The Role of Quinabactin in Improving Physiological and Yield Traits of Maize under Deficit Irrigation Conditions

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Abstract

In spring 2025, an outdoor study was to be carried out at the Al-Mahnawiya Extension Farm, Babylon, Iraq, and the aim of the study was to determine the impact of foliar quinabactin (QNB) application on the physiological and yielding properties of maize that had been exposed to different levels of water deficit. The study was conducted using a split-plot study in a randomized complete block trial with three replications: three levels of water depletion (50, 65 and 80 %) were researched and four concentrations of QNB (0, 20, 40, and 60 µmol L^{-1}). Findings of the study showed that a 50 % reduction level had the best growth and yield variables to give the highest plant height, leaf area, and grain production, and a 65 % deficit on irrigation water-use efficiency (IWUE). The concentration of 40 µmol $L^{-1}$of the QNB treatments improved most of the observed traits such as the chlorophyll content, grains per row, 500 -grain weight, and total grain yield; nevertheless, an increase in concentration to 60 µmol L^{-1} led to a significant decrease in the performance of the plant. Strong interaction was noted in extreme water stress conditions (80 % depletion) in which treatment of 40 µmol L^{-1}increased grain yield more than four-fold compared to the untreated control. These findings lend credence to the fact that foliar application of 40 µmol $L^{-1}$of QNB is a high-performing strategy of alleviating drought stress and improving the efficiency of water-use in maize production in water-limiting conditions.

Keywords: Quinabactin; Deficit irrigation; Abiotic stress tolerance; Water use efficiency; *Zea mays* L.

Introduction

The phytohormone that abscisic acid (ABA) regulates has developed is the dominant adaptive mechanism in vegetation [3,4]. ABA opens stomata and triggers stress-responsive genes by a complicated signaling pathway that incorporates PYR/PYL/RCAR receptors, PP2C phosphatases, and SnRK2 kinases [5,6]. Due to its key action on drought resistance, synthetic ABA receptors like quinabactin have become promising to be used as chemical interventions to either supplement natural defense systems and amplify plant functioning under dehydrating environments [7,8].

Maize (Zea mays L.) is a pillar of food security, as it serves as a key source of human nutrition, livestock food, and industrial food [1]. Maize has a high genetic plasticity, but it has a dire water limiting factor, particularly in arid and semi-arid areas. Water deficit at critical points of development like anthesis and grain filling disturbs the normal physiological pathways and results in an extended anthesis-silking interval (ASI), decreased kernel set and compromised translocation of dry-matter, resulting in secondary effects of lower end yield of grain [2].

association with different water stress levels only done on a field basis. This paper was therefore an attempt to examine the effects of various concentration levels of quinabactin on physiological and yield of Maize to three varying water stress conditions, with the aim of establishing an ideal quinabactin concentration level that caused reduction in the losses encountered due to drought, and enhanced water productivity.

Materials and Methods

A field experiment was conducted during the spring growing season of 2025 at the Extension Farm in Al-Mahnawiya, affiliated with the Agricultural Extension and Training Center, Babylon Province, Iraq. The experimental site is located at 32°36′41″ N latitude and 44°18′00″ E longitude (Figure 1).

The effectiveness of these chemical interventions is generally determined by a set of metrics of morpho-physiological and yield type. The major ones are plant height and leaf area, which are based on vegetative vigor and maintenance of turgor [9,10], relative water content (RWC) and stability of chlorophyll, which are crucial proxies of water status in plants and photosynthetic capacity [11,12]. In addition, both yield component analysis and irrigation water use efficiency (IWUE) constitute an analytical measure of the translation of such treatments to economic productivity per unit of water utilised [13].

Even though the ABA signalling pathways are thoroughly described on a molecular level, there is still limited evidence on the dose response of quinabactin in maize in

Figure 1. Location of maize field experiment, Al-Mahnaweya, Babylon.

Land Preparation, Sowing, and Crop Management

distribution of irrigation water among the experimental units. They were further split up into plots as mandated by experimental design put in place and adequate area between this experimental design plots and replications was provided so that there could be no cross-

Two consecutive perpendicular ploughings with a moldboard plough were performed in the field followed by harrowing with a disk harrow. This was done to achieve a uniformly smooth surface; thus providing the same initial conditions of the trial and also a constant

Four concentrations of quinabactin were applied as foliar sprays: 0 (control), 20, 40, and 60 µmol L^{-1}, following the experimental spraying schedule.

