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Article

The Effect of Spraying With Nano-Boron on Some Productive and Qualitative Traits of Six Genetic Combinations of Sugar Corn (*Zea mays* L. saccharata) in Salah al-Din Governorate

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Abstract: The experiment was conducted in Al-Mu'tasim sub-district, Samarra district, Salah al-Din Governorate, during the autumn season of 2023. Six genotypes of sweet corn (Gold Rush, Chocolate, 001, Seker Misir, Succar, Roi Soleal) were used, along with four levels of Nano boron spray (0, 6, 12, and 18 mg L^{-1}), applied according to a randomized complete block design (RCBD) with three replicates. The results showed that increasing the boron level significantly improved the total and biological yields, with the total yield increasing from 6165 kg ha^{-1} when not sprayed to 8552 kg ha^{-1} at 18 mg L^{-1}, and the biological yield from 13426 to 17064 kg ha^{-1}. The response of the genotypes also varied, with the 001 variety achieving the highest average total yield (7953 kg ha^{-1}) and biological (16120 kg ha^{-1}), while Seker Misir had the lowest. The interaction between varieties and boron levels showed that some varieties, such as 001 and Succar, respond best at the highest boron level. For qualitative traits, total sugars increased from 7.64% to 10.38%, and total soluble solids (TSS) from 7.12% to 8.68% with increasing boron, with the Chocolate variety recording the highest values (11.18% sugars and 11.18% TSS). Protein content also increased from 8.22% to 9.68%, with Succar responding best, while oil content decreased slightly from 4.18% to 4.00% at the highest boron level, with the highest oil content for the 001 variety (4.28%).

Keywords: Nano Boron, Productive Traits, Genetic Structures - Sweet Corn, Salah El-Din

Introduction

Sugar corn (*Zea mays* L. saccharata) is a globally important agricultural crop, due to its nutritional value and multiple uses in human food, animal feed, and various food industries. It is also distinguished by its ability to adapt to diverse environmental conditions, including semi-arid areas with limited water resources, making it an important source of food security in many countries [1].

The different genetic makeups of sweet corn play a pivotal role in determining its ability to produce and adapt to environmental conditions. Genetic makeups influence production and quality traits. Recent studies have shown that genetic diversity among genetic makeups can enhance productivity and improve nutritional quality.

It contributes to carbon storage and increases plants' resistance to environmental stresses such as drought, salinity, and high temperatures [2].

Boron is an essential micronutrient for plants, playing an important role in cell wall formation, cell reproduction, flower development, and seed formation. It also directly affects yield and quality traits, including protein and oil content in grains.

Boron deficiency is considered a limiting factor that leads to poor plant growth, poor flowering, low yield, and a negative impact on grain quality [3].

In recent years, the use of Nano Boron has emerged as an innovative fertilizer for precise plant nutrition. It is characterized by a minimal particle size that is easily absorbed through the leaves and roots, and increases the effectiveness of the element compared to traditional boron fertilizers. Studies have shown that spraying Nano Boron on sugar corn leads to improved protein and oil content in the grain.

It also contributes to enhancing the efficiency of using other nutrients such as nitrogen and phosphorus, which improves the crop's production response [4].

Studies also show that the response of different genetic makeups of sweet corn to nano-boron spraying varies from one variety to another, as some varieties show a clear increase in yield and quality, while other varieties are less responsive [5].

Due to the lack of studies that addressed the effect of nano boron on the different genetic structures of sugar corn in Iraq in general, and particularly in Salah al-Din Governorate, this study aims to study the effect of nano boron spray levels on plant production traits such as total grain yield and biological yield. and evaluating its impact on the qualitative characteristics of grains, including sugar content, total soluble solids, protein, and oil, in addition to comparing the response of six different genetic compositions of sweet corn to this application to determine the compositions most capable of achieving high productivity and improved quality.

Study factors

a. Six genetic compositions of sugar corn were obtained from the Department of Field Crops, College of Agriculture- University of Baghdad, shown as follows: (Gold Rush, Chocolate, 001, Seker Misir, Succar, Roi Soleal).
b. Boron spray level Using nano boron under four spray levels was obtained at a rate of (0, 6, 12, and 18) kg ha-1.

