

Article

# Ameliorative Effects of Calcium Sprays on Yield and Grain Nutritional Composition of Maize (*Zea mays* L.) Cultivars under Drought Stress

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**Abstract:** Drought stress is seriously affecting maize production. To investigate the influence of calcium (Ca) foliar application on maize production and chemical composition of grains under drought stress, two experiments were carried out at Cairo University Research Station, Giza, Egypt, during the summer seasons of 2018 and 2019. The experimental design was split-split plot design with a completely randomized blocks arrangement with three replications. Water regimes were assigned to the main plots [100 (control), 75, and 50% of estimated evapotranspiration]. Calcium levels (zero and 50 mg/L) were assigned to the sub plots. Maize cultivars (SC-P3444, Sammaz-35 and EVDT) were assigned to the sub-sub plots. Three maize cultivars were sprayed with Ca solution concentration (50 mg/L) under normal and drought conditions. The control treatment (0 mg/L) was sprayed with an equal amount of distilled water for comparison. Results indicated a significant decrease in total yield and grain characteristics [protein, ash, total sugars, nitrogen (N), phosphorus (P), potassium (K), and iron (Fe) contents] as a response of drought. Calcium foliar application significantly increased maize yield, protein, ash, carbohydrates, starch, total sugars, and ionic contents of grains, except for manganese (Mn), under all irrigation levels. Based on the drought tolerance index (DTI), only cultivar SC-P3444 showed drought tolerance while cultivars Sammaz-35 and EVDT were sensitive to drought stress. Foliar application of Ca on SC-P3444 cultivar achieved the highest grain yield per hectare (8061 kg) under the water regime of 100% of the total evapotranspiration, followed by Sammaz-35 (7570 kg), and EVDT (7191 kg) cultivars. At the water regime of 75% of estimated evapotranspiration (75% irrigation), Ca foliar application increased grain yield by 16, 13 and 14% in SC-P3444, Sammaz-35, and EVDT, respectively. At the water regime of 50% of the estimated evapotranspiration (50% irrigation), Ca foliar application increased grain yield by 17, 16, and 13% in SC-P3444, Sammaz-35, and EVDT, respectively. In brief, Ca had a clear impact on productivity and grain quality with important implications for maize yield under normal and water stress conditions. Our findings demonstrate that foliar application of Ca enabled drought stressed maize plants to survive better under stress. The most water stress tolerant cultivar was SC-P3444 followed by Sammaz-35 and EVDT under drought stress.

**Keywords:** corn; chemical constituents; ion contents; productivity; water regimes



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## 1. Introduction

Maize (*Zea mays* L.) is an important cereal crop with a wider range of uses than other cereals [1]. It ranks 3rd after wheat and rice in the world's production of cereal crops and is known as the king of grain crops [2,3]. Maize is valuable as a source of food, feed, oil, and biofuel [4]. Maize grains are a rich source of energy as 100 g seed provides 365 kilocalories of energy [5]. It is responsible for providing 1/2 of calorie consumption worldwide [6].

Drought or water deficiency is one of the most common abiotic stresses in agricultural production practically in arid and semi-arid environments. It is expected to be more frequent and intense as a result of global climate change, which may severely impact world crop production [7]. Drought is the most injurious stress that significantly influences the yield and quality traits of major cereal crops [8]. It reduces agricultural production mainly by disrupting the osmotic equilibrium and membrane structure of the cell [9]. Drought affects 20–25% of the cultivated area of maize around the world [10]. Water deficiency causes stomatal closure or destruction in photosynthetic reaction centers, which can lead to serious decline in photosynthetic rates and ultimately biomass accumulation [11,12]. In addition, it induces nutrient absorption, redistribution, and transport which results in a decline in productivity [13,14]. Water deficit severely reduces growth, dry matter content [15], and yield of maize hybrids [16]. Song et al. [17] concluded that severe maize yield loss could occur when maize was exposed to severe and extended water stress events during the seedling stage. Zhang et al. [18] indicated that irrigation deficit during maturation is more damaging than deficit during late vegetative stages due to the limitation of kernel development. In addition, drought significantly reduces starch, protein [19], and mineral contents in maize [9], while Balla et al. [20] found a reduction in grain starch and an increase in protein content in maize in response to drought stress.

