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RESEARCH ARTICLE

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Enhancing Bread Wheat *(Triticum aestivum L.)* Productivity and Quality Through Foliar Micronutrients and Ethephon Under Water Stress Conditions

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ABSTRACT

A greenhouse experiment was conducted from 1st December 2024 to 15th May 2025 at Gerdarash, Erbil, Kurdistan Region, Iraq, to investigate the effects of foliar application of combined micronutrients (Zn, Mn, B, and Fe) and ethephon on yield and grain quality of three bread wheat varieties (Hawler4, IBA99, and Jehan) under two water regimes (40–60% and 80–100% field capacities). Treatments were arranged in a randomized complete block design with three replicates. The results revealed that yield components and quality traits were significantly influenced by the interaction between varieties, micronutrient–ethephon combinations, and water availability. Under optimal water conditions (80–100% field capacity), Hawler4 variety recorded the highest spike length (cm), number of grains per spike, 1000-grain weight (g), and grain yield (9.18 g $plant^{-1}$), while Jehan variety showed better performance under water stress (40–60% field capacity) with improved tiller number, spike number, and protein yield (g $plant^{-1}$). The combined foliar application of micronutrients at 1 g L^{-1} with ethephon at 500 mg L^{-1} resulted in superior performance for most yield parameters and improved quality traits, including protein, gluten, proline, and carbohydrate contents. The results indicated that the integration of micronutrient enrichment with ethephon application effectively enhanced wheat productivity and grain quality under both normal and water-stressed conditions. Hawler4 was more responsive under well-watered conditions, while Jehan demonstrated better tolerance to water stress. These findings suggest that foliar application of micronutrients combined with ethephon can be a practical strategy to mitigate water stress effects and improve yield and quality in bread wheat production.

Keywords**:** Bread wheat, micronutrients; ethephon, water stress.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is grown in most countries and represents a major component of the world's food supply **[1]**. Wheat provides a rich source of several essential nutrients, such as protein, dietary fiber, manganese, phosphorus, and niacin, each contributing 20% or more of the recommended Daily Value (DV). Additionally, 100 grams of wheat supply approximately 1,368 kilojoules (327 kilocalories) of energy **[2]**. It is considered the crop with the largest cultivated area worldwide, and according to the Economic Research Service of the U.S. Department of Agriculture (USDA ERS, 2025) report for the 2024–2025 season, global wheat production reached approximately 798.2 million tons, while Iraq's production did not exceed 6.0 million tons **[3]**. Excessive amounts of mineral fertilizers are willfully applied by many farmers to increase production in response to the market's rising demand **[4]**. Crop productivity and quality are improved by micronutrients as important factors. A role in increasing production is played by adding nutrients directly because an important role in many vital processes within the plant is played by them **[5]**. The limited benefits of adding micronutrients to the soil as mineral salts under oxalic soil conditions have been shown by many studies. This is due to the rapid leaching and sedimentation of micronutrients. Adding micronutrients by spraying diluted solutions on plant leaves at appropriate times and concentrations has been recognized as a successful and modern method for meeting plant needs. Therefore, the most efficient and fastest way to add these nutrients is considered to be by spraying diluted solutions directly onto the vegetative system. This method, known as foliar feeding, is regarded as the best fertilization technique for micronutrients due to the significant benefits of increased nutrient absorption and reduced pollution **[6]**. A study was conducted by **[7]** on the effect of spraying some micronutrients, such as Fe, Zn, Mn, and B, at different concentrations (0, 500, 1000, and 1500 ppm) on two varieties of bread wheat (Jihan and Adana). Significant differences were observed among the studied traits, as the concentration of 1500 ppm was found to significantly increase the average number of spikes, number of seeds per spike, weight of 1000 grains, and the grain yield. When a micronutrient combination such as Zn, Mn, B, and Fe was applied at field capacity (100%), the highest values were obtained for grain yield, 1000-seed weight, grain revenue, high tiller number, number of spikes, biological yield, and straw yield, whereas at field capacity (60%), the lowest values were recorded for all traits **[8]**. Growth characteristics were improved and grain yield was increased by foliar application of ethephon, through an increased number of tillers, and consequently more spikes **[9]**. The final yield of crop plants largely is determined by the optimum photosynthesis rate, and ethylene synthesis from ethephon has been shown to improve photosynthesis through the enhancement of leaf area and photosynthetic pigments **[10]**. The results of **[11]** showed that wheat plants sprayed with ethephon at a level of 0.900 kg ha^{-1} exhibited an increased number of tillers, spikes per m^2, grains per spike, and 1000-grain weight. This was reflected in an increase in grain yield, with an average of 5.043 t ha^{-1}, and the highest protein was also recorded at the same ethephon level.

[12] indicated that considerable variances in grain yield traits were observed among the various wheat cultivars studied. The highest mean grain yield per hectare was produced by the Gemmeaza-11 cultivar, whereas the lowest mean grain yield per fed was recorded for the Sids-12 cultivar. **[13]**, in his study on four varieties of bread wheat (Abu Raghif, Baghdad, Babylon, Ibaa 99), showed significant differences among the varieties. The Ibaa 99 variety was found to be significantly superior in yield component traits, including the number of tillers, number of spikes per plant, number of grains per spike, and biological yield, whereas the Baghdad variety was superior in 1000-grain weight. Drought stress was found to have a significant effect on morphological and phenological parameters, including plant height, tillers per plant, number of spikes per square meter and number of spikelet's per spike. The average number of spikes per square meter under drought stress was observed to be lower, compared with irrigated conditions **[14]**. Drought is recognized as the major abiotic stress that severely affects wheat production worldwide. The morphology, physiology, and biochemistry of wheat are significantly affected under drought stress conditions **[15]**. Drought stress during sensitive growth stages of wheat, including grain filling, was found to decrease grain weight and the number of grains per spike, resulting in a considerable reduction in wheat yield **[16]**. The main objectives of the research study consist of studying the effect of spraying with macronutrients and ethephon to improve the characteristics of the yield, its components, and seed quality under two types of water stress, as well as studying the effect of using three varieties of bread wheat grown in northern Iraq on both the yield and quality and their tolerance to drought conditions.