Materials and Methods

Implementation of the Experiment

The field experiment was conducted during the autumn season of 2023 in the Al-Mu'tasim subdistrict of Samarra District, Salah al-Din Governorate. The field designated for the experiment was identified, and five random samples were taken from a depth of (0-30 cm) for physical and chemical analyses. The samples were mixed and ground using a wooden hammer, then passed through a sieve with 2 mm diameter holes, air-dried, and stored in plastic containers for analysis.

The experiment was designed according to a randomized complete block design (R.C.B.D) with split plots. The field was prepared by plowing and leveling and divided into three replicates, each containing 24 experimental units. Each experimental unit included four lines, with a distance of 70 cm between each line and 20 cm between each hole. The soil was fertilized with DAP (NPK 18:46:0) compound fertilizer before planting at a rate of 200 kg ha^{-1}, in addition to urea fertilizer (46% N) at a rate of 390 kg ha^{-1}, distributed in two batches; the first at planting and the second 40 days after planting Planting took place on July 15, 2023, with 2-3 seeds in each hole to ensure germination, then the plants were thinned to one plant per hole a month after planting [6].

After flowering and head growth, the plant heads were covered with paper bags to prevent bird attacks, and weeding and control were carried out manually. To control the corn stem borer (Sesamia cretica), 10% diazinon granules were used at a rate of 6 kg/ha^1, and were applied to the growing tip twice: the first as a preventative control at the 4-5 leaf stage, and the second 15 days after the first control [7].

Nano Boron spraying was applied in two stages: the first when the plant was 30 days old, and the second when the flowering rate reached 50%, using a backpack sprinkler. Irrigation was also carried out using a drip irrigation system with water sourced from a well.

Table 1. Physical and chemical characteristics of the experimental soil for the agricultural season (2023) AD.

Adjective	Unit	Value
pH		7.74
Ec	Desmans .m^{-1}	2.69
Organic matter	gm kg^{-1}	0.79
Available nitrogen		17.88
available phosphorus	mg kg^{-1}	7.11
available potassium		131.22
Sand	gm kg^{-1}	541
Gilt		227
Clay		232
Structure		S.C.L
Gypsum		48.96
Lime	gm kg $^{-1}$	20.57

Traits studied:

a. Total grain yield (kg ha-1).

The seeds of the ten plants taken from the two middle lines were separated and weighed, then the total weight was divided by ten plants to obtain the average yield per plant in each unit.

b. Biological yield (kg plant-1).

Was calculated by adding the weight of the leaves and stems of the plants and then dividing it by the number of plants. The leaves were dried naturally, while the stems were dried in an electric oven at a temperature of 65-70°C until the weight was constant. The average dry matter yield per plant was extracted.

Total Sugars (%)

The total sugars were estimated using the method described in Methods in Food Analysis [8]:

a. 2 grams of fresh grains were taken, crushed, and placed in a test tube. 80 ml of 80% ethyl alcohol was added.
b. The mixture was placed in a water bath at 60°C for 30 minutes.
c. Place the mixture in a centrifuge for 15 minutes, then extract the clear solution and collect it.
d. Complete the volume of the solution to 25 ml by adding perchloric acid. Then, take 1 ml of it and add 1 ml of phenol and 5 ml of sulfuric acid to it, and observe the appearance of a brown color.
e. The light absorption of the sample was measured using a spectrophotometer at a wavelength of 490 nanometers.
f. Prepare a standard solution of known concentrations of glucose, and plot the standard curve.
g. The optical absorbance readings were plotted on the standard curve to extract the sugar concentrations in the sample.

Total Soluble Solids (TSS) (%)

Mature grain samples were taken from each experimental unit after harvest, air-dried, and ground to a fine powder. An extract was taken from the ground grain using a specified amount of distilled water, and the TSS (%) was then measured using a digital refractometer, having previously calibrated the instrument with a standard solution [9].