Calcium is an essential element for plant growth and productivity. It plays a structural role in cell walls and membranes, counter-cation for inorganic and organic anions in the vacuole, acts as an intracellular messenger in the cytosol, and helps plants resist different environmental stresses [21–24]. Calcium ions can enhance drought stress tolerance in plants [25]. It alleviates the harmful effects of drought on plants by signaling anti-drought responses [26]. Ali et al. [27] indicated that the increasing cellular transient Ca participates in the processes abscisic acid (ABA)-induced drought signal transduction. The biosynthesis of ABA has improved water use efficiency and confer drought tolerance in plants [28]. Calcium foliar application improved drought tolerance in maize [29], sugar beet [30], wheat [31], and tea [32]. Fan [33] indicated that Ca concentration of 10 mM achieves the highest maize grain yield under both normal and drought conditions. Naeem et al. [29] found that foliar application of Ca ( $40 \text{ mg L}^{-1}$ ) is effective in improving maize growth and productivity. In addition, Naeem et al. [34] suggested that Ca application is effective to make maize plants survive under drought conditions.

Maintaining water balance in plants by reducing water loss or increasing water absorption is an essential way to improve plant tolerance to drought stress [35]. Maize requires large quantities of water to complete its life cycle and water deficiency negatively affects its vegetative growth and productivity [4,34]. Maize is sensitive to drought at different growth stages from germination to maturity [36]. However, a shortage of water during the period between pollination and maturity leads to a 15–20% decrease in yield [37]. Stress tolerance indicators are beneficial tools to determine high yield and stress tolerance potential of genotypes of crops [38]. Identifying high-yield genotypes under stress and non-stress conditions are more useful than developing new varieties [19,39]. Due to the continuous increase in irrigation water and global warming, maize production will face big difficulties and, as a result, testing techniques that can enhance drought tolerance in maize have become important. In this study, we will address the role of Ca sprays in maize drought stress tolerance. Little is known about the performance of cultivars SC-P3444, Sammaz-35, and EVDT under normal and water stress conditions. Therefore, the objectives of this research were to investigate the productivity and nutritional composition of grain in SC-P3444, Sammaz-35, and EVDT maize cultivars grown under different water regimes and to investigate the effect of foliar application of Ca on these cultivars under drought stress.

## 2. Materials and Methods

### 2.1. Experimental Site

The experiments were carried out at the Agricultural Experimental and Research Station, Faculty of Agriculture, Cairo University, Giza, Egypt ( $30^{\circ}02' \text{ N}$  and  $31^{\circ}13' \text{ E}$ , altitude

of 30 m above sea level) during the two successive seasons of 2018 and 2019. Monthly mean temperature, monthly relative humidity, and rainfall were recorded (Table 1). Monthly mean temperature values increased gradually from 28.2 and 27.6 °C in May to 30.5 and 30.8 °C in August in the 2018 and 2019 seasons, respectively. The maximum relative humidity was 56% during August and September in the first and second season, respectively. There was no rain in the two seasons.

**Table 1.** Average temperature, relative humidity and rainfall in the study area in Giza, Egypt, during the two growing seasons of 2018 and 2019 \*.

Month	2018			2019		
	Temperature (°C)	Relative Humidity (%)	Rainfall (mm)	Temperature (°C)	Relative Humidity (%)	Rainfall (mm)
May	28.2	43.3	0.00	27.6	34.9	0.00
June	29.9	45.4	0.00	29.9	47.1	0.00
July	30.7	52.9	0.00	30.6	50.3	0.00
August	30.5	56.0	0.00	30.8	51.4	0.00
September	29.4	54.7	0.00	28.5	56.2	0.00

\* Data obtained from the Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center (ARC), Egypt.

Soil physical analysis was conducted according to Klute [40] and chemical analysis was done as follows: pH; Soil pH [41], electrical conductivity; EC ( $\text{dS m}^{-1}$ ); Soluble Salts [42], organic matter (%) [43], N ( $\text{mg kg}^{-1}$ ); Nitrogen [44], P ( $\text{mg kg}^{-1}$ ); Phosphorus [45] and K ( $\text{mg kg}^{-1}$ ); Potassium [46]. The study site soil is classified as clay (Table 2). The soil pH was 7.21 and 7.41 and EC was 0.92 and 0.75  $\text{dS m}^{-1}$  in the first and second season, respectively. Chemical analysis of irrigation water was conducted according to Cottenie et al. [47]. The water pH was 7.02 and 7.37 and electrical conductivity (EC) was 0.78 and 0.86  $\text{dSm}^{-1}$  in the first and second season, respectively (Table 3).

