1.16	1.93 mno ± 0.05	36.59 ab–ac ± 0.56	30.36 w–z ± 6.13	127.80 af ± 11.48
AC8	38.89 r ± 2.05	1.93 mno ± 0.04	43.40 s–v ± 1.51	86.25 n–v ± 13.62	230.76 ac ± 22.30
AC9	48.33 h ± 1.07	2.42 ghi ± 0.05	42.84 t–x ± 0.48	118.05 j–r ± 9.36	292.31 yz ± 16.57
AC10	43.44 lm ± 3.48	2.57 fg ± 0.20	49.18 g–m ± 0.87	79.82 o–x ± 11.02	246.47 ab ± 18.27
AC11	38.44 r ± 0.73	2.22 jk ± 0.03	47.83 j–n ± 1.62	97.26 l–t ± 20.22	274.39 aa ± 37.48
AC12	41.06 p ± 2.47	2.21 jk ± 0.04	43.96 r–v ± 1.93	29.66 xyz ± 6.21	126.24 af ± 12.93
AC13	54.83 c ± 1.33	3.27 b ± 0.03	48.12 i–n ± 0.94	198.89 def ± 21.13	452.80 lmn ± 9.33
AC14	46.06 j ± 3.36	2.50 fgh ± 0.04	48.95 h–m ± 2.83	133.30 i–n ± 8.46	410.97 st ± 3.97
AC15	44.00 kl ± 0.29	2.40 ghi ± 0.06	44.61 p–u ± 1.69	129.55 i–o ± 17.29	367.80 vw ± 37.26
AC16	48.00 hi ± 0.41	2.45 f–i ± 0.04	44.04 r–u ± 0.54	203.69 def ± 20.39	484.32 j ± 7.02
AC17	44.28 k ± 1.04	2.49 f–i ± 0.08	46.01 n–r ± 0.94	209.53 cde ± 28.96	464.93 l ± 12.39
AC18	47.67 i ± 0.54	2.10 klm ± 0.12	38.62 z–ab ± 2.18	51.22 t–z ± 1.00	227.47 ac ± 43.00
AC19	53.44 d ± 1.16	2.20 jk ± 0.02	37.06 aa–ac ± 0.81	94.34 l–u ± 7.42	300.77 xy ± 10.50
AC20	23.39 xy ± 0.31	1.28 uvw ± 0.02	45.92 n–s ± 0.94	104.01 l–s ± 11.16	310.36 x ± 3.70
AC21	56.83 b ± 2.17	3.23 b ± 0.11	47.67 k–o ± 0.37	202.32 def ± 21.99	479.92 jk ± 17.12
AC22	41.22 p ± 0.87	2.19 jk ± 0.06	47.02 l–p ± 0.64	140.83 g–m ± 12.52	376.85 uv ± 5.25
AC23	19.98 ac ± 0.54	1.34 u ± 0.08	51.64 efg ± 4.53	86.46 n–v ± 15.12	360.14 w ± 33.58

Table 6. *Cont.*

Accessions	SNS	SWS (g)	1000-KW (g)	TY (g)	STW (g)
AC24	23.83 x ± 0.23	1.34 u ± 0.02	48.96 h–m ± 0.94	104.27 l–s ± 23.13	313.80 x ± 47.55
AC25	22.56 zaa ± 0.41	1.80 op ± 0.06	63.66 de ± 1.89	229.29 cd ± 21.18	726.23 b ± 18.39
AC26	23.67 xy ± 0.22	1.15 vwx ± 0.02	44.04 r–u ± 0.97	129.26 i–o ± 9.95	377.34 uv ± 14.31
AC27	23.06 yz ± 0.22	1.39 tu ± 0.03	52.37 def ± 1.17	158.37 f–k ± 14.82	409.17 st ± 37.01
AC28	25.17 w ± 0.47	1.72 pq ± 0.04	56.94 b ± 0.99	188.16 d–g ± 18.60	537.90 fg ± 7.03
AC29	27.50 u ± 2.07	1.89 no ± 0.12	56.59 b ± 1.02	184.63 d–g ± 25.17	539.63 f ± 30.43
AC30	31.83 t ± 0.56	2.00 lmn ± 0.05	51.13 e–h ± 0.86	255.06 bc ± 18.02	630.47 d ± 4.43
AC31	23.44 xy ± 0.78	1.69 pqr ± 0.02	56.63 b ± 1.63	189.66 d–g ± 16.10	509.07 h ± 17.00
AC32	24.94 w ± 0.61	1.61 qrs ± 0.04	49.89 g–k ± 0.93	167.30 e–j ± 24.20	440.33 nop ± 10.31
AC33	21.06 ab ± 0.25	1.05 xy ± 0.02	42.36 u–x ± 1.03	117.74 j–r ± 7.58	458.23 lm ± 16.21
AC34	23.78 x ± 0.73	1.26 uvw ± 0.03	46.01 n–r ± 1.04	122.67 j–q ± 21.88	467.58 kl ± 14.16
AC35	44.44 k ± 0.26	2.38 hi ± 0.04	48.22 i–n ± 1.01	134.22 i–n ± 15.98	499.93 hi ± 16.57
AC36	28.06 u ± 0.28	1.51 st ± 0.02	51.29 e–h ± 0.82	71.85 q–y ± 10.66	241.77 ab–ac ± 23.96
AC37	26.22 v ± 0.68	1.56 q–t ± 0.04	46.64 m–q ± 0.90	128.35 i–p ± 17.63	369.46 vw ± 45.64
AC38	22.11 aa ± 0.59	1.32 uv ± 0.07	49.41 g–l ± 1.91	119.29 j–r ± 14.87	415.43 rst ± 4.43
AC39	22.00 aa ± 0.26	1.52 rst ± 0.02	55.36 bc ± 1.12	180.20 d–h ± 39.55	485.06 j ± 68.21
AC40	24.61 w ± 0.31	1.68 p–s ± 0.02	54.07 cd ± 1.04	80.56 o–w ± 5.44	301.92 xy ± 1.74
AC41	23.61 xy ± 0.80	1.31 uv ± 0.06	44.41 q–u ± 1.46	114.09 k–r ± 21.49	423.04 qrs ± 22.18
AC42	26.56 v ± 0.63	1.60 qrs ± 0.05	49.56 g–l ± 0.93	101.83 l–t ± 9.89	314.77 x ± 21.00
AC43	49.83 g ± 0.25	2.45 f–i ± 0.06	43.64 r ± 1.14	212.27 cde ± 10.84	525.90 fg ± 7.04
AC44	21.00 ab ± 0.78	0.98 xy ± 0.03	40.81 w–z ± 1.29	83.43 n–v ± 10.48	437.39 opq ± 6.34
AC45	25.22 w ± 1.51	1.41 tu ± 0.04	47.59 k–o ± 1.68	144.53 g–l ± 16.38	427.37 pqr ± 32.25
AC46	22.50 zaa ± 0.90	1.13 wxy ± 0.07	42.52 u–x ± 1.76	92.38 m–u ± 13.76	449.60 mno ± 19.91
AC47	18.22 ad ± 0.29	0.77 z ± 0.02	36.46 ab–ac ± 1.25	69.57 r–y ± 12.16	368.86 vw ± 20.63
AC48	19.94 ac ± 0.39	0.81 z ± 0.02	35.01 ac ± 1.23	77.61 p–x ± 10.51	402.90 t ± 8.17
AC49	43.28 mn ± 0.31	2.40 ghi ± 0.02	49.07 h–m ± 0.58	155.21 f–k ± 16.41	490.05 ij ± 2.67
AC50	41.94 o ± 0.56	1.95 mno ± 0.02	40.65 x–z ± 0.69	213.84 cde ± 11.80	572.49 e ± 12.35
AC51	48.61 h ± 0.99	2.13 kl ± 0.05	39.21 y–aa ± 0.44	68.88 r–y ± 11.85	291.12 yz ± 5.14
AC52	19.78 ac ± 0.26	1.06 xy ± 0.03	46.06 n–r ± 2.06	70.26 r–y ± 7.23	367.29 vw ± 32.83
AC53	21.94 aa ± 2.12	0.97 y ± 0.07	37.90 aaab ± 1.39	61.91 s–z ± 9.42	371.47 vw ± 12.27
AC54	24.56 w ± 0.33	1.56 q–t ± 0.06	53.31 cde ± 3.09	92.70 m–u ± 11.22	284.98 zaa ± 9.37
AC55	51.39 e ± 1.38	3.03 c ± 0.19	47.30 k–o ± 2.45	337.47 a ± 42.52	741.59 a ± 16.77
AC56	40.83 p ± 0.52	2.21 jk ± 0.03	43.05 t–x ± 1.33	84.16 n–v ± 17.77	378.81 u ± 44.64
AC57	50.67 f ± 2.44	2.32 ij ± 0.12	38.67 z–ab ± 0.72	128.16 i–p ± 7.11	387.33 u ± 13.44
AC58	46.11 j ± 2.25	3.07 c ± 0.08	50.32 f–j ± 0.99	176.44 e–i ± 20.98	523.77 g ± 62.66
AC59	65.72 a ± 2.87	3.74 a ± 0.12	49.04 h–m ± 0.49	291.98 b ± 35.86	656.98 c ± 37.16