A buffer distance of 2 m was maintained between replications and between main plots to minimize lateral water movement and prevent interference among irrigation treatments.

Irrigation Management and Soil Moisture Determination

Irrigation Method and Water Measurement

Irrigation was pumped through a network created by pipelines which were connected to a pumping unit and a calibrated volumetric meter was connected to the main supply conduit to measure the amount of aliquot water applied to each treatment plot. The establishment irrigation regime was modified to be standardized and aimed at achieving field capacity before initiating the deficit irrigation treatments which were implemented according to the established depletion cadence.

Soil Moisture Monitoring

Gravimetric method was used to measure the content of soil moisture. Sampling of effective root zone Periodically, soil samples were collected and dried to constant mass in the oven and percentage of soil moisture was determined as:

Gravimetric soil moisture (%) =(Fresh weight − Dry weight) / Dry weight × 100

interference of irrigation or foliar treatment.

Zea mays L. seeds were sown on 17M March 2025. The size of each experimental unit was 3.5 x 2.5 x 8.75 m (8.75 m^2) and the distance between rows and the distance between rows were 75 x cm. The result of this layout was a rough planting density of 533333 plants ha^{-1}. All plots got uniform agronomic practices such as hoeing, weed control, and irrigation to counter the effects of confounding factors due to non-experimental factors. The crop was harvested (physiologically) and on 1 July 2025, the yield and yield components were measured following the procedures mentioned below.

Experimental Design and Treatments

The experiment was arranged in a randomized complete block design (RCBD) with a split-plot layout and three replications.

Main plots (deficit irrigation treatments):

1. Irrigation at 50% depletion of available water (control treatment).
2. Irrigation at 65% depletion of available water (moderate water stress).
3. Irrigation at 80% depletion of available water (severe water stress).

Subplots (quinabactin concentrations):

Studied Traits

using a measuring tape, and the average was calculated.

1. **Plant height (cm):** Measured at 100% anthesis from the soil surface to the uppermost node

Statistical Analysis

GenStat statistical software was then used to analyse the data in terms of an analysis of variance (ANOVA) that is desirable to a randomized complete block design, where the arrangement is split-plot in nature. An experiment was done to compare the mean treatment at the probability level at 0.05 and the least significant difference test (LSD) was used to determine the significant difference as per the conditions of the experiment[19].

Results and Discussion

1. Plant Height (cm)

Table 1 results showed that there were significant effects of water-stress levels, quinabactin concentrations and their interaction on plant height. Due to incremental increase in water shortage, there was a significantly low plant height. The highest mean plant height (195.65 cm) was recorded at an irrigation of 50 per cent depletion of available water (FC50), with significantly lower and statistically equivalent means of 179.05 and 176.38 cm, respectively in the FC65 and FC80. Reduction in plant height due to water deficiency can be explained by decrease in the cell turgor pressure, constriction of cell elongation in apical meristems and decrease in cell division because of the constraint in carbohydrate transport and hormonal homeostasis. These processes are well reported as the main reasons of inhibited vegetative growth in cases of drought [9].

Considering quinabactin application, there was a high difference between concentrations. The overall mean plant height (210.13□cm) was the highest in the untreated control (0 µmol L^{-1}), with 20 µmol L^{-1} (197.50 2L 1) coming second. There was a drastic drop at 40

2. **Leaf area (cm^2):** Determined from five representative plants using the equation: Leaf length below the $ear^2 \times 0.75$.[14]

3. **Number of kernel rows per ear (row ear^{-1}):** Counted manually from representative ears per plot and averaged.

4. **Number of kernels per row (kernel row^{-1}):** Determined by manually counting kernels from a representative row on selected ears and calculating the mean.

5. **500-kernel weight (g):** A random sample of 500 kernels was taken from selected ears and weighed using an electronic balance after adjusting grain moisture content to 15.5% [15].

6. **Grain yield (t ha^{-1}):** Calculated based on the mean grain yield per plant (five plants) multiplied by plant density per hectare.

7. **Irrigation water use efficiency (kg m^{-3}):** Calculated as: Water use efficiency = Grain yield (kg ha^{-1}) / Total irrigation water applied (m^3 ha^{-1})[16].