**Table 2.** Soil properties at the experimental site in 2018 and 2019 seasons.

Soil Analysis	2018	2019
Physical properties		
Fine Sand (%)	27	21
Silt (%)	29	26
Clay (%)	44	53
Texture	Clay	Clay
Chemical properties		
pH <sub>(1:1)</sub>	7.21	7.41
EC <sub>(1:1)</sub> ( $\text{dS m}^{-1}$ )	0.92	0.75
Organic matter (%)	2.43	2.12
Available N ( $\text{mg kg}^{-1}$ )	12.3	10.7
Available P ( $\text{mg kg}^{-1}$ )	19.5	14.3
Available K ( $\text{mg kg}^{-1}$ )	76.0	91.0
Irrigation system	Surface irrigation	Surface irrigation

**Table 3.** Chemical properties of irrigation water at the experimental site in 2018 and 2019 seasons.

Season	pH	EC ( $\text{ds m}^{-1}$ )	Soluble Ions (meq/L)						
			$\text{HCO}_3^-$	$\text{Cl}^-$	$\text{SO}_4^-$	$\text{Ca}^+$	$\text{Mg}^+$	$\text{Na}^+$	$\text{K}^+$
2018	7.02	0.78	4.78	0.92	1.09	3.6	3.12	0.59	0.11
2019	7.37	0.86	5.12	1.04	1.28	4.3	2.60	0.90	0.18

## 2.2. Experimental Design and Treatments

Maize commercial Nigerian cultivars Sammaz-35 and EVDT were obtained from the National Agricultural Seeds Council, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria and the Egyptian cultivar SC-P3444 was obtained from DuPont Pioneer Company, Egypt. Cultivars used in the present study are single cross hybrids SC-P3444, Sammaz-35, and EVDT and were evaluated under three water regimes [irrigation amounting to 100 (control), 75, and 50% of estimated evapotranspiration]. Irrigation interval and amount of irrigation water over the growing season were calculated according to Allen et al. [48] (Table 4). The Ca solution was prepared by using Calcium Chloride Dihydrate ( $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ ). Three maize cultivars were sprayed with Ca solution concentration (50 mg/L about 25 g/ha) under normal and drought conditions in two equal doses using foliar spraying before the first and second irrigations. The control treatment (0 mg/L) was sprayed with an equal amount of distilled water for comparison. Calcium doses were sprayed at morning time (8:00–10:00 a.m.) on a dry and sunny day.

**Table 4.** Water irrigation scheme of field experiments.

Date	Day	Stage	No. of Irrigation	Gross ( $\text{m}^3/\text{ha}$ )				
				mm *	100% Irrigation	75% Irrigation	50% Irrigation	
23	May	9	Init	1	28	286	215	143
1	June	18	Init		30	304	228	152
13	June	30	Dev	3	61	610	457	305
22	June	39	Dev		73	732	549	366
30	June	47	Dev		82	829	621	414
9	July	56	Mid	3	115	1161	871	581
18	July	65	Mid		119	1202	901	601
27	July	74	Mid		116	1173	880	587
5	August	83	Mid	2	113	1139	854	570
14	August	92	Mid		109	1094	820	547
25	August	103	End		114	1151	863	576
7	September	116	End	1	92	930	698	465
16	September	End	End		Harvest			
Total uptake of water during season ( $\text{m}^3/\text{ha}$ )						10,611	7958	5306

mm \* = milliliter of water depth, Init = initiation, Dev = development, Mid = mid-season and End = end season.

Each experiment was laid out in a split-split plot design using randomized complete blocks arrangement with three replications. Water regimes were assigned to the main plots, while Ca treatments were assigned to the sub plots. Maize cultivars were assigned to the sub-sub plots.

## 2.3. Cultural Practices

The preceding crop was faba bean (*Vicia faba* L.) in both seasons. Sowing dates were on May 10 and 16 in the 2018 and 2019 seasons, respectively. Seeds were sown in hills by hand at a seeding rate of 57,600 plants/ha. Before the 1st irrigation, thinning was done to one plant per hill. Each plot contained 6 rows (70 cm width and 5 m long). Calcium super phosphate fertilizer (15.5%  $\text{P}_2\text{O}_5$ ) at the rate of 60 kg  $\text{P}_2\text{O}_5/\text{ha}$  was applied uniformly before sowing. Ammonium nitrate (33.5% N) at a nitrogen rate (288 kg N/ha) was added in two equal doses before the 1st and 2nd irrigations. The weed management was carried out during the growing season by hoeing two times, before the 1st and the 2nd irrigations. Cultural practices were conducted according to the recommendation of the Agricultural Research Center (ARC), Egyptian Ministry of Agriculture.