SNS: number of seeds per spike, SWS: seed weight per spike, 1000-KW: 1000-kernel weight, TY: total yield per plot, and STW: straw weight per plot. Any means values in the same column with the same letter are not significant. The mean ± standard error is used to represent the values.

With a value of 1.68 g, the seed weight per spike of all barley accessions significantly increased in the presence of MOE (Table 3). The mean comparison of tested barley accessions revealed that AC59 and AC47 had the highest and lowest values for this trait, respectively (3.49 and 0.66 g) (Table 6). In terms of interaction with MOE, the seed weight per spike of barley accessions studied exhibited the same response pattern as the barley accessions. The values ranged from 3.49 to 0.66 g for the AC59 and AC47 samples, respectively (Table S2).

Analysis of the data showed significant negative effects of foliar MOE application for 1000-kernel weight (1000-KW) across all barley accessions (Table 3). In the absence of MOE application, the highest value of 1000-KW (47.52 g) was measured. Among the evaluated barley accessions, AC25 (63.66 g), AC2 (57.30 g), and AC28 (56.94 g) had the highest value for the studied trait, followed by AC48 (35.01 g), AC47 (36.46 g), and AC7 (36.59 g) (Table 6). The interaction between the evaluated barley accessions and the MOE application revealed, with a value of 67.12 g, that AC25, with the absence of MOE application, performed better than the other accessions for the trait under study. The AC48 accession under MOE treatment, on the other hand, had a minimum 1000-KW value (33.82 g) (Table S2).

In response to the MOE application, positive significant results were obtained in the analysis of total yield per plot (TY) and straw weight per plot (STW) performances (Table 3).

The foliar MOE application yielded the highest value of TY, measuring 138.83 g. For TY, AC55 outperformed the other barley accessions, followed by AC59 and AC30, with values of 337.47, 291.98, and 255.06 g, respectively. Barley accession AC3 had the lowest value (15.83 g), followed by AC5 (27.29 g) and AC12 (29.66 g) (Table 6). In the case of the treatment interaction (MOE application) for the same studied trait, AC59 had the highest variability in TY for its mean among the investigated accessions, with a value of 363.27 g under MOE application. In contrast, AC5 record the lowest value of TY with a value of 12.24 g under control conditions (WOM) (Table S2). Similarly, the greatest value of STW was stated under MOE application across all accessions (Table 3). In the case of studying the STW, AC3 had the lowest value (72.51 g), followed by AC12 and AC6, with values of 126.24 and 136.54 g, respectively. AC55, on the other hand, verified the highest record with a value of 741.59 g. It was followed by the AC25 and AC59 barley accessions, with values of 726.23 and 656.98 g, respectively (Table 6). The interaction of barley accessions with MOE for STW, on the other hand, revealed a wide range of variability, as stated in Table S2. In the absence of a MOE application, AC3 had the lowest record of 45.62 g. Meanwhile, when compared to the other barley accessions, AC25 had the highest value (764.32 g) in the presence of MOE treatment.

3.3. Relationship among Various Accessions and Traits under Untreated and Treated Conditions

A heat map of pairwise correlations (two-side dendrogram) based on mean values obtained from all measured traits in the presence and absence of moringa plant extract was constructed to gain a better understanding of the relationships between studied barley accessions and studied morphological traits (Figure 1). Despite the fact that six groups were estimated in both cases, the barley accessions studied behaved and grouped differently. The majority of barley accessions associated with studied traits clustered together in group 5 under control conditions, indicating that these barley accessions shared the same linkage for the majority of the studied traits. Group 3 is considered the smallest group among constructed clades because only three genotypes were clustered in this group (AC51, AC56, and AC57), demonstrating that these barley accessions share similar associations with investigated traits and are distinct from the remaining barley accessions studied. The remaining barley accessions were classified into four groups (Figure 1A). However, a different arrangement was observed in the case of foliar application of MOE, with significant responses to this treatment by the studied barley accessions and its impacts on selected morphological parameters. The largest group in the MOE treatment (Figure 1B) included 21 barley accessions. This group (Group 2) reacted similarly to the characteristics under consideration. While two distinct barley accessions (AC59 and AC55) grouped together and demonstrated a positive relationship with studied traits, they formed a distinct cluster distinct from all other accessions, whereas the remaining barley accessions fell into other distinct clusters.