Materials And Method

The experiment was carried out from December 1, 2024, to May 15, 2025, in a semi-closed greenhouse located at Gerdarash-Erbil (36°11'3" N, 44°1'48" E; elevation 415 m above sea level), under the Ministry of Agriculture and Water Resources, Kurdistan Region of Iraq. Two water regimes were imposed: 40–60% and 80–100% of field capacity. Treatments were arranged in a randomized complete block design (R. C. B. D.) with three replicates. The first factor consisted of nine combinations of micronutrients (Zn, Mn, B, and Fe) and ethephon (480 g/L): Control, M1 = Zn, Mn, B, and Fe at 1 g L^{-1}, M2 = Zn, Mn, B, and Fe at 2 g L^{-1}, E1 = ethephon 500 mg L^{-1}, E2 = ethephon 1000 mg L^{-1}, M1E1 = Zn, Mn, B, and Fe 1 g L^{-1} combined with E1, M1E2 = Zn, Mn, B, and Fe 1 g L^{-1} combined with E2, M2E1 = Zn, Mn, B, and Fe 2 g L^{-1} combined with E1, and M2E2 = Zn, Mn, B, and Fe 2 g L^{-1} combined with E2. The second factor included three bread wheat cultivars: Hawler 4, IBA 99, and Jehan. Seeds were sown at the date (1/12/2024) in plastic pots of uniform size (20 cm diameter and 24 cm depth) containing 10 kg dry sandy loam soil. In each pot, 10 seeds were sown. After germination, the plants were thinned to maintain 6 plants per pot, the plants were allowed to establish for 51 days in the seedling stage (ZS15) before the onset of various water regimes 40-60% and 80-100% field capacities. The gravimetric method was used to determine the amount of water required to be added to pots based on the field capacity used in the experiment, 40-60% and 80-100% as shown in Table (1). Wheat leaves were sprayed by micronutrient and ethephon with a one dose at the tillering stage (ZS25) until completely wet, according to the treatments and combinations used in the experiment. Some soil physiochemical properties for soil elucidated in table (2) Physiochemical properties for irrigation water for Gerdarash-Erbil location the pH is 7.73 and the Electrical Conductivity is 0.85 dS/m.

Table (1): Explains information about added water to two levels of field capacity of water in the pots.

Field capacity	Weight of pot (kg)	Weight of soil (kg)	Water added liter	Total pot weight (kg)	Amount of water added per time/liter	Number of irrigation to flowering stage	Total weight of water added/liter to the flowering stage	Number of irrigation to maturity stage	Total weight of water added/liter to the maturity stage
40%	0.110	10	1.16	11.27	0.58	22	12.76	33	18.56
60%	0.110	10	1.7	11.85					
80%	0.110	10	2.32	12.43	0.58	33	19.14	48	28.71
100%	0.110	10	2.90	13.01					

Table (2): Some of soil physiochemical properties for Gerdarash-Erbil locations.

Value	EC ds/m	pH	N %	P ppm	K ppm	O.M %	Classification USDA			So4%	CaCO	Zn%	Mn%	B%	Fe%
							Clay	silt	sand						
Grdarasha field	0.73	7.7	0.0029	4.79	220	2.10	30.95	25.5	43.55	0.0318	14	0.000966	0.000224	0.0000702	0.0000173
							Clay loam								

Soil moisture curve:

The soil water retention curve (Figure 1) was determined based on the physical properties of the experimental soil (Clay Loam) using standard pedotransfer functions **[17]**. The volumetric water content at field capacity (−33 kPa) was estimated to be 0.318 $cm^3\ cm^{-3}$, while the permanent wilting point (−1500 kPa) was 0.175 $cm^3\ cm^{-3}$, resulting in a total available water capacity of 0.143 $cm^3\ cm^{-3}$. The experimental irrigation regimes were strictly established based on these physical parameters: the optimal condition treatment was maintained at 80–100% of field capacity, whereas the water stress treatment was maintained at a critical depletion level of 40–60% of field capacity.

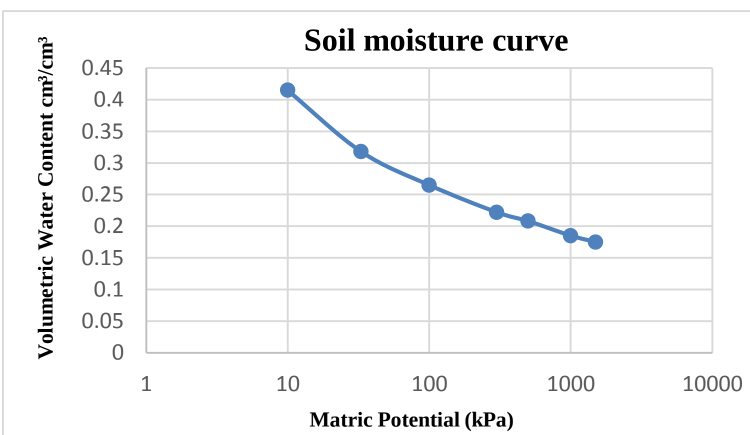


Figure 1: Soil moisture characteristic curve of Gerdarash.

Yield and yield components parameters:

The following parameters were recorded after plant maturation at harvesting stage.

1- Number of tillers plant^{-1}: The total number of tillers was recorded for plant.

2- Number of spikes plant^{-1}: The total number of spikes was recorded for plant.

3- No. of grains spike^{-1}: The mean number of grains spike-1 was measured for plant^{-1} basis.
4- Weight of 1000 grains (g): grains weight (g) (total weight of 1000 grains) in 3 replications based on 13% moisture
5- Grain yield (g plant^{-1}): Grain yield was measured on per plant.
6- Biological yield (g plant^{-1}): This is the total above ground or biological yield (grain + straw weight) as describe above **[18]**.

Grain quality parameters:

1- **Protein yield (g plant^{-1}):**

Grain protein yield was calculated based on the percentage of protein in the grain multiplied by the grain yield for each treatment **[19]**.

2- **Protein Percentage%:**

The protein content of the samples was determined using an Inframatic 8600 grain analyzer in the Laboratory Department of the Nineveh Agriculture Directorate which operates based on Near-Infrared Reflectance (NIR) technology. The instrument was calibrated using standard reference methods of the American Association of Cereal Chemists (AACC) **[20]**.