## 2.4. Data Collection

### 2.4.1. Agronomic Traits

Plant height (cm) measured from soil surface up to point of flag leaf, ear length (cm), number of rows plant<sup>-1</sup>, number of grains row<sup>-1</sup>, ear weight/plant (g), and 100-grain weight (g) were recorded for twenty plants selected from the inner ridges of each plot at harvest time. Grain yield ha<sup>-1</sup> in kg was weighed from whole area of each experimental unit (sub-sub-plot) and then adjusted into kilogram per hectare (kg/ha). The grain yield per hectare was adjusted on the basis of 15.5% grain moisture content.

### 2.4.2. Drought Tolerance Index (DTI)

Drought tolerance index is the factor used to compare drought tolerance among the tested cultivars. It was calculated as an Equation (1), [49].

$$DTI = (Y_w/\bar{Y}_w) * (Y_s/\bar{Y}_s) \quad (1)$$

where,  $Y_w$  = mean of grain yield/hectare for a genotype at well watering.  $\bar{Y}_w$  = average of grain yield/hectare for all genotypes at well watering.  $Y_s$  = mean of grain yield/hectare for a genotype at water stress.  $\bar{Y}_s$  = average of grain yield/hectare for all genotypes at water stress. For drought tolerant (T) cultivars, DTI is  $\geq 1$  while DTI is  $< 1$  for drought sensitive (S) cultivars.

## 2.5. Grain Quality Traits

### 2.5.1. Preparation of Samples

Fully developed grains were arbitrarily selected from each plot, picked, and taken to the laboratory for grain quality analysis. Grains were manually removed and dried at 65 °C to a constant weight, ground and stored in polyethylene bags in dark at 4 °C for chemical analysis.

### 2.5.2. Chemical Characteristics of Grain

The protein content was determined by the Kjeldahl method, ashing was carried out in a muffle and oxidizing atmosphere at a temperature of  $900 \pm 10$  °C, crude fiber and ether extract was determined by the Soxhlet method, and grains were measured by using the appropriate protocols according to Association of Official Agricultural Chemists, A.O.A.C. [50]. Carbohydrate content of grains was calculated according to Fraser and Holums [51] as follows: carbohydrates (on dry basis) =  $100 - (\text{ash} + \text{ether extract} + \text{protein} + \text{fiber})$ . Total sugar was determined with the phenol-sulfuric acid method according to Dubois et al. [52]. Starch content was determined via starch hydrolysis as described by Rasmussen and Henry [53]. The total polyphenol content was determined by the preparation of grain flour that will be used in extraction: the sample was extracted with ethanol according to Mohan and Rajinder [54] and the total polyphenol content was carried out using a modified method described by McDonald et al. [55].

### 2.5.3. Elemental Composition of Grain

Two grams of sample was weighed and burned at 550 °C. The ashes were dissolved with 100 mL 1 M HCl. Dissolved ash was analyzed for Fe and Mn contents according to Association of Official Agricultural Chemists, A.O.A.C. [50]. Perkin Elmer (Model 3300, Wellesley, MA, USA) Atomic Absorption Spectrophotometer was used to quantify the contents of these minerals. Nitrogen (N) of the dried material was determined by using the modified-Micro-Kjeldahl method as described by Jones et al. [56]. Phosphorus (P) was determined spectrophotometrically and potassium was analyzed by flame photometer (Jenway, PFP, Jenway, Essex, UK) as described in Association of Official Agricultural Chemists, A.O.A.C. [50].

## 2.6. Statistical Analysis

Data were checked out for normal distribution in each trait by the Shapiro–Wilk method [57], using SPSS v. 17.0 [58] computer package. Additionally, data were tested for violations of assumptions underlying the combined analysis of variance by separately analyzing data of each season and then running combined analysis across the two seasons. Means were separated using LSD testing when significant difference was obtained [59] using MSTAT-C [60].