To display the correlations between the various plant parameters, principal component analysis (PCA) was performed on the experimental dataset for multifactorial comparison. PCA was used to analyze all 13 measured morphological traits in both normal and treated conditions. In both the control and treated conditions, PCA revealed that 59 different barley accessions were clustered into four clades (Figure 2). Under normal conditions, the first two factorial axes (F1, F2) account for 62.93% of the variance in the data. In the current MOE foliar application, it represented 56.97% of the data variance. Under normal circumstances, all measured traits were divided into two major clusters. Cluster 1 (upper left quarter) included SNP, TNP, SL, PH, and 1000-KW, whereas Cluster 2 (upper right quarter) included TY, TCC, AL, SWS, SW, LA, and SNS (Figure 2A). In relation to the distribution of barley accessions, the PCA plot classified 59 barley accessions into four clades. Clade 1 (upper left quarter) consisted of 11 barley accessions that are predominantly grown in the south of Iraq, whereas clade 4 (lower right quarter), with a performance that differed from clade 1, consisted of 14 barley accessions. In addition to these two clades, 16 accessions of studied barley were distributed in clade 2 (upper right quarter). The traits studied contributed

more positively to this clade, suggesting that this component reflected the yield potential of each barley accession in this clade.

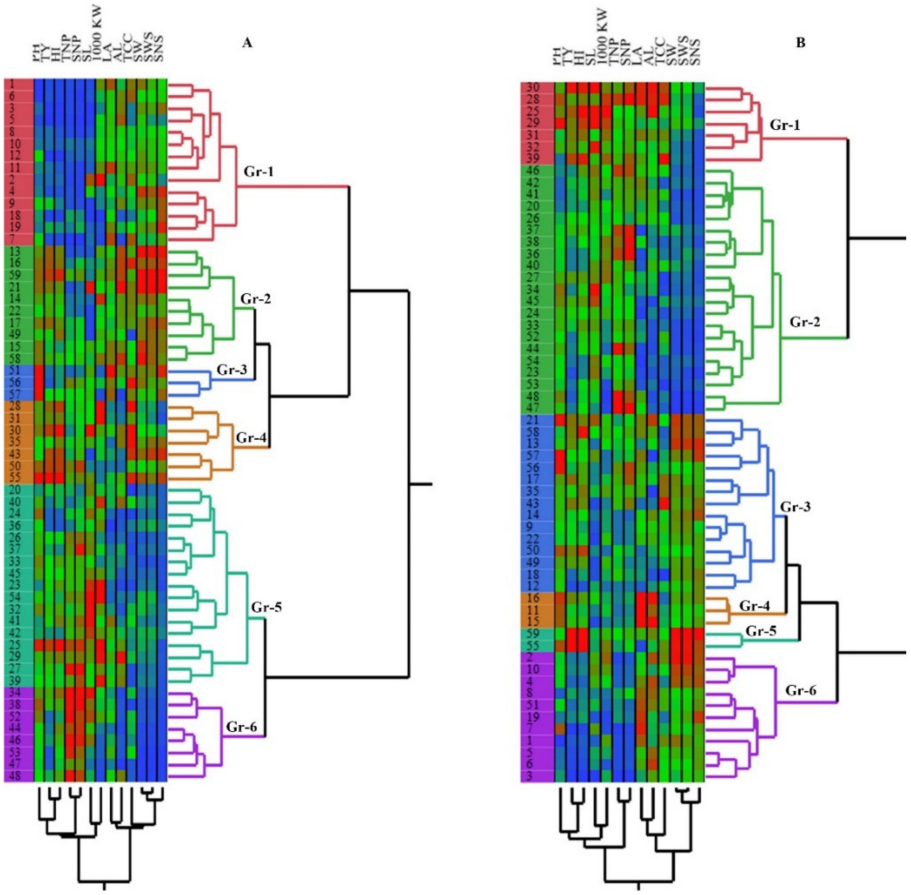

Figure 1. Dendrogram showing association among the 59 studied barley accessions and 13 measured morphological traits under both untreated (control) condition (**A**) and moringa plant extract foliar application (**B**). PH: plant height, LA: leaf area, TCC: total chlorophyll content, TNP: number of the tiller per plant, SNP: number of the spike per plant, SL: spike length, AL: awan length, SW: spike weight, SNS: number of seeds per spike, SWS: seed weight per spike, 1000-KW: 1000-kernel weight, TY: total yield per plot, STW: straw weight per plot. The numbers (1–59) denote the barley accessions. The number of formed groups ranges from Gr-1 to Gr-6.

In addition, the remaining 18 barley accessions, as shown in Figure 2A, belong to clade 3 (bottom left quarter). This determines the genetic differences between those groups that can be selected for crossing in the future breeding program, particularly in the case of AC59 and AC47, in clades 2 and 3, and AC25 and AC1, in clades 1 and 4, respectively.

Regarding the analysis of PCA in the presence of foliar application of moringa extract, distinct distribution patterns of barley accessions and studied traits can be observed when compared to the untreated condition. As depicted in Figure 2B, nearly half of the studied barley accessions are separated and evenly distributed between clades 1 and 2, with 13 accessions for each clade. In addition, clade 3 contained 17 barley accessions, in contrast to clade 1, and the remaining 16 barley accessions remained in clade 4. The present study found that studied traits had a strong correlation with barley accessions distributed across clades 1 and 2, indicating that greater emphasis should be placed on these barley accessions in order to boost final productivities in the presence of moringa plant extract. The attributed differences between these accessions may be partially attributable to their distinct genetic backgrounds and varied responses to the utilized application.