Proline content (%):

[21] described a method for determining proline in seeds. Approximately 0.250 mg of dried seed powder to 10 ml of 3% aqueous sulfosalicylic acid and filtered it using a centrifuge, 2 ml of the filtrate mixed with 2 ml of acid ninhydrin (100 ml of acid ninhydrin = 2.5 g of acid ninhydrin, 60 ml of glacial acetic acid, and 40 ml of (H2PO4), 2 ml of glacial acetic acid, and 2 ml of orthophosphoric in a test tube, the mixture placed in a water bath at 100°C for 1 hour and transferred it using an aspirated funnel, then 4 ml of toluene was added, shook the buchner, and two layers formed: the upper pink layer and the lower colures layer, the solution was cooled to room temperature and measured the absorbance at 520nm using a spectrophotometer appropriate proline standards to calculate the proline content of the samples.

Proline content = (proline in extract *4)/(115/(g sample/5)) (µg. g-1D.Wt.)

3- **Carbohydrate percentage %:**

Total carbohydrates were analyzed in the central laboratory of the College of Agriculture and Forestry-University of Mosul, using the phenol–sulfuric acid method to determine the total carbohydrates in wheat flour. The experiment required several materials, including wheat flour, a 5% phenol solution, concentrated sulfuric acid, distilled water, test tubes and measuring bottles, and a spectrophotometer at 490 nm. The steps begin by weighing approximately 0.5–1 g of flour and placing it in a test tube. 5 ml of distilled water is then added, and the sample is heated for a few minutes to extract the sugars. 1 ml of a 5% phenol solution is then added to each sample, followed by 5 ml of concentrated sulfuric acid. The tubes are allowed to cool for 10–15 minutes to develop color, and the absorbance at 490 nm is measured. Finally, the results are compared to a glucose standard to calculate the total carbohydrate content of the flour **[22]**.

Statistical analysis

According to Duncan's Multiple Range Test (DMRT), differences in the application groups were analyzed with a statistical significance value of $p \leq 0.01$. Statistical analyses were performed using the SAS package V9 standard for the Statistical Analysis System **[23]**, and differences between the control and application groups were analyzed using one-way analysis of variance (ANOVA) **[24]**.

Results And Discussion

Table 3: Analysis of variance (ANOVA) with (Mean Squares) for yield and quality traits of bread wheat under water stress and foliar application.

Sources of Variation	d.f	No. of Tillers plant^{-1}	No. of Spikes plant^{-1}	No. Grains spike^{-1}	Weight of 1000 grain g	Grain Yield g plant^{-1}	Biological Yield g plant^{-1}	Protein Yield g plant^{-1}	Proline %	Protein %	Carbohydrate %
Field Capacity (40–60%)											
Blocks	2	0.444	1.345	5.532	0.369	1.749	6.752	0.241	0.004	0.649	2.542
Varieties (A)	2	2.333 **	1.345 n.s	6.241n.s	40.086**	21.787 **	186.109 **	5.060**	0.028 **	9.405 **	69.388 **
Micro. + Ethephon (B)	8	1.722 **	1.197 **	86.130**	41.928**	0.868*	3.970 *	54.652**	0.071 **	9.727 **	43.418 **
Interaction A×B	16	0.236 *	0.179 *	9.372 *	4.025 *	0.638*	3.645*	7.178 **	0.087 **	5.516 **	73.758 **
Error	52	0.390	0.384	4.092	1.850	0.375	1.876	0.555	0.003	0.130	0.522
Total	80										
Field Capacity (80–100%)											
Blocks	2	0.345	0.481	0.397	1.395	3.048	3.831	0.500	0.019	0.101	0.421
Varieties (A)	2	0.345 n.s	2.259 n.s	198.458 **	167.998 **	3.655 *	158.485 **	310.328 **	2.123 **	1.073 *	344.386**
Micro. + Ethephon(B)	8	2.743 **	1.777 **	60.939 **	29.736 **	0.884n.s	8.3083**	62.698**	0.516 **	8.936 **	7.822 **
Interaction A×B	16	0.290 *	0.592 **	36.226 **	15.208 **	1.183*	7.103**	32.273**	0.450 **	2.984 **	152.661**
Error	52	0.755	0.404	4.883	3.883	0.948	2.322	1.126	0.010	0.261	0.581
Total	80										

From field capacity 40-60%, Jehan variety obtained highest number of tillers plant^{-1} (3.963) and weight of 1000 grains (28.588 g), but number of spikes plant^{-1} and number of grains spike^{-1} have not significant difference traits between varieties (table 1), wheat varieties differ in the characteristics of their yield components due to differences in genetic composition and their interaction with environmental conditions **[25]**, this is agree with **[26]**. From combined micronutrient (Zn, Mn, B and Fe) at 1 g l^{-1} with ethephon foliar applications at 500 mg l^{-1}, the highest number of tillers plant^{-1} (4.44), while the number of spikes plant^{-1} (3.44), number of grains spike^{-1} (41.113) and weight of 1000 grains (31.089 g) recorded in ethephon foliar applications at 500 mg l^{-1} (Figs. 2, 3, 4 and 5). The increase in the number of tillers and spikes may be attributed to the role of ethephon in inhibiting the transport of auxins in plant tissues through the release of ethylene, which leads to a reduction in apical dominance and the release of tillers from the resulting inhibition, consequently, crop production is increased **[27]**. This result is agreed with **[28]** and **[29]**. The results from interaction between combined micronutrient with ethephon and varieties, Jehan variety superior on both varieties of obtaining highest number of tillers plant^{-1} (4.66), number of spikes plant^{-1} (3.66) and grain yield (8.196) g plant^{-1} when application of combined micronutrient (Zn, Mn, B and Fe) at 1 g l^{-1} with ethephon 500 mg l^{-1}, but the highest number of grains spike^{-1} (42.823) and weight of 1000 grains (32.339 g) was recorded from Jehan variety and application of ethephon by 500 mg l^{-1} (table 4). The significant reduction in yield components under the 40-60% field capacity treatment can be physiologically explained by the soil water retention characteristics of the experimental clay loam soil (Figure 1). At this reduced moisture level, the soil approaches a higher matric potential (suction), meaning the remaining water is tightly held within the soil's micropores. Consequently, wheat plants must expend significantly higher physiological energy to extract water, this is agreed with **[8]**.