## 3. Results and Discussion

### 3.1. Agronomic Traits

There was no significant difference between the two years of the study and as a result data for the two years were pooled together. Significant differences among water regimes, Ca levels, and cultivars in agronomic traits were observed (Table 5). Water stress resulted in a significant decrease in the agronomic traits in different cultivars compared to the control. The foliar application of Ca (50 mg/L) significantly enhanced most agronomic traits in different cultivars compared to the control (zero Ca) under water stress conditions. Drought stress significantly reduced the yield and yield components of all cultivars. Foliar application of Ca was effective and improved the yield and its components such as ear length (cm), number of rows, number of grains row<sup>-1</sup>, ear weight plant<sup>-1</sup> (g), 100-grain weight (g) and grain yield per hectare (kg/ha). At the water regime of 75% of estimated evapotranspiration, grain yield decreased by 28, 28 and 35% for SC-P3444, Sammaz-35, and EVDT cultivars, respectively compared to the control. Under severe water stress (50% of estimated evapotranspiration), the grain yield significantly decreased by 51, 50, and 50% in SC-P3444, Sammaz-35, and EVDT cultivars, respectively, compared to the control (Table 5). At the control water regime, Ca foliar application significantly increased the grain yield of all tested cultivars. Grain yields of SC-P3444, Sammaz-35, and EVDT were increased by 5, 12, and 7%, respectively. At the water regime of 75% of estimated evapotranspiration, Ca foliar application increased grain yield by 16, 13, and 14% in SC-P3444, Sammaz-35, and EVDT cultivars, respectively. Under severe water stress (50% of estimated evapotranspiration), Ca foliar application significantly increased the grain yield of all cultivars. Grain yields of SC-P3444, Sammaz-35, and EVDT, were increased by 17, 16, and 13%, respectively.

**Table 5.** Agronomic characteristics of three maize cultivars at different levels of irrigation and foliar application of Ca.

Water Stress	Ca Levels (mg/L)	Cultivars	Ear Length (cm)	No. of Rows	No. of Grains/ Row	Ear Weight/Plant (g)	100-Grain Weight (g)	Grain Yield/ha (kg)
100% Irrigation	50	SC-P3444	19.2	14.0	36.5	171.4	33.5	8061
		Sammaz-35	17.0	14.0	37.0	159.2	33.6	7570
		EVDT	18.0	12.7	37.8	143.6	28.0	7191
	0	SC-P3444	15.8	14.0	34.0	148.1	31.1	7676
		Sammaz-35	17.5	14.7	30.5	129.8	28.6	6670
		EVDT	17.3	13.0	35.2	115.7	26.1	6718
75% Irrigation	50	SC-P3444	13.2	12.7	31.2	121.3	30.6	6588
		Sammaz-35	15.5	12.7	28.0	95.8	27.3	5518
		EVDT	15.7	12.3	27.3	88.1	25.5	5079
	0	SC-P3444	11.7	12.0	29.7	97.2	27.4	5518
		Sammaz-35	14.7	12.0	26.3	90.2	25.7	4779
		EVDT	16.3	13.3	24.8	73.8	24.9	4379
50% Irrigation	50	SC-P3444	15.0	12.0	22.2	63.6	23.7	4482
		Sammaz-35	15.7	12.0	20.8	58.7	23.2	4006
		EVDT	14.8	12.0	19.7	54.2	22.8	3882
	0	SC-P3444	16.5	11.7	21.5	56.5	23.2	3733
		Sammaz-35	16.8	11.3	20.7	52.2	22.0	3364
		EVDT	18.0	11.7	17.3	42.7	21.1	3391
LSD <i>p</i> = 0.05			1.69	1.40	3.11	15.64	1.78	439.3

Maize yield reduction has been commonly reported under water stress conditions [61,62]. Ear height, number of grains per row<sup>-1</sup>, and grain yield of maize have been adversely affected by drought stress [57]. Further, Anjum et al. [63] found a reduction in the number of grains per row, grains weight, and grain yield of maize when plants were exposed to drought at the tasseling stage. Results indicate that SC-P3444 cultivar treated with foliar Ca application achieved the highest ear length (19.2 cm), the greatest number per row (14.7), the highest ear weight plant<sup>-1</sup> (171.4 g), the highest 100-grain weight (33.5 g), and the highest grain yield ha<sup>-1</sup> (8061 kg) under the water regime of 100% of estimated evapotranspiration, followed by Sammaz-35 and EVDT cultivars (Table 5). The foliar fertilization of Ca (50 mg/L) was effective in enhancing maize yield. This effect might be due to the vital role of Ca in maintenance of turgor, enhancing photosynthesis and transpiration rate under water stress conditions [29,34,64]. Additionally, Ca is involved in signaling anti-drought responses [32]. Calcium participated in abscisic acid (ABA)-induced drought signal transduction which improved water use efficiency and confer drought tolerance [27,28]. In addition, Ca-sensing proteins have shown to up-regulate drought tolerance signaling events, whereas negative regulation of drought stress is also attributed to these proteins [65].