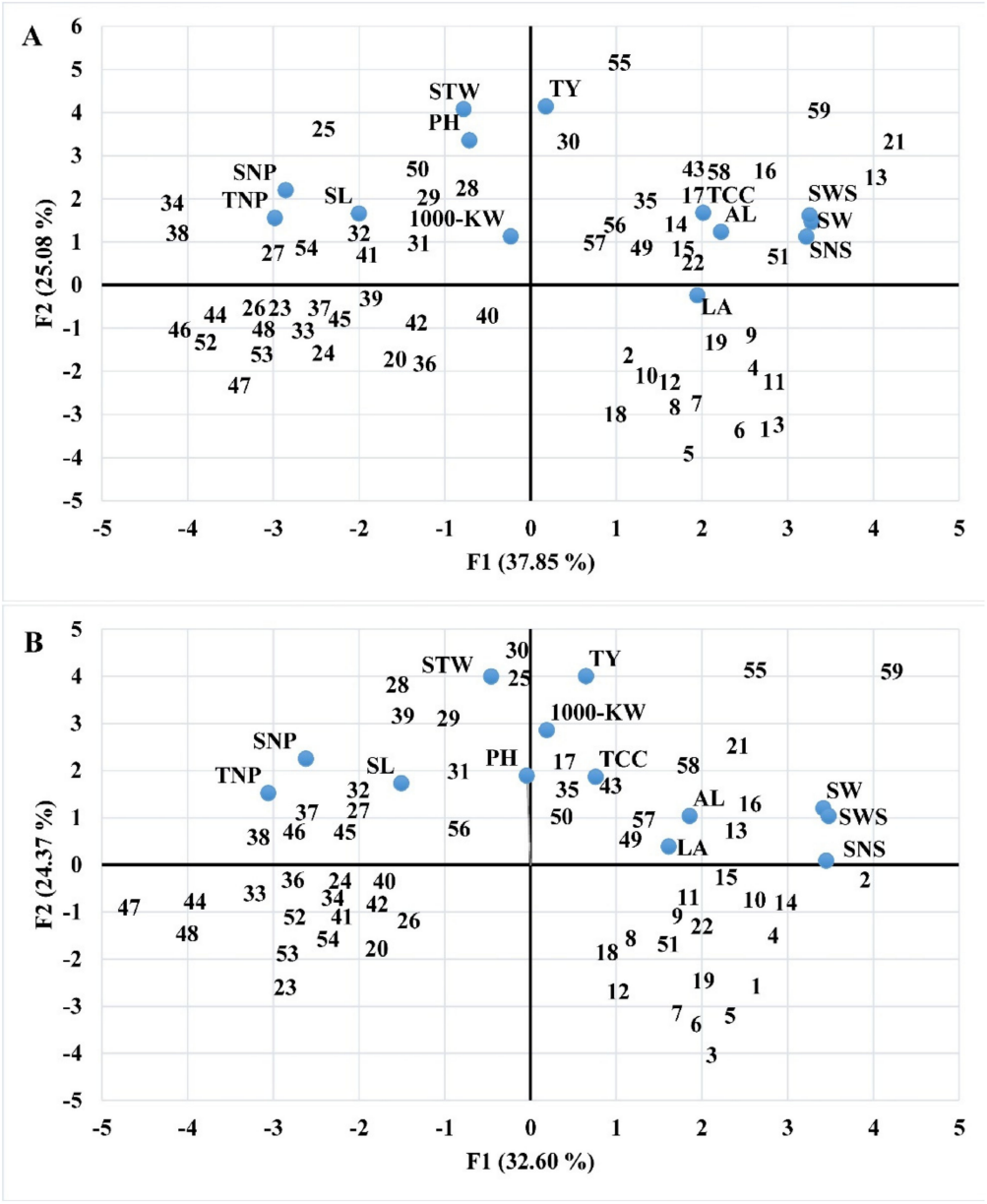

Figure 2. Biplot diagram of principal component analyses based on the first and second components for 59 barley accessions obtained from 13 morphological parameters under both control (**A**) and foliar application of moringa organ extract (**B**). PH: plant height, LA: leaf area, TCC: total chlorophyll content, TNP: number of the tiller per plant, SNP: number of the spike per plant, SL: spike length, AL: awan length, SW: spike weight, SNS: number of seeds per spike, SWS: seed weight per spike, 1000-KW: 1000-kernel weight, TY: total yield per plot, STW: straw weight. The numbers (1–59) represent the barley accessions.

The correlation coefficients measure the degree of similarity and dissimilarity between two characteristics or variables, and the nature of the association between studied parameters can be evaluated. From these mean values, Pearson correlations (r) of the studied traits under control and MOE application conditions are calculated and displayed (Figure 3). Under control conditions, a strong positive significant correlation (r = 0.97, $p < 0.0001$) was observed between SW and SWS traits, followed by TNP and SNP (r = 0.94, $p < 0.0001$) and SNS and SWS (r = 0.93, $p < 0.0001$), while weak positive significant associations were observed between AL and TY (r = 0.26 *, $p = 0.05$), SW and TY (r = 0.30 *, $p = 0.02$), and LA and TCC (r = 0.30 *, $p = 0.02$). A negative significant relationship (r = −0.27 *, $p = 0.04$)

was observed between SNS and 1000-KW (Figure 3A). Concerning the correlations between investigated parameters following foliar application of moringa plant part extract. Positive correlations among studied traits for the r value ranged between 0.98 and 0.27, corresponding to the association between SW and SWS and SL and SNP. As depicted in Figure 3B, a very robust positive significant association was found between SW and SWS yield-related characteristics (r = 0.98, $p < 0.0001$), followed by the association between SNS and SWS (r = 0.93, $p < 0.0001$) and TNP and SNP (r = 0.91, $p < 0.0001$), whereas a weak positive linkage was found with a nearly identical pattern between SL and SNP (r = 0.28 *, $p = 0.03$). A negative correlation between AL and TNP was observed (r = −0.37, $p = 0.003$).

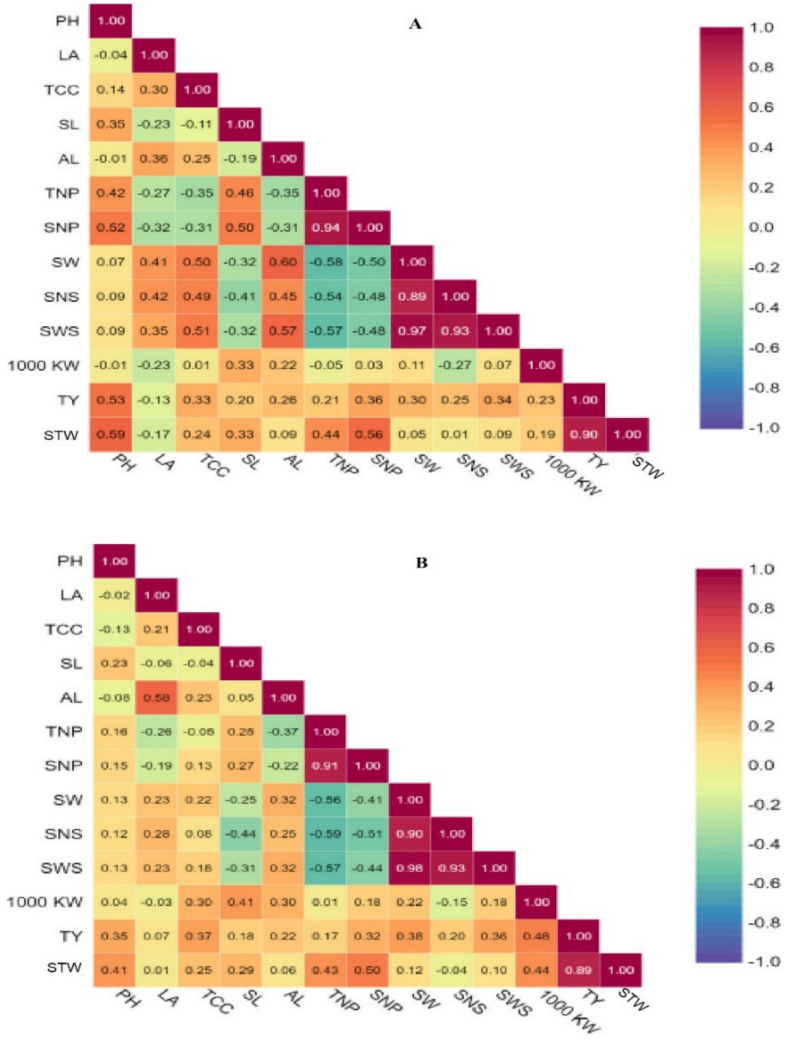

Figure 3. Pearson correlation (r) between 13 morphological parameters in the untreated (**A**) and treated (**B**) conditions with moringa organ extract. PH: plant height, LA: leaf area, TCC: total chlorophyll content, TNP: number of the tillers per plant, SNP: number of the spikes per plant, SL: spike length, AL: awan length, SW: spike weight, SNS: number of seeds per spike, SWS: seed weight per spike, 1000-KW: 1000-kernel weight, TY: total yield per plot, STW: straw weight per plot.