Protein percentage (%): The nitrogen content of the seeds was calculated using a Kjeldal Macro device, and then the equation was applied:

% protein = % nitrogen × 6.25

Oil percentage (%): Random samples were taken from the seeds, and the oil content was determined using a Soxhlet device in the laboratory of the Department of Field Crops, College of Agriculture, Tikrit University [10].

Statistical Analysis

Data were collected and then analyzed statistically using SAS software, using a factorial experiment for a randomized complete block design with a single-panel system. Duncan's multiple range test was used to compare means at a probability level of 0.05 [11].

Results and Discussion

A. Grain yield (kg ha-1)

The results of Table (2) showed that the genetic makeup of sugar corn had a clear significant effect on the total grain yield. Variety 001 outperformed the other varieties, recording the highest average yield of 7953 kg ha-1, followed by the variety Succar with a yield of 7767 kg ha-1. While the Seker Misir variety recorded the lowest production rate of 7336 kg ha^{-1}. The difference was attributed to the variation in the ability of the varieties to convert the products of the carbon metabolism process into granular material and their efficiency in absorbing nutrients, which was confirmed in studies on sugar corn, where it was indicated that the productive performance of varieties varies depending on the efficiency of nutrient absorption and conversion to grain [11]. As for the level of spraying with nano-boron, it showed a significant effect on the total yield, as the average yield gradually increased with increasing boron concentration from 6165 kg ha^{-1} when not sprayed to 8552 kg ha^{-1} at 18 mg L^{-1}. This effect is attributed to the role of boron in enhancing plant growth and improving yield components such as the number of ears, the number of grains per ear, and the weight of 500 grains, which was reflected in increasing the total yield [1].

Regarding the interaction between genetic compositions and spraying level, it had a significant effect on the total grain yield, as the interaction between variety 001 and spraying level 18 mg L^{-1} recorded the highest yield, reaching 8997 kg ha^{-1}. While the interaction between the Seker Misir variety and no spraying (0 mg L^{-1}) was the least productive, at 5900 kg ha^{-1}. This interaction indicates that some varieties respond better when certain levels of boron are applied, which enhances their efficiency in using nutrients and increases productivity.

Table 2. Effect of Nano Boron spray level, genetic compositions of sweet corn, and their interaction on total grain yield (kg h-1).

Genotypes	Boron spray level (mg L^{-1})				Average of genotypes
	0	6	12	18	
Gold Rush	6201 f	7199 de	8203 bc	7800 cd	**7351 cd**
Chocolate	6001 f	7100 e	8122 bc	8505 ab	**7432 bc**
001	6489 ef	7610 cd	8715 ab	8997 a	**7953 a**
Seker Misir	5900 g	7032 e	8014 bc	8400 ab	**7336 cd**
Succar	6150 f	7419 cd	8600 ab	8900 a	**7767 ab**
Roi Soleal	6250 f	7533 c	8452 ab	8710 a	**7736 ab**
Boron Average	6165 d	7315 c	8351 b	8552 a	

* Averages with similar letters are not significantly different according to Duncan's test at a probability level of 0.05

B. Biological yield (kg ha-1)

The results of Table (3) indicate that both the level of Nano Boron spraying and the genetic makeup of sweet corn had a significant effect on the biological yield, in addition to the presence of clear significant differences due to the interaction between them. Increasing the level of Nano Boron from (0) to (18 mg L^{-1}) led to a gradual increase in the average biological yield from 13426 to 17064 kg ha^{-1}, this is attributed to the vital role of boron in promoting cell division and elongation and stimulating the transfer of carbohydrates and sugars to vegetative tissues, which is reflected in increasing the plant's biomass. An increase in vegetative growth as a result of improved photosynthetic efficiency and enhanced bioaccumulation was achieved through foliar boron fertilization in sweet corn [12].

On the other hand, the genetic compositions showed significant differences, as the 001 variety excelled, achieving the highest average of 16120 kg ha^{-1}, followed by the Succar variety with an average of (15887 kg ha^{-1}), while the Seker Misir variety was the lowest (15004 kg ha^{-1}). The variation was attributed to genetic differences in the representative efficiency of the varieties and their ability to exploit environmental resources and convert the products of photosynthesis into dry matter, as confirmed by studies showing that varieties differ in biomass productivity according to their capacity to form a larger leaf area and achieve more efficient vegetative growth [13].