Results indicate that the foliar application of Ca increased the grain yield and its components under drought stress. Calcium foliar application likely increased intracellular Ca levels. Ca binding proteins that function as Ca sensors perceive the elevated Ca levels, which can lead to the activation of Ca dependent protein kinases. The activated kinases or phosphatases can phosphorylate or dephosphorylate specific transcription factors, thus regulating the expression levels of stress-responsive genes. The activated Ca sensors can also bind to cis-elements of major stress-responsive gene promoters or can interact with DNA binding proteins regulating these genes, resulting in their activation or suppression [66,67]. In this context, Marques et al. [68] reported a positive effect on maize production with the application of calcium silicate under water stress. Fan [33] concluded that Ca application at 10 mM achieved the highest maize yield under both normal and drought conditions while Naeem et al. [29,34] found an increase in maize yield with the foliar application of Ca (40 mg L<sup>-1</sup>). A continuous supply of Ca was required by plants for vigorous leaves and overall canopy development [69]. However, Al-Naggar et al. [70] stated that SC-P-3444 cultivar is characterized by the ability to stay green under water stress.

### 3.2. Yield Reductions and Drought Tolerance Index (DTI)

The maximum yield reduction due to water stress was observed in EVDT cultivar (70%) and Sammaz-35 (67%) under the water regime of 50% of estimated evapotranspiration. SC-P3444 was less affected (23%), followed by Sammaz-35 (28%), under the water regime of 75% of estimated evapotranspiration (Table 6). From an agronomic approach, the tolerant cultivar to water stress should have the highest mean yield and the lowest reduction in yield under stress compared to non-stress conditions [71]. Based on this approach, the best maize cultivars for tolerance to water stress were SC-P3444 followed by Sammaz-35 and EVDT cultivars under all conditions.

**Table 6.** Mean grain yield (kg ha<sup>-1</sup>), change (%) and drought tolerance index (DTI) for maize cultivars under water stress (data are combined across 2018 and 2019 seasons).

Cultivars	Mean			Change%		Drought Tolerance Index (DTI)	
	100% Irrigation	75% Irrigation	50% Irrigation	75% Irrigation	50% Irrigation	75% Irrigation	50% Irrigation
SC-P3444	7868	6053	4108	23	62	1.23 (T)	1.16 (T)
Sammaz-35	7120	5149	3685	28	67	0.94 (S)	0.94 (S)
EVDT	6955	4729	3636	32	70	0.85 (S)	0.91 (S)

Change% = [(100% – 75% or 50%)/100% Irrigation] × 100. T and S indicate tolerant and sensitive, respectively.

Drought tolerance index (DTI) is one of the most-used tools to assess drought tolerance potential of plants [38]. Drought tolerance index (DTI) ranged from 1.23 to 1.16 in SC-P3444 cultivar, 0.94 in Sammaz-35 cultivar, and 0.85 to 0.91 in EVDT cultivar under moderate and severe water stress conditions, respectively. Based on the drought tolerance index (DTI), only cultivar SC-P3444 proved tolerance (T) while cultivars Sammaz-35 and EVDT were sensitive (S).

Water stress during maize growth leads to a 15–20% decrease in yield [37]. However, Pandey et al. [72] found a reduction in maize yield ranging from 22.6 to 26.4% under water stress and this reduction was mainly attributed to a reduction in the number of grains and in grain weight. Cultivar SC-P3444, which was found to be stress tolerant, was characterized by having significantly higher grain yield/ha, higher ear weight/plant, and higher 100-grains weight. These results came in agreement with those reported by Al-Naggar et al. [73,74] and Atta et al. [75]. Further, Al-Naggar et al. [70] indicated that the highest DTI was recorded for SC-P3444 cultivar under water stress. Application of supplementary irrigation increases the yield of 2009 EVDT cultivar under water deficiency [76]. Further, Oluwaranti and Ajani [77] indicated that EVDT-W 2000 cultivar was less drought tolerant. Mubarik et al. [78] suggested that foliar spray of Ca delayed senescence and ameliorated the adverse effects of water stress in maize seedlings. The application of Ca reduces toxicity to reactive oxygen species by increasing the concentration of antioxidant enzymes in plant cells [79]. Additionally, external Ca supplementation helps plants to recover from stress [80].