3.4. Percentages of Increasing (Positive Value) and Decreasing (Negative Value) Index of Various Traits among the Barley Accessions Utilized in This Study

A range of growth and yield traits are positively and negatively affected by MOE application, with the ranges varying from −14.89% to 39.90%, −20.68% to 85.04%, −44.67% to 302.06%, −38.78% to 137.14%, −34.92% to 37.75%, −32.14% to 44.25%, −45.90% to 192.86%, −26.21% to 85.84%, −15.68% to 89.37, −28.91% to 71.03%, −29.00% to 28.25%, −57.19% to 246.12%, and −54.11% to 146.17%, for PH, LA, TCC, TNP, SL, AL, SNP, SW,

SNS, SWS, 1000-KW, TY, and STW, respectively (Figure 4). As shown in Figure 4, the barley accessions responded differently to MOE. The highest scores for PH, LA, TCC, TNP, SL, AL, SNP, SW, SNS, SWS, 1000-KW, TY, and STW were, respectively, AC6, AC36, AC39, AC36, AC5, AC28, AC8, AC2, AC2, AC2, AC18, AC5, and AC18. Among the growth and yield traits studied, 1000-KW (−3.04%) was the most severely affected trait and was decreased in the majority of barley accessions (Figure 5). The most significant increase was in the TY (3.7.55%), which was followed by increases in the STW (22.29%), TNP (21.44%), and SNP (21.36%).

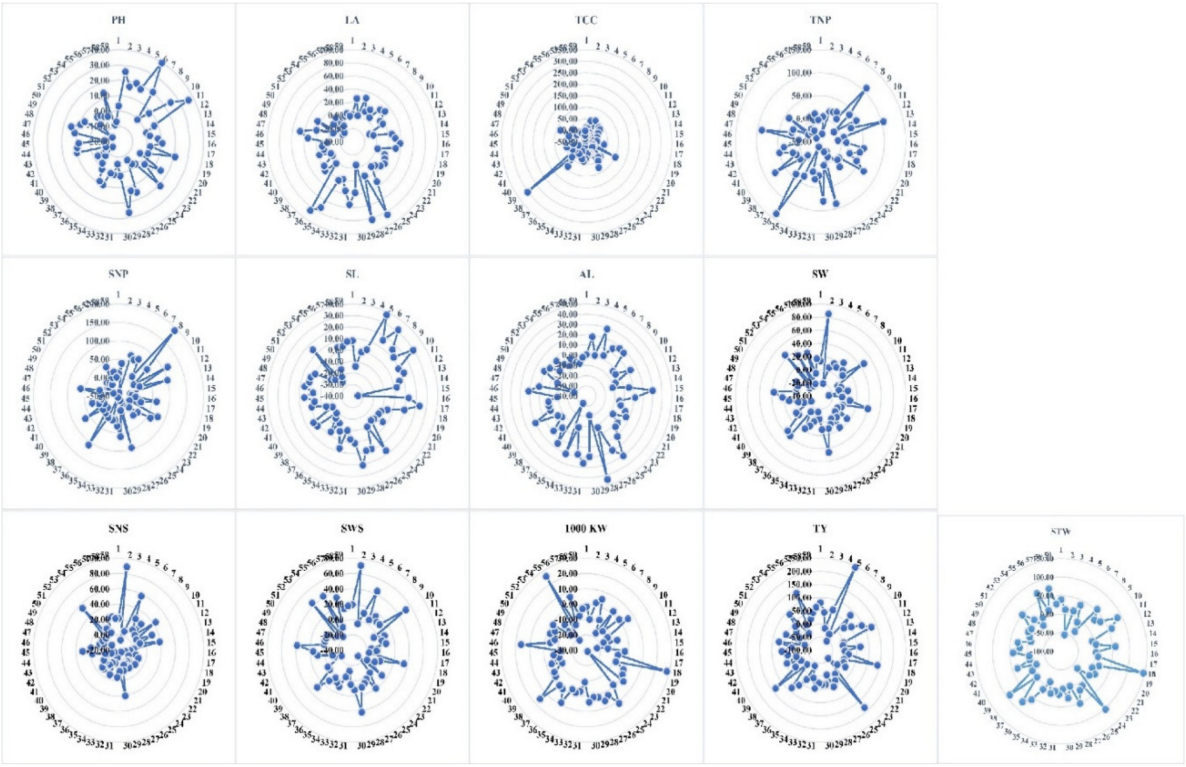

Figure 4. The radar graph depicts the responses of various accessions to MOE treatment based on growth and yield characteristics. PH: plant height, LA: leaf area, TCC: total chlorophyll content, TNP: number of the tillers per plant, SNP: number of the spikes per plant, SL: spike length, AL: awan length, SW: spike weight, SNS: number of seeds per spike, SWS: seed weight per spike, 1000-KW: 1000-kernel weight, TY: total yield per plot, STW: straw weight per plot. The numbers (1–59) represent the barley accessions.

Figure 6 depicts a PCA analysis of the studied characteristics used to establish a preliminary insight into the main distinction between barley accessions in relation to MOE response. The PCA explained a total of 42.53% of the variance, with the first axis (F1) accounting for 25.08% of the variation, and the second axis (F2) accounting for 17.45% of the variation. The PCA biplot demonstrated clearly that accessions react differently to MOE application. The PCA diagram classified all accessions into four distinct categories. The first groups (upper-right quarter) and fourth group (lower-right quarter) comprised the accessions that responded positively to MOE treatment and were deemed to have the best performance under MOE application. In contrast, the accessions in the second group (upper-left quarter) and third group (lower-left quarter) were deemed to have the lowest performance under MOE treatment. Based on the TY and STW traits, AC5 and AC18 accessions demonstrated the best performance, whereas AC2 and AC10 accessions demonstrated the best performance for the SNS, SW, and SWS traits.