As for the interaction, it was also significant, as the interaction between the 001 variety and the boron level (18 mg L^{-1}) recorded the highest biological yield, amounting to 17841 kg ha^{-1}, while the lowest yield was when the interaction between the Seker Misir variety and not spraying with boron (0 mg L^{-1}) with an average of 12987 kg ha^{-1}. This indicates that the response of varieties to spraying with boron depends on their genetic efficiency in absorbing nutrients and utilizing them in accumulating dry matter.

Table 3. Effect of Nano Boron spray level, genetic compositions of sweet corn, and their interaction on the biological yield (kg h-1).

Genotypes	Boron spray level (mg L-1)				Average of genotypes
	0	6	12	18	
Gold Rush	13212 f	14985 e	16548 cd	16172 cd	**15229 b**
Chocolate	13155 f	14735 e	16128 cd	16785 bc	**15151 b**
001	13842 ef	15562 d	17234 bc	17841 a	**16120 a**
Seker Misir	12987 g	14542 f	15978 cd	16510 c	**15004 c**
Succar	13618 f	15324 d	17042 bc	17563 ab	**15887 ab**
Roi Soleal	13745 ef	15508 d	16752 bc	17412 ab	**15854 ab**
Boron Average	13426 c	15159 b	16647 a	17064 a	

* Averages with similar letters are not significantly different according to Duncan's test at a probability level of 0.05

C. Total sugars (%)

The results of Table (4) indicate that the levels of Nano Boron spraying significantly affected the concentration of total sugars in sugar corn grains. The average sugar concentration increased from 7.64% when no boron was added to 10.38% at the highest level (18 mg/L^{1}). This is attributed to the fact that the element boron plays an important role in the transport of sugars across cell membranes and regulating their accumulation in grains, in addition to its role in enhancing the activity of enzymes responsible for carbohydrate metabolism. It was explained that boron is one of the essential elements responsible for transporting sugars within the plant, which is directly reflected in its accumulation in the storage organs, and it was also shown that foliar spraying with boron increases the concentrations of soluble sugars in sweet corn by enhancing photosynthetic efficiency [14], [15].

As for the genetic compositions, clear differences were observed, as the Chocolate variety recorded the highest average total sugars of 9.96%, followed by the Succar variety (9.14%) and Roi Soleal (9.07%), while the Seker Misir variety had the lowest average (8.67%). The difference was attributed to the genetic variation among varieties in the efficiency of carbohydrate metabolism and its accumulation in grains, which was indicated in studies showing that the genetic compositions of sweet corn differ in their qualitative characteristics, particularly in sugar content, due to variations in genes regulating the starch and sugar metabolism pathway [16]. The interaction between boron levels and varieties was significant, as the interaction between the Chocolate variety and the spray level (18 mg L^{-1}) recorded the highest sugar percentage, reaching 11.18%. While the lowest concentration of sugars was found in the interaction between variety 001 and no boron addition (7.44%). This indicates that the response of varieties to boron varies according to their genetic ability to absorb the role of this element in regulating carbon metabolism and the distribution of sugars in grains.

Table 4. Effect of Nano Boron spray level, genetic compositions of sweet corn, and their interaction on the concentration of total sugars in grains (%).

Genotypes	Boron spray level (mg L^{-1})				Average of genotypes
	0	6	12	18	
Gold Rush	7.48 e	8.36 d	9.82 bc	9.54 bc	**8.80 b**
Chocolate	7.83 de	8.71 c	10.12 ab	11.18 a	**9.96 a**
001	7.44 e	8.28 d	9.48 bc	10.23 ab	**8.86 b**
Seker Misir	7.61 f	8.19 de	9.24 c	9.62 bc	**8.67 c**
Succar	7.73 e	8.47 d	9.83 bc	10.52 ab	**9.14 ab**
Roi Soleal	7.76 e	8.58 cd	9.72 bc	10.21 ab	**9.07 ab**
Boron Average	7.64 c	8.43 b	9.70 a	10.38 a	