### 3.3. Chemical Constituents of Grain

Significant differences among water regimes, Ca levels, and cultivars in chemical constituents of grain were observed (Table 7). Drought stress significantly decreased protein, ash, and total sugars. Crude fiber and fat contents were significantly increased under water stress, while little effect was recorded on carbohydrates and starch under drought stress. Application of Ca increased protein, ash, carbohydrates, starch, and total sugars. Sammaz-35 cultivar sprayed with Ca application had the highest protein content (4.95 and 4.89 g/100 g) under well water irrigation (100% of normal irrigation) and severe water irrigation (50% of estimated evapotranspiration). Sammaz-35 and SC-P3444 cultivars had a higher ash content (2.2 and 2.2 g/100 g, respectively). Cultivar SC-P3444 which was sprayed with Ca attained the highest crude fiber content (1.5 g/100 g) both under normal and drought stress. Cultivars EVDT and Sammaz-35 achieved higher carbohydrates content (90 g/100 g in both) and there was no significant difference between them under well water and moderate water stress with and without Ca application, respectively. SC-P3444 and Sammaz-35 cultivars achieved a higher starch content (85.1 and 84.9 g/100 g, respectively), and there was no significant difference between them under severe and moderate water stress without and with Ca application, respectively. EVDT and Sammaz-35 cultivars attained the highest total sugar content (1.8 and 1.7 g/100 g, respectively), and there was no significant difference between them under moderate water stress and well water. and SC-P3444 cultivar achieved a higher total phenols content (2025, 1932 and 1412 mg gallic acid/100 g, respectively), and there was a significant difference between them under well water, moderate, and severe water stresses, respectively.

In agreement with our findings, Barutcular et al. [19] found that drought significantly reduced starch and protein, while Balla et al. [20] reported that drought reduced grain starch and increased protein content in maize. Zhao et al. [81] indicated that protein components are sensitive under water stress during the grain filling stage of maize. Crude protein, oil content, and carbohydrate percentages were significantly decreased under 50% water regime [82]. Drought decreases the development of cells and tissues and nutrients uptake that causes many biochemical changes [83]. Drought may decrease photosynthetic rate, so declining the number of photo-assimilates leads to decreasing carbohydrates and protein in the grains [84,85]. Water stress reduced the kernel sugar, oil, protein, and moisture contents with a subsequent increase in the seed fiber and ash contents [86]. Moreover, the starch

content increased and the oil content decreased with decreasing irrigation [87]. In addition, Zhao et al. [81] reported that water deficit decreased the starch content while Lu et al. [88] showed that water deficit had no effect on the starch content of fresh waxy maize.

**Table 7.** Grain chemical contents (g/100 g) as affected by water regimes, calcium level, and cultivars.

Water Stress	Ca levels (mg/L)	Cultivars	Protein	Ash	Crude Fiber	Ether Extract	Carbohydrate	Starch	Total Sugar	Total Phenols *
100% Irrigation	50	SC-P3444	4.45	1.90	1.48	3.83	88.34	83.48	0.97	1319
		Sammaz-35	4.95	1.59	1.17	3.56	88.73	84.53	1.64	1127
		EVDT	4.32	1.44	1.06	3.12	90.06	84.91	1.29	797
	0	SC-P3444	4.24	1.68	1.01	3.38	89.69	83.72	0.64	2025
		Sammaz-35	4.44	1.40	1.02	7.13	86.01	82.61	1.73	837
		EVDT	4.38	1.36	1.34	3.97	88.95	83.79	1.14	692
75% Irrigation	50	SC-P3444	4.62	1.61	0.98	3.36	89.43	83.46	1.20	1842
		Sammaz-35	4.50	1.48	0.97	3.47	89.58	84.93	0.93	704
		EVDT	4.26	1.83	1.17	3.21	89.53	82.62	1.51	688
	0	SC-P3444	4.47	1.54	1.11	3.44	89.44	84.81	1.38	1932
		Sammaz-35	4.45	1.15	1.02	3.48	89.90	84.05	1.33	395
		EVDT	4.19	1.48	1.22	3.82	89.29	82.79	1.79	634
50% Irrigation	50	SC-P3444	4.69	2.16	1.54	3.95	87.66	83.34	1.31	1156
		Sammaz-35	4.89	2.23	1.27	6.96	84.65	81.44	1.21	469
		EVDT	4.46	1.90	1.36	4.08	88.20	83.51	1.43	698
	0	SC-P3444	4.68	1.62	0.91	3.20	89.59	85.41	1.42	1412
		Sammaz-35	4.76	1.84	1.25	4.07	88.08	84.56	1.59	627
		EVDT	4.02	1.82	1.33	3.31	89.52	82.43	1.19	592
LSD $p = 0.05$			0.16	0.14	0.18	0.12	2.30	1.21	0.15	30.28

\* Total phenols: (mg gallic acid/100 g).