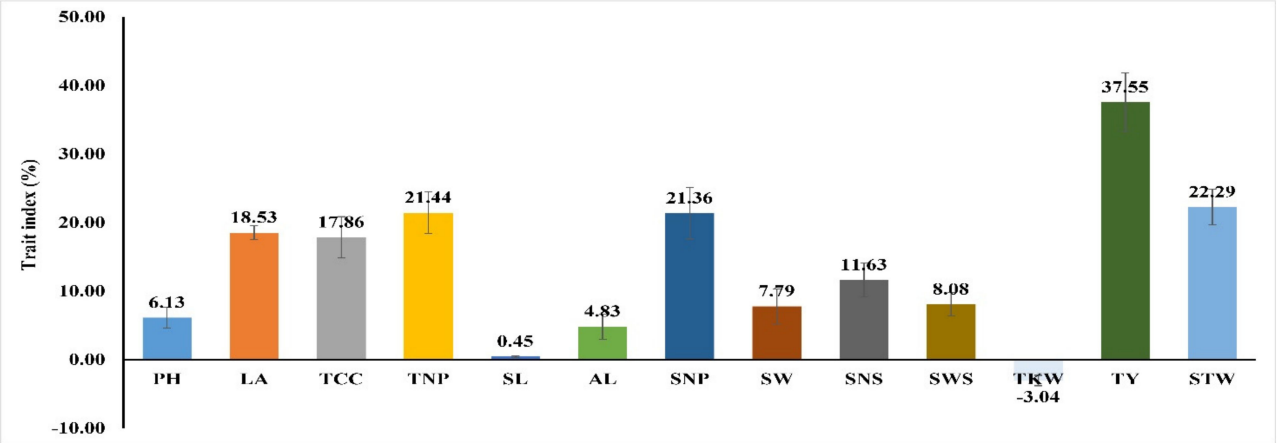

Figure 5. Percentage responses (increasing or decreasing index) of various studied characteristics across all accessions of barley under MOE application compared to control plants. PH: plant height, LA: leaf area, TCC: total chlorophyll content, TNP: number of the tillers per plant, SNP: number of the spikes per plant, SL: spike length, AL: awan length, SW: spike weight, SNS: number of seeds per spike, SWS: seed weight per spike, 1000-KW: 1000-kernel weight, TY: total yield per plot, STW: straw weight per plot. Positive and negative scores on the bars reflect the values of increasing and decreasing traits, respectively.

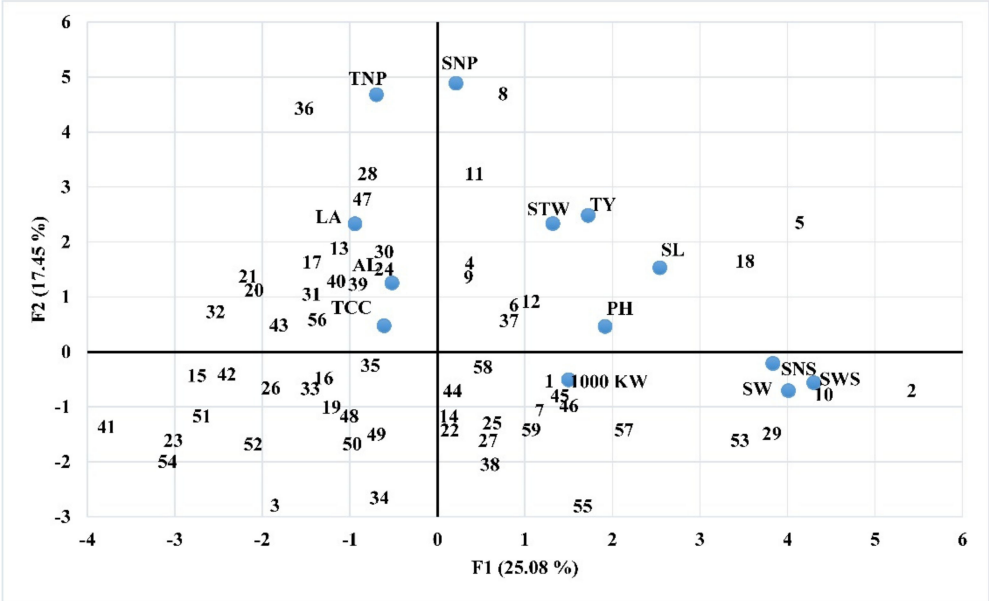

Figure 6. PCA plot depicts the distribution of barley accessions and investigated characteristics based on the percentage of responses under MOE application. PH: plant height, LA: leaf area, TCC: total chlorophyll content, TNP: number of the tillers per plant, SNP: number of the spikes per plant, SL: spike length, AL: awan length, SW: spike weight, SNS: number of seeds per spike, SWS: seed weight per spike, 1000-KW: 1000-kernel weight, TY: total yield per plot, STW: straw weight per plot. The numbers (1–59) represent the barley accessions.

3.5. Percentage of Positive and Negative Effects of MOE Application on the Studied Traits, Based on the Responses of 59 Barley Accessions

Different patterns of responses by the barley accessions under the foliar application of moringa plant parts were detected. As shown in Figure 7, the results confirmed that the application used in our investigation increased all morphological studied parameters, especially the yield traits, with the only exception of the 1000-KW trait. Regarding the analysis for displaying the percentage response by all barley accessions in the case of

conducting such a foliar application, the overall view of responses for plant height trait, as shown in Figure 4, indicated the huge impact of such a treatment on the studied barley accession, in which 68% of the accession responded positively in their height to MOE application. Similarly, 83% of accessions demonstrated a positive effect of MOE on leaf area. Regarding the positive responses by barley accessions in total chlorophyll content (TCC), 64% of accessions were detected. Sixty-three percent of barley accessions were documented as having positive awn length (AL) responses. In addition, more than half of the barley accessions responded positively to moringa extract application for the spike length (SL) parameters. A progressive response was observed for the other three traits, namely tiller number per plant (TNP), total yield (TY), and straw weight (STW), in which three-quarters of the tested barley accessions responded positively to foliar application of moringa. In addition to the previous parameters, the other two traits, spike number per plant (SNP) and seed weight/spike (SWS), responded positively in 69% of barley accessions. For 1000-KW traits, 31% of barley accessions responded positively to foliar application.