Despite off from field capacity 80-100% the results of yield components were affected by bread wheat varieties and foliar application with micronutrient combined and ethephon under water stress (Figs. 2, 3, 4, 5 and 6). Hawler4 variety given the highest number of grains spike^{-1} (47.955), and weight of 1000 grains (39.218g), but number of tillers plant^{-1} and number of spikes plant^{-1} have not significant difference. However the highest number of tillers plant^{-1} (5.444), number of spikes plant^{-1} (4.111) and number of grains spike^{-1} (49.768) recorded from combined micronutrient (Zn, Mn, B and Fe) at 1 g l^{-1} with ethephon foliar applications at 500 mg l^{-1} however the heights weight of 1000 grains (41.386 g) was recorded in from combined micronutrient (Zn, Mn, B and Fe) at 1 g l^{-1}. Table (4) indicated that interaction between micronutrient combined (Zn, Mn, B and Fe) with ethephon foliar applications and bread wheat varieties on some yield components traits under 80-100% showed significant differences between each of the treatments as well as water stress.; highest number of tillers plant^{-1} (6.00) and number of spikes plant^{-1} (4.66) gives from Jehan variety when applications of combined micronutrient (Zn, Mn, B and Fe) at 1 g l^{-1} with ethephon at 500 mg l^{-1}, while Hawler4 variety superior other varieties of weight of 1000 grains (44.483 g) when sprayed by combined micronutrient (Zn, Mn, B and Fe) at 1 g l^{-1}, but number of grains spike^{-1} (54.856) was obtained from interaction between micronutrient combined (Zn, Mn, B and Fe) 1 g l^{-1} with ethephon foliar applications 500 mg l^{-1} and Hawler4 variety. The decrease in yield under water stress was attributed to a reduction in one of the yield components, as decreases in the number of tillers, the number of spikes and spikelets per plant, the number of grains per spike, and the weight of 1000 grains were found to have a negative impact on grain yield. These results are agreed with **[8]** showed that the highest rate (1260.1 g m²) was yielded at the 100% field capacity level, whereas the lowest significant rate (344.36 g m²) was yielded at the 60% field capacity level.

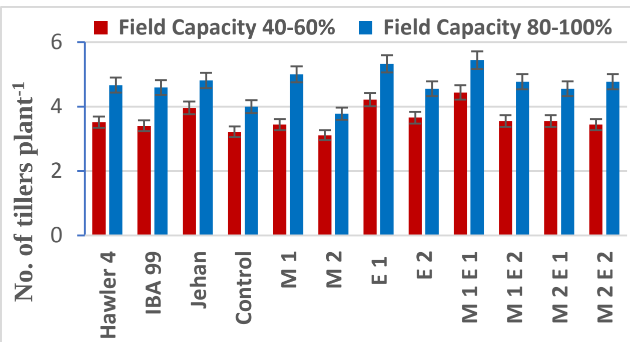


Figure 2: Number of tillers per plant under water stress

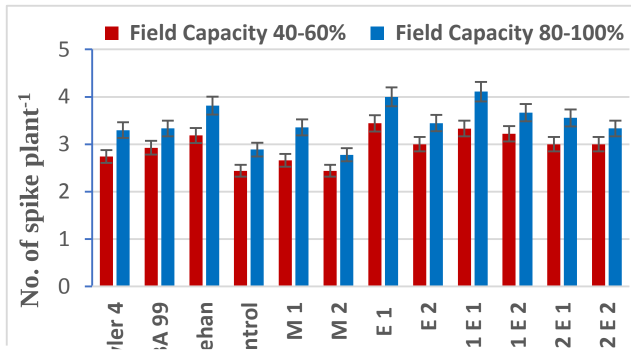


Figure 3: Number of spikes per plant under water stress

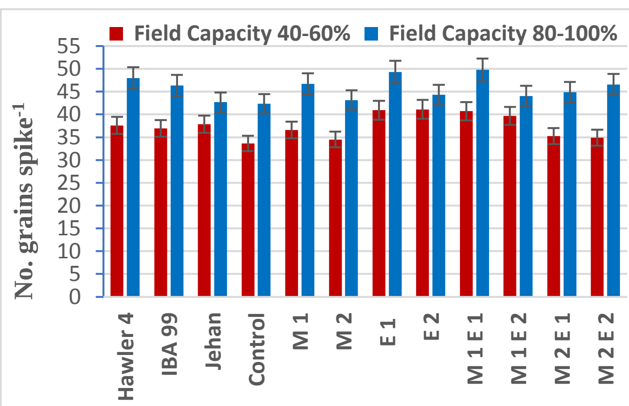


Figure 4: Number of grains per spike under water stress

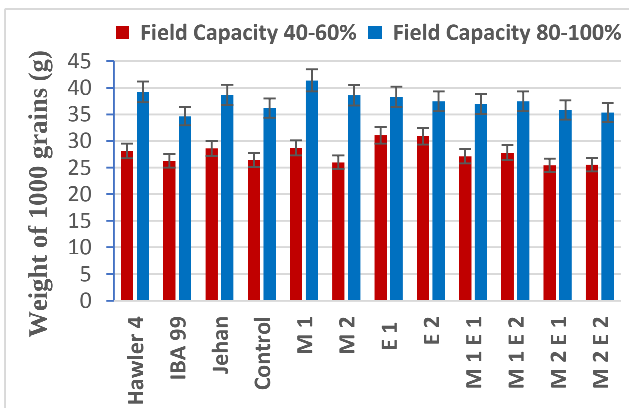


Figure 5: Weight of 1000 grains (g) under water stress

Table (4): Effect of interaction between micronutrient, ethephon applications and bread wheat varieties on yield components under water stress condition.