* Averages with similar letters are not significantly different according to Duncan's test at a probability level of 0.05

D. Total Soluble Solids (TSS) (%)

The results of Table (5) indicate that the level of Nano Boron spraying and genetic compositions significantly affected the percentage of total soluble solids (TSS) in sweet corn grains, and the interaction between the two factors played a prominent role. In general, the TSS averages increased with increasing boron concentration from 7.12% when not sprayed to 8.68% at 18 mg·L^{-1}, indicating that adding boron enhanced the accumulation of soluble sugars in the grain. This is scientifically due to boron's role in improving the transport of sugars from the leaves to the grain and regulating the activity of enzymes responsible for carbohydrate metabolism (such as sucrase/invertase). As well as improving cell membrane stability and transport disturbances, all of this contributes to increasing the total solute concentration in the granulation tissue. The results of recent reviews and studies support that the availability of boron may increase the TSS content in crops and affect the quality of the final product [17].

Table (5) also showed clear differences between the varieties; the Chocolate variety recorded the highest average TSS of 8.31%, along with the highest overlap value of 11.18% at 18 mg L^{-1}, while other varieties had lower levels. This variation is explained genetically: sweet corn varieties differ in the genes responsible for sugar accumulation pathways (such as differences in the genes sugar1, su, se, sh2). And in the efficiency of converting and transporting sugars within the grain, which leads to a clear difference in TSS between varieties and their hybrids. Various studies on sweet corn hybrids and varieties showed significant variation in TSS and constituent sugars (sucrose, glucose, fructose) between varieties and genetic groups [18].

As for the interaction between the two factors, the table showed that some varieties benefited more from spraying with nano-boron; the interaction between Chocolate and a concentration of 18 mg L^{-1} gave the highest percentage of 11.18%, while some varieties had a lower response to the same treatment. This shows that the variety's response to boron depends on the variety's genetic flexibility in using this element to regulate carbohydrate distribution and sugar fixation in the grain; therefore, choosing the right variety with the appropriate boron level is directly reflected in the grain quality (sweetness level/TSS).and thus on the marketing value of sweet corn. Experimental and field studies support the importance of variety and treatment interaction in determining TSS and quality characteristics of sweet corn.

Table 5. Effect of nanoboron spray level, sweet corn genetics, and their interaction on total dissolved solids (T.S.S) concentration (%).

Genetic types	Boron spray level (mg L-1)				Average of genotypes
	0	6	12	18	
Gold Rush	7.10 a	7.85 d	8.50 g	8.10 e	**7.89 d**
Chocolate	7.25 b	8.00 e	8.80 i	9.10 k	**8.29 i**
001	7.00 a	7.70 c	8.20 f	8.60 h	**7.88 d**
Seker Misir	6.92 a	7.55 b	8.10 e	8.30 f	**7.72 c**
Succar	7.15 b	7.90 d	8.60 h	8.80 j	**8.11 f**
Roi Soleal	7.20 b	8.05 d	8.70 i	9.00 j	**8.24 g**
Boron Average	7.10	7.84	8.48	8.65	

* Averages with similar letters are not significantly different according to Duncan's test at a probability level of 0.05

E. Protein (%)

The results of Table (6) indicate that the level of Nano Boron spraying significantly affected the protein concentration in sugar corn grains. Protein averages increased from 8.22% when not sprayed to 9.68% at the highest level (18 mg L^{-1}). This is attributed to the role of boron in improving the absorption of nutrients such as nitrogen and phosphorus, activating protein metabolism in plants, and enhancing the efficiency of transport and accumulation within the grain. A study [20] confirmed that spraying with boron improves the protein content of corn by supporting amino acid formation and photosynthesis processes.

As for the genetic compositions, the results showed significant differences between the varieties. The Succar and Seker Misir varieties recorded the highest protein averages of 9.58% and 9.33%, respectively, while the 001 variety recorded the lowest value (8.65%).This is attributed to the difference in the genetic efficiency of varieties in converting nutrients into proteins stored within the grain, which is supported by the results of Tracy (2001), which showed a clear difference between sugar corn varieties in the ability to accumulate protein and maintain the protein mass of the grain.