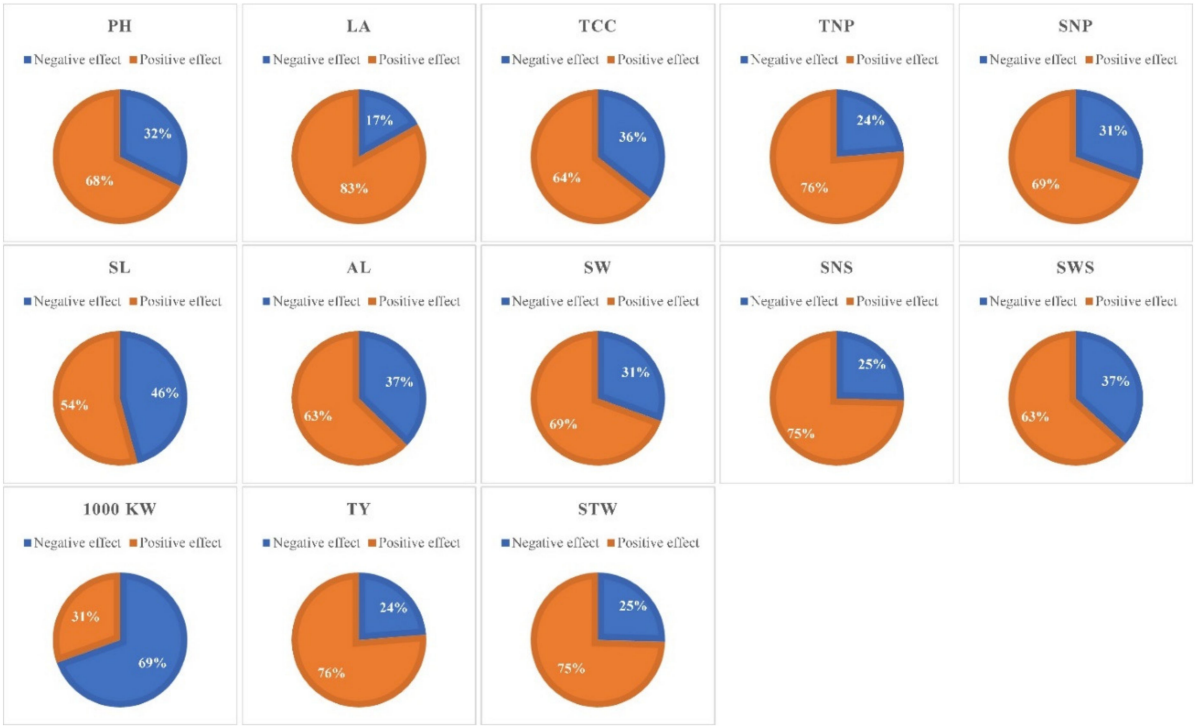

Figure 7. Illustration of the proportion of positive and negative effects of MOE application on the studied traits, based on the responses of 59 barley accessions.

4. Discussion

Plant scientists are now focusing on biostimulants and how to use them in their research to increase crop yields. Plant stimulants have been shown to improve plant health and yield quality by increasing nutrient uptake, changing plant physiology, and making plants more resilient to stress [19,22]. The ultimate goal of any breeding strategy is to increase barley and other cereal yields. To increase the yield of contributing factors, several strategies are being implemented. Crop yield in cereals is primarily determined by measuring the most important traits that are strongly related to the final yield product, such as spike length, spike number per plant, seed weight per spike, 1000-kernel weight, seed number per spike, spike weight, total yield, and harvest index. Foliar application of moringa plant extract is well-documented because it is important in improving yield contributing parameters in many plant species [21,23,28,29]. Moringa leaf extract is measured as one of the essential plant biostimulants due to the presence of phenols, antioxidants, essential nutrients, phytohormones, and ascorbates [22]. When compared to the respective control

conditions, exogenous application of moringa plant part extract had a positive impact on these parameters in our experiment.

In this study, MOE had a significant positive impact on plant height. As previously stated, the moringa plant possesses an abundance of phytohormones, including gibberellin [30]. Gibberellin's metabolism and signaling are both essential for controlling plant height. The presence of this phytohormone enhanced internode elongation, leading to an increase in cell division and cell elongation [31]. Similar to our study, Rehman et al. [32] discovered a significant increase in wheat height due to the use of moringa extract.

Some traits, such as leaf area [33], awn length [34], and chlorophyll content [35], have been shown to play a major role in increasing photosynthesis under normal and stressful conditions. The primary organ, which takes a huge portion of the energy in photosynthesis, is the flag leaf. The characteristics of flag leaf are considered essential selection criteria for high grain yields in barley [36]. For this reason, the lower leaves are mostly covered by the upper plant parts and, therefore, do not directly take part in absorbing the radiation of solar energy. After the application of moringa plant extract, a significant increase in leaf area was observed, probably due to the presence of the critical phytohormones in their nature. Several phytohormones with an obvious portion were detected in moringa leaf extract by Ali et al. [30], including gibberellins, auxin, and cytokinins. It is well-documented that gibberellins improve plant height, while auxins improve the elongation of cells and promote the growth of stems, and cytokinins play a critical role in the promotion of cell division and modification of apical dominance [37]. In accordance with our findings, Chattha et al. [38] found similar outcomes in the case of using this type of extract on the wheat plant. Additionally, Ali et al. [39] showed a significant increase in the measurement of this trait on wheat varieties, after conducting the same exogenous application of moringa leaf extract.

Since chlorophyll is required to convert light energy into stored chemical energy, crop growth and yield are directly affected by chlorophyll content [40]. Correlations between leaf area, chlorophyll content, and yield were shown by many studies for barley cultivars [41–43]. This is probably due to capturing lighter chloroplast, while including a denser chloroplast. New opportunities to predict total chlorophyll content (TCC) at the various crop growth stages have been provided with the development of remote sensing equipment (SPAD), which is widely accepted by researchers [44,45]. In the regulation of photosynthesis and many physiological processes, salicylic acid (SA) plays a main role under stress conditions in maintaining these regulations within plant cells [37]. Until very recently, for barley genotypes, a foliar application of combination gibberellic acid and (SA) with a concentration of (110 mg/l and 1.5 mM) showed a significant increase in different plant physiological properties, including total chlorophyll content [46]. Many essential developmental processes are modulated by the presence or absence of cytokinins, including leaf development in the last phase, well-known as senescence, which is associated with the breakdown of chlorophyll and photosynthetic collapse. All of these undesirable changes can be slowed by cytokinins [47]. Taking all the phytohormones present in moringa leaf extract into account, it is possible to conclude that a strong direct correlation is present between the total chlorophyll content and those phytohormones. For all the above reasons, these traits (leaf area and total chlorophyll content) could be used as growth morphological markers for the selection of barley accessions having higher photosynthetic activity.

Cereals have at least two types of tillers (fertile and non-fertile). The first, also known as the productive tiller, causes the formation of spikes and is, thus, necessary for seed yield. The first type depletes the plant's mineral resources. Since this type of tiller rarely survives until the end of the plant's life, it cannot produce a yield [48]. To assess the final productivity of studied cereals, it is critical to measure the fertile tiller number per plant at this point. The obvious increase in tiller number in our results was most likely due to the presence of a cytokinin growth regulator in the moringa plant extract [30]. As a result, the trait of tiller number can be carefully chosen for studying the application of moringa plant extract. Afzal et al. [49] and Rehman et al. [32] reported that the application of moringa

leaf extract increased the studied yield traits, including tiller number, in wheat, which is consistent with our findings. In addition to these findings, Koprna et al. [50], from Palack University Olomouc, stated that cytokinin application has a positive effect on the tiller number of barley varieties.