8. **Total chlorophyll content (SPAD units):** Measured using a SPAD-502 chlorophyll meter (Minolta, Japan) by taking three readings from three leaves per plant and averaging five plants per plot.[17]

9. **Relative water content (RWC, %):** Determined using leaf discs collected from the third fully expanded leaf from the top. Fresh weight, turgid weight, and dry weight were recorded, and RWC was calculated according to standard procedures[18].

(Table□1) which implies that the response to quinabactin is sensitive to the level of water stress. The plant height decrease was more intense at μmol L^{-1} in the moderate (FC65) and severe stress (FC80) levels of stress than the well-watered treatment (FC50). This effect can be indicative of an increased sensitivity of hormones during water-restricted conditions, in which stimulation of the ABA signalling pathway, and, especially, inhibition of PP2C phosphatases, aggravates growth-restrictive pathways. In this case, the enhanced growth inhibitory effect of endogenous drought-based ABA accumulation and exogenous quinabactin application is likely to increase compared with non-stressed plants[12]. and μmol L^{-1}, and the plant height dropped to 180.17 and 146.97 cm, respectively. This tendency indicates that even though quinabactin increases the drought tolerance by promoting the abscisic acid (ABA) signalling pathway, it accompanies the inhibited longitudinal vegetative growth, especially at a high concentration. This type of inhibition of growth is consistent with the physiological function of ABA-regulated signalling that redirects plant resources towards stress survival and conservation of vital metabolic processes as opposed to vegetative growth[20].

It was also found that a great interaction between irrigation regime and quinabactin concentration was present

Table (1): Effect of water stress and Quinabactin on plant height (PH) (cm)

Water Depletion Levels	**Quinabactin Concentrations (μmol L^{-1})**				**Stress Mean**
	0	**20**	**40**	**60**	
FC50	214.20	201.60	202.80	164.00	**195.65^{a}**
FC65	217.70	205.90	165.70	126.90	**179.05^{b}**
FC80	198.50	185.00	172.00	150.00	**176.38^{b}**
Quinabactin Mean	**210.13^{a}**	**197.50^{b}**	**180.17^{c}**	**146.97^{d}**	**183.69**
LSD (0.05): Stress = 8.58, Concentration = 7.07, Interaction = 12.31					

2. Leaf Area per Plant (cm^2)

The data contained in Table 2 showed that water deficit levels, quinabactin concentrations, and their combination had a significant impact on the leaf area per plant. With the increase in the intensity of water stress, a serious decline in the leaf area occurred. The mean leaf area was highest in FC50 (4304.50 cm^2) then FC65 (3827.25 cm^2) and FC80 (2500.00 cm^2) had the lowest mean leaf area. The reduction in the leaf area during a water deficit could be explained by the slowed cell expansion, lessening of new leaf development and early senescence of older leaf. Also, the decrease in assimilatory surface area is an adaptive process intended to decrease the amount of transpirational water loss. Leaf area has been long considered to be one of the most drought-sensitive characteristics because of its direct relationship with water balance of the plant and energy relationships of the canopy[21].

The irrigation regime-quinabactin level interaction was also important (Table 2), which meant that plant reaction to quinabactin was dependent on the degree of stress. The beneficial impact of 40 µmol L⁻ ¹ was the strongest in the case of moderate stress (FC65), and the leaf area under such stress was kept on comparatively high rates in contrast to the untreated control. Conversely, the positive impact of quinabactin was relatively small in case of extreme stress (FC80). This effect could be provided by the fact that extreme water shortage causes structural and physiological limits of leaf expansion exceeding the compensatory proficiency of hormonally mediated stress signalling even in situations where the ABA-related pathways are optimized[23].

With respect to quinabactin use, there were major differences in the concentrations. The overall mean area of the leaf (4799.33cm^2) was the greatest in the 40 µmol L⁻ ¹ compared to all other concentrations. The second highest ranking treatment (4163.67 cm^2 of treatment) was the 20 µmol L⁻ ¹ treatment, and the lowest values were 2475.33 cm^{2}control and 2737.33 cm^{2}treatment. This trend suggests that foliar application at 40 µmol L⁻ ¹ was able to help it sustain the expansion of leaves through deficit irrigation conditions. Nevertheless, the further increase in concentration (to 60 µmol L⁻ ¹) did not lead to the further increase and was correlated to the significant decrease in the leaf area. This reaction indicates that photosynthetic capacity maintenance and water loss reduction determine leaf growth control, and a balance between the two seems to be optimised at intermediate concentrations of ABA activation pathways and not when these are highly active[22].