Treatment		No. of tillers plant^{-1}	No. of spikes plant^{-1}	No. grains spike^{-1}	Weight of 1000 grain (g)	Grain yield (g plant^{-1})	No. of tillers plant^{-1}	No. of spikes plant^{-1}	No. grains spike^{-1}	Weight of 1000 grain (g)	Grain yield (g plant^{-1})
Varieties x Fertilizer		Field Capacity 40-60%					Field Capacity 80-100%				
Hawler 4	Control	3.00 cd	2.33 b	32.567 g	27.139 e-i	5.282 g-j	3.666 bc	2.33 e	42.433 i-l	35.660 h-k	8.180 a-d
	M 1	3.33 b-d	2.33 b	36.337 d-g	27.125 e-i	5.679 f-j	5.00 a-c	3.666 a-d	45.343 e-i	44.483 a	8.630 a-d
	M 2	3.33 b-d	2.33 b	32.350 g	25.371 g-i	5.215 h-j	4.00 bc	2.666 de	43.373 g-k	42.040 a-c	8.080 a-d
	E 1	3.66 a-d	3.33 ab	41.417 a-c	30.990 a-c	6.046 c-j	5.333 ab	4.333 ab	53.353 ab	39.080 c-h	8.650 a-d
	E 2	3.33 b-d	2.66 ab	41.167 a-c	31.762 a	6.281 c-i	4.666 a-c	3.333 bcde	52.637 ab	37.673 e-j	8.850 a-c
	M 1 E 1	4.33 ab	3.33 ab	42.823 a	28.478 d-f	6.333 c-i	5.333 ab	4.333 ab	54.856 a	39.947 b-g	9.180 a
	M 1 E 2	3.66 a-d	3.00 ab	37.507 c-f	30.319 a-d	5.703 e-j	5.00 a-c	3.666 a-d	43.270 g-k	40.653 b-f	8.493 a-d
	M 2 E 1	3.66 a-d	2.66 ab	35.427 fg	25.691 g-j	5.976 c-j	4.00 bc	2.666 de	46.697 d-h	36.500 g-k	7.956 a-d
	M 2 E 2	3.33 b-d	2.66 ab	38.790 a-f	26.301 e-j	5.254 g-j	5.00 a-c	2.666 de	49.633 b-d	36.930 f-k	7.700 a-d
IBA 99	Control	2.66 d	2.66 ab	33.077 g	25.706 g-j	5.358 g-j	4.333 a-c	3.333 b-e	44.047 f-k	36.053 g-k	7.546 a-d
	M 1	3.00 cd	3.00 ab	35.403 fg	27.853 d-h	5.658 f-j	5.00 a-c	3.333 b-e	50.807 bc	38.130 e-i	8.626 a-d
	M 2	2.66 d	2.33 b	35.217 fg	24.299 j	5.137 h-j	3.333 c	2.33 e	43.720 f-k	34.080 j-l	7.330 a-d
	E 1	4.33 ab	3.33 ab	39.920 a-d	29.939 a-d	5.755 e-j	5.333 ab	3.666 a-d	48.587 c-e	34.640 i-l	8.106 a-d
	E 2	3.66 a-d	3.00 ab	40.580 a-c	28.945 b-e	5.081 ij	4.333 a-c	3.333 b-e	38.843 l	31.580 l	6.686 d
	M 1 E 1	4.33 ab	3.33 ab	39.513 a-e	26.069 f-j	4.954 j	5.00 a-c	3.666 a-d	53.070 ab	35.627 h-k	7.470 a-d
	M 1 E 2	3.33 b-d	3.00 ab	40.443 a-c	25.249 h-j	5.307 g-j	4.666 a-c	3.666 a-d	47.610 c-f	33.607 kl	7.470 a-d
	M 2 E 1	3.33 b-d	2.66 ab	34.860 fg	24.109 j	5.557 f-j	4.666 a-c	3.333 b-e	43.633 f-k	33.813 j-l	7.826 a-d
	M 2 E 2	3.33 b-d	3.00 ab	33.450 g	24.420 ij	5.688 d-j	4.666 a-c	3.333 b-e	47.040 c-g	34.250 i-l	8.293 a-d
Jehan	Control	4.00 a-c	2.33 b	35.163 fg	26.522 e-j	6.635 c-f	4.00 bc	3.00 c-e	40.567 kl	36.800 f-k	7.440 a-d
	M 1	4.00 a-c	2.66 ab	38.083 b-f	31.145 ab	6.486 c-g	5.00 a-c	3.666 a-d	43.917 f-k	41.547 a-d	7.060 b-d
	M 2	3.33 b-d	2.66 ab	35.930 e-g	28.294 d-g	7.050 b-d	4.00 bc	3.333 b-e	42.310 j-l	39.683 b-g	6.876 cd
	E 1	4.66 a	3.66 a	41.397 a-c	32.339 a	8.110 ab	5.333 ab	4.00 a-c	45.893 d-i	41.230 a-e	8.046 a-d
	E 2	4.00 a-c	3.33 ab	41.593 ab	31.962 a	7.030 b-d	4.666 a-c	3.666 a-d	41.437 j-l	43.157 ab	8.753 a-c

	M 1 E 1	4.66 a	3.33 ab	39.757 a-e	26.833 e-j	8.196 a	6.00 a	4.333 ab	41.380 j-l	35.297 h-l	8.920 ab
	M 1 E 2	3.66 a-d	3.66 a	41.093 a-c	27.815 d-h	6.924 c-e	4.666 a-c	3.666 a-d	41.290 j-l	38.077 d-i	8.220 a-d
	M 2 E 1	3.66 a-d	3.66 a	35.410 fg	26.505 e-j	7.155 a-c	5.00 a-c	4.666 a	44.303 f-k	37.173 f-k	8.230 a-d
	M 2 E 2	3.66 a-d	3.33 ab	32.463 g	25.879 f-j	6.386 c-h	4.666 a-c	4.00 a-c	42.957 h-k	34.893 i-l	7.440 a-d