As for the interaction between the two factors, the table showed that the varieties with a high response to boron (such as Succar at 18 mg L^{-1}) recorded the highest protein content (10.52%), while the varieties with a lower response at the same level showed a limited increase. This demonstrates that choosing the appropriate variety with the ideal spraying level enhances protein yield in grains.

Table 6. Effect of Nano Boron spray level, genetic compositions of sweet corn, and their interaction on protein concentration in grains (%).

Genotypes	Boron spray level (mg L-1)				Average of genotypes
	0	6	12	18	
Gold Rush	8.20 g	8.80 fg	9.50 de	9.10 ef	**8.90 bc**
Chocolate	8.03 g	8.72 fg	9.22 ef	9.63 cd	**8.88 bc**
001	7.82 g	8.52 g	9.03 ef	9.33 de	**8.65 c**
Seker Misir	8.32 fg	9.03 ef	9.82 de	10.22 ab	**9.33 ab**
Succar	8.52 ef	9.22 de	10.12 ab	10.52 a	**9.58 a**
Roi Soleal	8.42 ef	9.12 de	9.92 cd	10.32 a	**9.43 ab**
Boron Average	8.22 c	8.90 b	9.60 a	9.68 a	

* Averages with similar letters are not significantly different according to Duncan's test at a probability level of 0.05

F. Oil (%)

The results of Table (7) indicate that the level of spraying with nano-boron significantly affected the oil concentration in the sugar corn grains, as a slight decrease in the oil content was observed with an increase in the boron concentration from 4.18% when not sprayed to 4.00% at the highest level (18 mg L^{-1}).This is attributed to the fact that increased accumulation of sugars in the grain (as shown by the results of the previous tables for TSS and sugars) may be accompanied by a relative decrease in oil accumulation, which explains the known inverse relationship between protein/sugars and oil in corn grains (Huang et al.,).

As for genetic compositions, the results showed significant differences between the varieties. Variety 001 recorded the highest oil content (4.28%), while Succar recorded the lowest value (3.83%). This disparity is attributed to genetic differences between the varieties in the lipid synthesis pathways within the grain, and their ability to distribute carbohydrates between sugar and oil. This was confirmed by studies on sugar corn [19].

As for the interaction between the two factors, the table showed that some varieties responded more to low or moderate boron concentrations, while other varieties were not significantly affected at the same level. For example, the Chocolate variety, at 6 mg L^{-1}, showed a good balance between oil content and sugar content.

Table 7. Effect of Nano Boron spray level, genetic compositions of sweet corn, and their interaction on oil concentration in grains (%).

Genotypes	Boron spray level (mg L^{-1})				Average of genotypes
	0	6	12	18	
Gold Rush	4.27 ab	4.12 de	4.03 ef	4.08 def	**4.13 b**
Chocolate	4.35 a	4.21 cd	4.10 def	4.15 cde	**4.20 b**
001	4.42 a	4.28 bc	4.18 cde	4.23 bc	**4.28 a**
Seker Misir	4.10 cde	3.98 e	3.88 f	3.92 ef	**3.97 c**
Succar	3.95 ef	3.85 fg	3.72 h	3.78 gh	**3.83 d**
Roi Soleal	4.00 def	3.90 fg	3.80 gh	3.85 gh	**3.89 c**
Boron Average	4.18 b	4.06 ab	3.95 a	4.00 a	

* Averages with similar letters are not significantly different according to Duncan's test at a probability level of 0.05

Conclusion

1. Spraying with Nano Boron increased the total and biological yield, sugars, TSS, and protein, while slightly reducing the oil content.

2. The 001, Succar, and Chocolate varieties had the highest yield and quality, while Seker Misir had the lowest.

3. The interaction between the variety and the boron level showed that choosing the appropriate variety with the boron concentration improves productivity and quality.

Recommendations

1. Use boron spray at a concentration of 18 mg/L^1 to improve yield and quality.

2. Select highly responsive varieties such as Chocolate, Succar, and 001.

3. Ensure a balance between sugar, protein, and oil according to the production purpose.

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