### 3.4. Elemental Composition of Grain

Results indicate a significant difference among water regimes, Ca levels, and cultivars in grain ionic contents (Table 8). However, drought stress significantly reduced the grain N, P, K, and Fe contents as compared to control. However, Mn accumulation was not affected by drought stress. Foliar treatment of Ca significantly improved the ionic contents of grains in all cultivars under all water regimes, except for Mn (Table 8). Application of Ca increased macronutrient contents in grain, N (7.3, 10 and 13%), P (3, 35 and 20%), and K (5, 18 and 3%) of all cultivars under well water, moderate, and severe water stress, respectively. Increasing micronutrient contents in grain was observed with Fe (23, 68 and 65%) of SC-P3444, Sammaz-35, and EVDT cultivars under normal irrigation levels, 75%, and 50% of estimated evapotranspiration, respectively. The application of Ca on Sammaz-35 cultivar resulted in the highest content of N (835 mg/kg), P (4987 mg/kg) under 75% of estimated evapotranspiration. Further, the foliar application of Ca on EVDT cultivar resulted in the highest content of Fe (179 mg/kg) under all water regimes. Cultivar Sammaz-35 achieved the highest content of Mn (106 mg/kg) under the water regime of 50% and without Ca application. Cultivar SC-P3444 achieved the highest K content (3055 mg/100 g) with Ca application under all water regimes (Table 8).

Grain ionic contents decreased under drought compared to normal conditions, indicating the restriction of nutrient uptake under drought conditions because of the declined transpiration rate, reduced active transport and lowered membrane permeability [34]. Further, Aqaei et al. [9] reported that drought stress level led to a decrease in the concentrations of P, Ca, Fe, Mn and Si in maize grain. In addition, Naeem et al. [29] revealed that concentration of macro-nutrients (N, K, Ca) and micro-nutrients (Fe, Mn) in maize grains was improved by Ca application. Likewise, Ge et al. [89] indicated that severe water stress caused a significant increase in N, Ca, Mg, and Cu contents and a decrease in P and K contents in maize grain. Ali and Ashraf [86] indicated that drought stress significantly reduced the levels of all macro-minerals (K, Mg, P, N, and Ca) and micro-minerals (Mn, Cu, and Fe).

**Table 8.** Ion contents (N, P, K, Mn, and Fe mg/kg) as affected by water regimes, calcium level and maize cultivars.

Water Stress	Ca Levels (mg/L)	Cultivars	N *	P	K	Mn	Fe
100% Irrigation	50	SC-P3444	740	3506	3055	62.1	37.9
		Sammaz-35	850	3420	2570	59.8	31.5
		EVDT	752	3066	2446	62.9	79.5
	0	SC-P3444	730	3082	2904	46.8	27.6
		Sammaz-35	729	3164	2287	71.5	25.2
		EVDT	725	3404	2490	84.5	68.7
75% Irrigation	50	SC-P3444	787	3234	2605	48.8	33.1
		Sammaz-35	853	4988	2946	44.6	60.6
		EVDT	838	3980	2478	90.5	178.9
	0	SC-P3444	705	3229	2480	46.3	28.5
		Sammaz-35	745	2819	2187	101.4	54.3
		EVDT	798	2969	2138	60.3	79.1
50% Irrigation	50	SC-P3444	832	4306	2985	76.5	32.1
		Sammaz-35	851	4750	3020	100.6	64.8
		EVDT	853	4362	2366	89.4	96.8
	0	SC-P3444	791	3249	2500	54.8	22.0
		Sammaz-35	805	4132	2696	105.9	44.0
		EVDT	647	3782	2923	71.1	51.3
LSD $p = 0.05$			27	205	221	5.9	6.7

\* N: mg/100 g.

#### 4. Conclusions

Calcium foliar application (50 mg/L) significantly increased maize yield, grain protein, ash, carbohydrates, starch, total sugars, and ionic contents of grains under normal and water stress conditions. The present study concludes that Ca has a diverse impact on productivity and grain quality with important implications for maize yield under normal and water stress conditions.

Our findings demonstrate that foliar application of Ca enabled drought-stressed maize plants to survive better. The highest drought tolerant cultivar was SC-P3444 followed by Sammaz-35 and EVDT. The cultivar SC-P3444 had the highest yield under drought stress and could be a better choice for use as a parent in future breeding efforts to enhance drought tolerance in maize. More efforts are required to investigate the linkage analysis between yield, grain quality and genetic variation in maize cultivars that can tolerate drought stress.

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