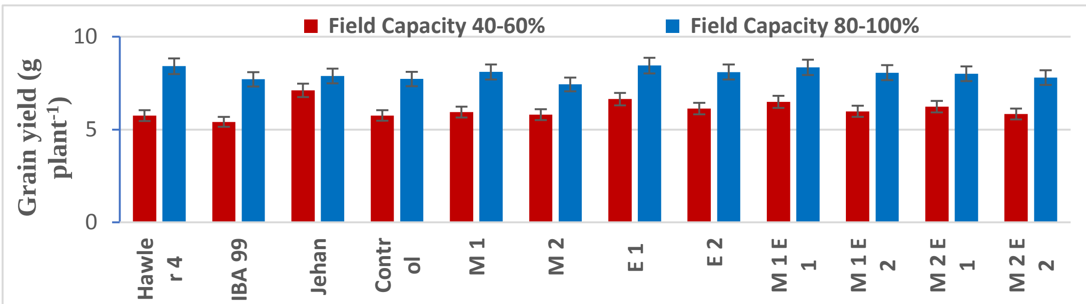


Figure 6: Grain yield g per plant under water stress

The data were decreased at field capacity 40-60% it was recorded the highest biological yield (15.358 g plant^{-1}), protein yield (0.800 g plant^{-1}), proline, protein and carbohydrate percentages (2.582, 11.251 and 53.764 %) was observed in Jehan variety. Ethephon foliar application at 500 mg l^{-1} obtained the highest biological yield (13.487 g plant^{-1}), and protein yield (0.742 g plant^{-1}), while ethephon foliar application at 500 mg l^{-1} when applied without micronutrient given highest protein (11.33%) and carbohydrate (54.486 %), However highest proline percentage (2.221 %) obtained from applied of ethephon by 1000 mg l^{-1}, figures (7,8,9,10 and 11). As a result of table (5), a combination of micronutrients enriched with ethephon for three bread wheat varieties under water stress, 40-60% field capacity the data were always decreased about yield and quality compared with field capacity 80-100%, but the application of combined micronutrients enriched with ethephon for bread wheat varieties was significantly difference of yield and quality as the Jehan variety was superior of highest protein yield (0.951 g plant^{-1}) and protein % (11.60) achieved when applied combination of micronutrients (Zn, Mn, B and Fe) at 1 g l^{-1} with ethephon foliar application at 500 mg l^{-1}, also Jehan variety surpassed in proline percentage (4.300 %) when using ethephon foliar application at 1000 mg l^{-1}. These results agree with the physiological concept that proline regulates osmotic pressure, protects proteins and membranes, and contributes to the antioxidant system under drought stress. Therefore, foliar application of ethephon blend, particularly with high-proline-accumulating cultivars like Jihan, represents a promising strategy for enhancing drought tolerance in wheat water management and harvest programs **[30]**. Inspection of IBA99 variety recorded heist biological yield (17.885 g plant^{-1}) was obtained by applied ethephon foliar application at 500 mg l^{-1} and carbohydrate (62.413%) from applied micronutrients combination by 1 g l^{-1}. Water stress reduces nutrient transport, thereby reducing grain filling due to diminished activity of enzymes responsible for carbohydrate%. This is agreed with, **[29]** demonstrated that starch content in grains significantly decreased under water stress conditions.

From field capacity 80-100% the data regarding biological yield (g plant^{-1}), protein yield (g plant^{-1}), proline%, protein% and carbohydrate%, are significant affected by foliar application of combined (Zn, Mn, B and Fe) with ethephon and various bread wheat varieties at different field capacity (table 1). The results from (figures 7, 8, 9, 10 and 11) indicated that the maximum biological yield (20.415 g plant^{-1}) and protein yield (0.723 g plant^{-1}) was observed in Hawler4 variety but Jehan variety achieved highest value of proline and protein percentage (1.496 and 9.144 %) respectively, while IBA99 variety given highest percentage of carbohydrate (58.577 %). The observed significant differences in protein yield among the studied varieties can be attributed to variations in both grain yield and protein%, these differences are primarily due to genetic variability among the varieties, these are in agreement with those reported by **[32]** and **[33]**, who also documented considerable variation in protein yield among different varieties. Foliar application of micronutrients (Zn, Mn, B and Fe) at 1 g l^{-1} from field capacity 80-100% was significantly increased biological yield (18.927g plant^{-1}) and protein yield (0.756 g plant^{-1}) was increased from application of ethephon 500 mg l^{-1}.

From interaction between combination of micronutrients enriched with ethephon for three bread wheat varieties.

Hawler4 variety response the highest weights of biological yield (22.113 g $plant^{-1}$) from combination of micronutrients (Zn, Mn, B and Fe) at 1 g l^{-1} with ethephon foliar application at 500 ml l^{-1}, and protein yield (0.847 g $plant^{-1}$) obtained at ethephon foliar application at 500 mg l^{-1}, in addition Jehan variety achieved highest percentage of proline (2.863 %) in foliar application of combination of micronutrients at 1 g l^{-1} and ethephon at 500 mg l^{-1}, protein% (9.70) at 2 g l^{-1} of micronutrients combination with ethephon applied by 500 mg l^{-1} and carbohydrate% (64.606) from micronutrients combination sprayed at 1 g l^{-1} (table 5). The observed increase in protein content may be attributed to the application of a combination of micronutrients, particularly zinc and manganese, the proposed mechanism involves the interaction of these micronutrients with sulfur-containing amino acids such as cysteine and methionine, which promotes the formation of disulfide bonds during protein polymerization **[34]**.