The number of spikes per plant is one of the most important yield characteristics. The selection of barley genotypes based on the number of spikes per plant may eventually lead to the selection of accessions with better yielding performance among tested accessions. This trait has a significant impact on barley genotype yield [51]. This could be due to these barley accessions' ability to respond strongly to this management. In our study, the variation in the number of spikes per plant can be attributed to the genetic potential of barley accessions and their diverse responses to foliar moringa application. In the current foliar treatment, the three barley accessions, AC28, AC47, and AC36, with values of 25.33, 25.00, and 23.67, respectively, had greater potential to produce a large SNP. The current study's findings are consistent with the findings of another group that investigated the effect of moringa extract on this specific yield trait. Afzal et al. [49] investigated the effects of three different foliar applications, moringa leaf, sorghum water extract, and salicylic acid, at concentrations of 3%, 0.075%, and 0.01%, respectively, on wheat plants under current heat stress. They applied the foliar application three times in one month, beginning with the tillering stage. Among the tested foliar applications, moringa extract and salicylic acid significantly improved this trait's performance. Similarly, Khan et al. [22] demonstrated a significant impact of moringa leaf extract alone and in combination with other plant growth promoters such as ascorbic acid and salicylic acid for this trait on wheat, by administering this treatment twice during the tillering and flowering stages.

The presence of various phytohormones and secondary metabolites in moringa plant parts may be linked to the longer spike length in the current study [30]. Similarly, Khan et al. [22] observed a significant increase in spike length on the wheat plant in the field, as a result of using the same application method. Furthermore, Zaheer et al. [52] studied wheat cultivars using various foliar applications, including cytokinins at 25 mg L^{-1} concentrations, used under drought stress conditions at three different growth stages (tiller formation, flowering, and grain filling). The longevity of spikes in their study was significantly improved in the presence of this application. As a result, it is perfectly reasonable to apply moringa foliar to increase spike length.

In our study of the awn length trait, a significant increase was observed when moringa extract was applied foliarly. As a result, increasing awn length could eventually lead to increased barley crop productivity. After the flag leaf, the awns of barley are the most important photosynthetic organs. This organ is the closest plant part to the developing grains in spikelets within the spike, acting as a source of assimilation for grain formation. The photosynthesis of barley spike organs (including awn) accounts for more than 75% of the accumulation of kernel dry weight [53]. It has been long-established that under normal growth conditions in barley, the awns organ can achieve more than 90% of spike photosynthesis [54]. As a result, these plant parts can significantly increase the proportion of net photosynthesis, resulting in a higher value of grain dry matter. Awn removal in barley genotypes had a significant effect on grain yield performance, transpiration rate, and net photosynthetic rate, all of which were reduced [55].

The increased spike weight of plants sprayed with moringa organ extract in our research was due to increased spike length, number of seeds per spike, and other yield-contributing factors previously described. A cheap, rich, and natural source of important secondary metabolic products and plant phytohormones plays an important role in barley trait improvement. The application of the moringa plant part as a foliar spray significantly increased the studied parameters in our study due to the phenomenon of remaining green for a longer period of time during grain filling. This could be due to the high concentration of cytokinin hormone in moringa extract, which is the most general coordinator between senescence and remaining green traits, ultimately improving final yield productivities.

Foliar application of moringa plant part extract had a positive effect on the trait of seed number per spike in tested barley accessions. The grain number and final yield are thought to be positively correlated with the dry weight of the spike during the spike growth phase, possibly due to improved photosynthetic capacity [56]. Zhang et al. [57] used CRISPR/Cas9 gene-editing techniques to determine the roles of cytokinin oxidase and dehydrogenase in rice among eleven candidate CKXs families for their effects on grain number, leaf senescence, and regulating the source of leaf and sink of grain. They discovered that OsCKX11 knockout significantly increased cellular cytokine levels, resulting in a delayed leaf senescence phenotype. Furthermore, the mutant OsCKX11 showed a significant increase in grain number, when compared to the wild type. It is possible that OsCKX11 regulates both grain number and photosynthesis. Previous research, as mentioned above, demonstrated the positive regulation of cytokinin in increasing the number of seeds per spike. The significant findings in our study for this trait may be linked to the presence of these essential phytohormones in moringa organ extract. As a consequence, the higher the cytokinin content, the greater the number of seeds detected in this study. It is quite clear that the combination of the activity of particular phytohormones as well as the nutritional condition of the reproductive meristem both have significant effects on final grain number [48].

MOE application positively affected seed weight per spike in the majority of barley accessions, indicating efficient nutrient use by the plant and translocation of these substrates into reproductive plant parts [58]. Similar to our results, a considerable increase in the seed weight per pod in pea plants [59], seeds in maize kernel [60], and snap bean [61] was detected due to the treatment of moringa leaf extract.

The majority of barley accessions reacted negatively to the MOE application. This reduction in 1000-KW was caused by producing a large number of seeds with small kernels that were less dense and had a low amount of food reserves, because embryo size and reserved nutrient quantity determine the quantity and quality of the seed [62].

The study of total yield and straw weight performance for its production is dependent on the genetic characteristics of the cereal crop, the nutrient status of the soil texture, the exogenous application of growth promoters, and the environmental conditions of the crop plants [22]. Under MOE, we discovered statistically significant positive values for nearly all of the explored yield traits. This is likely due to the presence of cytokinins in moringa leaves, which stimulate carbohydrate metabolism [29,63]. In addition, this characteristic creates a new sink source, leading to an increase in dry matter content. From accession to accession, the total yield of cereal grain and the values of its constituents vary. These differences in yield are strictly correlated with variation in grain number and must, therefore, rely on variation in shoot number, which produces more spikes [64]. In a similar vein, a team of researchers led by Brockman and Brennan [21] discovered significant results in grain yield and dry biomass when moringa leaf extract was applied to a greenhouse-grown wheat cultivar. In addition to total yield, straw weight is an important trait for plant breeding because it reveals the plant's capacity to allocate biomass to reproductive plant parts. It is related to grain yield and biomass in accordance with the multiplicative yield component, wherein grain yield is a product of yield biomass and harvest index [65]. This study's hypothesis, that moringa plant extract is a significant plant growth enhancer, is supported by the numerous MOE compositions discovered by other researchers as well as by the growth and productivity characteristics exhibited by plants treated with moringa plant extract.

5. Conclusions

To increase the development and productivity of barley, foliar application of moringa aqueous extract (MOE) during the crucial growth stage can be used to control the growth and productivity of barley crop plants, as demonstrated by our inquiry into increasing nearly all investigated attributes. It is possible to shed light on this unusual plant for the purposes of further research. Exogenous application of MOE positively affected all

the characteristics, with the exception of 1000-kernel weight. MOE treatment exhibited the most favorable effects on overall yield and straw weight per plot. The outcome of this investigation documented that the barley accessions behaved differentially to MOE treatment. Accessions AC8 and AC18 demonstrated the largest enhancement in total yield and straw weight per plot. Further, this form of treatment may be utilized as an alternative biostimulant to conventional plant growth hormones, especially when the objective is to build an organic agricultural system. From this point, it is feasible to shed light on this amazing plant for future research programs.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture12091502/s1, Table S1. Mean pairwise comparisons of growth trait interactions between accessions and plant treated by MOE. According to the Multiple Range Duncan's test at $p \leq 0.05$, any mean values with a common letter are not considered significant; Table S2. Mean pairwise comparisons of the interaction between 59 barley accessions and foliar MOE application with yield contributing traits, based on the Multiple Range Duncan's test at $p \leq 0.05$. Any values of means holding common letter are not significant.

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