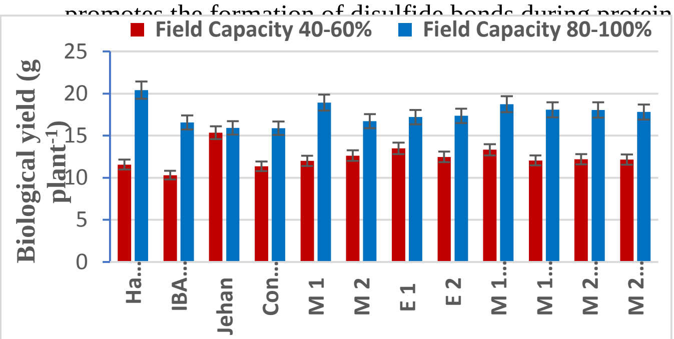


Figure 7: biological yield under water stress

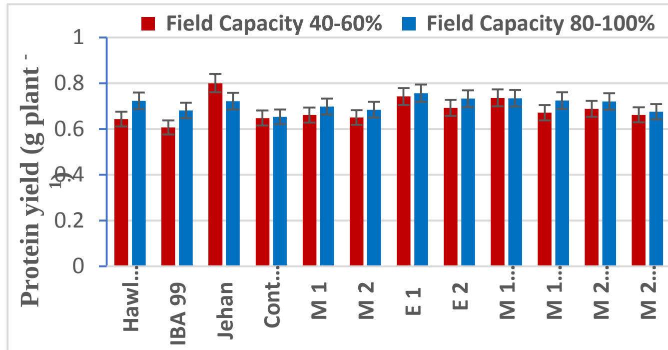
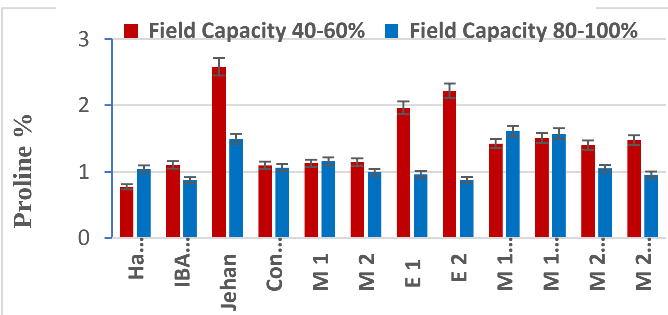
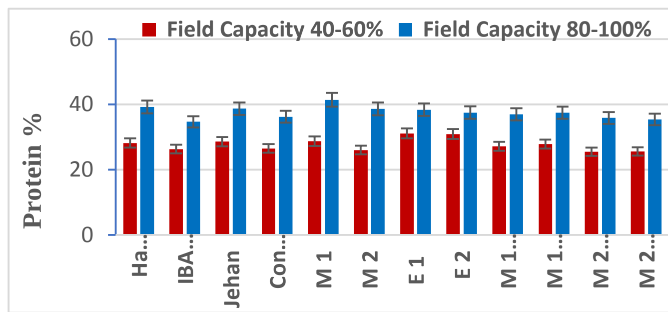


Figure 8: protein yield under water stress





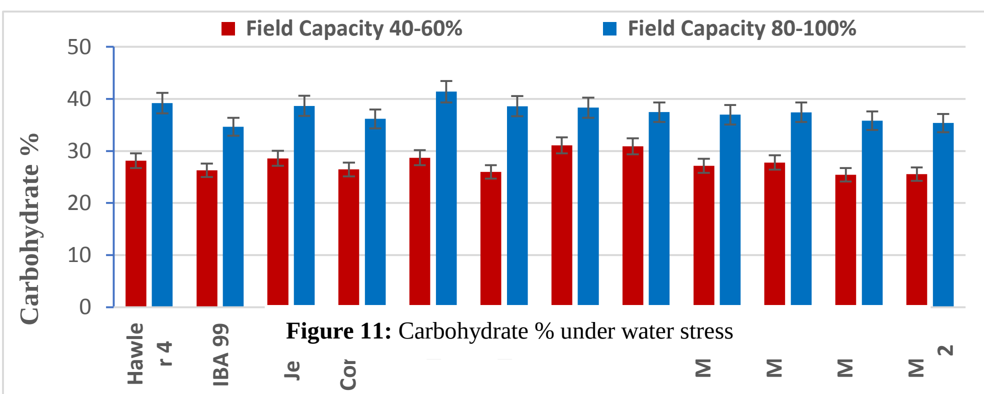


Figure 11: Carbohydrate % under water stress

Table (5): Effect of interaction between micronutrient, ethephon applications and bread wheat varieties on yield and quality under water stress condition

Treatment		Biological yield (g plant^{-1})	Protein yield (g plant^{-1})	Proline %	Protein %	Carbohydrate %	Biological yield (g plant^{-1})	Protein yield (g plant^{-1})	Proline %	Protein %	Carbohydrate %
Varieties x Fertilizer		Field Capacity 40-60%					Field Capacity 80-100%				
Hawler 4	Control	11.293 f-i	0.602 d-g	0.733 m-o	11.400 bc	44.693 p	17.967 c-i	0.679 a-c	1.090 f-h	8.303 h	45.033 j
	M 1	11.617 f-i	0.630 d-g	0.779 l-n	11.100 ef	47.620 mn	19.370 b-f	0.737 a-c	1.171 e	8.546 fg	48.130 j
	M 2	10.740 g-i	0.573 fg	0.716 no	11.00 f	52.470 ij	19.737 a-e	0.753 a-c	0.998 i-k	9.333 b	55.080 e
	E 1	12.377 e-h	0.683 c-g	0.825 l	11.300 cd	59.220 b	19.897 a-e	0.847 a	0.911 lm	9.230 bc	63.700 a
	E 2	13.151 c-g	0.722 c-e	0.771 l-n	11.500 b	55.683 de	20.447 a-d	0.800 ab	1.037 g-i	9.040 de	56.160 d
	M 1 E 1	12.467 e-h	0.703 c-f	0.800 lm	11.100 ef	51.040 kl	22.113 a	0.692 a-c	1.051 g-i	8.00 I	53.366 f
	M 1 E 2	10.747 g-i	0.644 d-g	0.767 l-n	11.300 cd	55.845 d	21.553 ab	0.705 a-c	1.106 e-g	8.300 h	57.596 d
	M 2 E 1	11.117 f-i	0.645 d-g	0.772 l-n	10.800 g	52.621 h-j	21.890 a	0.668 a-c	0.961 j-l	8.400 gh	59.390 bc
	M 2 E 2	10.600 g-i	0.588 e-g	0.757 l-o	11.200 ed	55.451 c	20.777 a-c	0.624 bc	1.046 g-i	8.100 i	55.620 e
IBA 99	Control	10.160 hi	0.605 d-g	0.683 o	11.300 cd	41.213 q	16.170 g-l	0.656 bc	1.156 ef	8.700 f	56.870 d
	M 1	10.800 g-i	0.633 d-g	0.737 m-o	11.200 ed	62.413 a	18.670 b-g	0.742 a-c	1.288 d	8.600 f	64.176 a
	M 2	10.721 g-i	0.580 fg	0.999 k	11.300 cd	50.386 lm	16.00 g-l	0.653 bc	0.816 n	8.900 e	50.810 h
	E 1	10.200 hi	0.644 d-g	1.303 i	11.200 ed	57.451 c	18.447 c-i	0.697 a-c	0.557 p	8.600 f	63.736 a
	E 2	9.507 i	0.569 fg	1.594 h	11.200 ed	51.746 jk	13.833 kl	0.601 c	0.565 p	9.00 de	56.440 d
	M 1 E 1	10.260 hi	0.555 g	1.161 j	11.200 ed	48.541 n	17.553 d-i	0.672 a-c	0.919 lm	9.00 de	60.308 b
	M 1 E 2	10.003 hi	0.589 e-g	1.175 j	11.100 ef	46.480 o	15.670 h-l	0.702 a-c	0.922 lm	9.400 b	63.956 a
	M 2 E 1	10.440 hi	0.622 d-g	1.111 j	11.200 ed	53.186 fg	15.667 h-l	0.694 a-c	0.888 m	8.900 e	54.625 f
	M 2 E 2	10.760 g-i	0.671 c-g	1.163 j	11.400 bc	51.066 kl	17.520 e-i	0.713 a-c	0.708 o	8.600 f	57.273 d
Jehan	Control	12.647 d-h	0.736 cd	1.873 f	11.100 ef	53.260 g-i	13.557 l	0.625 bc	0.938 k-m	8.400 gh	58.273 c
	M 1	13.600 c-f	0.720 c-e	1.864 f	11.100 ef	59.896 b	13.557 l	0.614 c	1.006 i-k	8.700 f	64.606 a
	M 2	16.447 ab	0.787 bc	1.712 g	11.300 cd	52.263 i-k	14.467 j-l	0.646 bc	1.158 ef	9.400 b	55.433 f
	E 1	17.885 a	0.900 ab	3.765 b	11.100 ef	55.493 d-f	16.223 g-l	0.725 a-c	1.372 c	9.00 de	56.640 e
	E 2	14.776 b-e	0.787 bc	4.300 a	11.200 ed	53.473 f-h	17.777 c-i	0.797 ab	1.022 h-j	9.100 cd	53.293 g

	M 1 E 1	17.250 ab	0.951 a	2.315 e	11.600 a	53.376 e-g	18.767 b-g	0.838 a	2.863 a	9.300 b	54.621 fg
	M 1 E 2	15.437 bc	0.782 bc	2.582 c	11.300 cd	51.761 kl	17.00 e-j	0.764 a-c	2.692 b	9.400 b	52.948 h
	M 2 E 1	15.041 b-d	0.799 bc	2.326 e	11.166 e	51.483 j-l	16.610 f-k	0.798 ab	1.304 d	9.700 a	53.036 f
	M 2 E 2	15.147 b-d	0.728 c-e	2.507 d	11.400 bc	50.868 gh	15.443 i-l	0.688 a-c	1.107 e-g	9.300 b	51.363 gh

Conclusion

The results revealed that bread wheat yield and quality were significantly influenced by the interaction between varieties, foliar application of combined micronutrients (Zn, Mn, B, and Fe), ethephon, and water stress. Under optimal water conditions (80–100% field capacity), the Hawler4 variety showed the highest yield components and grain quality, while Jehan variety performed best under water stress (40–60% field capacity). The combined foliar application of micronutrients at 1 g l^{-1} with ethephon at 500 mg l^{-1} enhanced spike traits, grain yield, protein content. Overall, integrating micronutrient enrichment with ethephon foliar spraying effectively improved yield and grain quality, particularly under water-limited conditions, and can be recommended to enhance wheat productivity and stress tolerance.

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تحسين إنتاجية وجودة حنطة الخبز (*Triticum aestivum L.*) من خلال الرش الورقي بالعناصر الصغرى والاثيفون تحت ظروف الإجهاد المائي

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الخلاصة

طبقت تجربة في بيت بلاستيكي في كردةرش، أربيل، إقليم كردستان، العراق، خلال الفترة من1 ديسمبر 2024 إلى15 مايو 2025، لدراسة تأثير الرش الورقي بتوليفات من العناصر الصغرى (الزنك، والمنغنيز، والبورون، والحديد) والاثيفون على حاصل وجودة حبوب ثلاثة أصناف من حنطة الخبز (هولير 4، وإباء99، وجيهان) تحت تأثير مستويين من الاجهاد المائي (40-60% و80-100% من السعة الحقلية). وُزعت المعاملات وفق تصميم القطاعات العشوائية الكاملة بثلاثة مكررات. أظهرت النتائج أن مكونات الحاصل وخصائص جودة الحبوب تتأثر بشكل كبير مع الأصناف، وتوليفة العناصر الصغرى والاثيفون، حيث عند توافر المياه تحت ظروف الري المثلى (80-100% من السعة الحقلية)، سجل صنف هولير 4 أعلى طول للسنبلة (سم)، وعدد الحبوب في السنبلة، ووزن 1000 حبة (غم)، وإنتاجية حبوب (9.18 غم نبات-1)، بينما أظهر صنف جيهان أداءً أفضل تحت ظروف الإجهاد المائي (40-60% من السعة الحقلية) مع تحسن في عدد الاشطاء، وعدد السنابل، وحاصل البروتين (غم نبات-1). أدى الرش الورقي المشترك للعناصر الصغرى بتركيز 1 غم لتر-1 مع الإثيفون بتركيز 500 ملغم لتر-1 إلى أداء متميز لمعظم معايير الحاصل وتحسين خصائص الجودة، بما في ذلك محتوى البروتين، والكلوتين، والبرولين، والكربوهيدرات. تشير النتائج إلى أن دمج توليفة العناصر الصغرى مع استخدام الإثيفون يعزز بشكل فعال إنتاجية الحنطة وجودة الحبوب في كل من الظروف العادية وظروف الإجهاد المائي. كان صنف هولير 4 أكثر استجابة في ظل ظروف الري الكامل، بينما أظهر صنف جيهان تحملاً أفضل للإجهاد المائي. تشير هذه النتائج إلى أن الرش الورقي بالعناصر الصغرى بالتزامن مع استخدام الاثيفون يُعد استراتيجية فعّالة للتخفيف من تأثيرات الإجهاد المائي، مما يسهم في تحسين كل من الإنتاجية والصفات النوعية في محصول حنطة الخبز.

الكلمات المفتاحية: حنطة الخبز، العناصر الصغرى، الاثيفون، الإجهاد المائي.