Table (2): Effect of water stress and Quinabactin on leaf area per plant (LA) (cm²)

Water Depletion Levels	Quinabactin Concentrations (µmol L⁻ ¹)				Stress Mean
	0	20	40	60	
FC50	2703.00	5278.00	5547.00	3690.00	4304.50^a
FC65	2623.00	4413.00	5351.00	2922.00	3827.25^b
FC80	2100.00	2800.00	3500.00	1600.00	2500.00^c
Quinabactin Mean	2475.33^c	4163.67^b	4799.33^a	2737.33^c	3543.92
LSD (0.05): Stress = 227.50, Concentration = 348.00, Interaction = 544.10					

very high. FC50 treatment gave the largest mean (17.94 rows^{-1}), FC65 and FC80 gave slightly but significantly lower means of 17.69 and 17.64 rows^{-1}, respectively, but it was found that there is no significant difference between FC65 and FC80. The reduction of the kernel rows with water deficit may be explained by the fact that the trait is established at initial stages of ear

3. Number of Kernel Rows per Ear (row ear⁻ ¹)

The outcomes in Table 3 showed that there were substantial impacts of the levels of water deficit, quinabactin concentrations, and their respective interaction on the number of kernel rows per ear. The effect of water stress on kernel row count was excessive activation of ABA signaling pathway due to the high concentration (60 µmol L^{-1}), which might have increased the restraint of growth and negatively impacted reproductive growth[25].

The correlation between quinabactin concentration and irrigation regime also played an important role (Table^{-} 3) meaning that the response of quinabactin to the severity of stress was different. The 20 and 40 µmol L^{-1} treatment were more superior when using a mild and moderate stress (FC50 and FC65), but the effect was less pronounced when using severe stress (FC80). This finding indicates that in the extreme cases where water is scarce, affecting the physiological limitations of reproductive development limits the ability of the plant to take full advantage of the hormonally mediated stress-reduction ability. Structural and metabolic limitations in such cases can supersede the beneficial action of quinabactin on ear development[26].

initiation and differentiation which is very sensitive to the water conditions in plants, photosynthetic activity, and carbohydrate levels of a plant. Drought at these sensitive development stages can negatively affect meristematic tissue differentiation of the growing ear, and this will lower the amount of kernel rows[24].

In the case of quinabactin application, there arose substantial variations among concentrations. At 20 and 40 µmol L^{-1} of treatment, performances were better, and the performance was 18.43 and 18.34 rows ear^{-1}, respectively, which is very high in comparison to the untreated control (17.32 rows ear^{-1}). On the other hand, the highest mean (16.94 rows ear^{-1}) was obtained after 60 µmol L^{-1}. The results suggest that moderate levels of quinabactin will help to preserve or increase the formation of kernel rows in the conditions of deficit irrigation, which is probably due to the enhanced preservation of the plant water status and photosynthetic efficiency during ear differentiation. It could have caused the

Table (3): Effect of water stress and Quinabactin on number of rows per ear (rows ear^{-1})

Water Depletion Levels	Quinabactin Concentrations (µmol L^{-1})				Stress Mean
	0	20	40	60	
FC50	17.18	18.74	18.63	17.23	**17.94^{a}**
FC65	17.95	18.13	18.16	16.52	**17.69^{b}**
FC80	16.82	18.44	18.22	17.08	**17.64^{b}**
Quinabactin Mean	**17.32^{b}**	**18.43^{a}**	**18.34^{a}**	**16.94^{c}**	17.76
LSD (0.05): Stress = 0.15, Concentration =0.34, Interaction = 0.52					

4. Number of Kernels per Row (kernel row^{-1})

row^{-1}). This trend is a clear indication that 40 µmol L^{-1} foliar application was the most effective in improving the set of the kernel and reducing losses in reproductive processes. The excellence of the level of this concentration might be explained by the possibility to optimize physiological activities, especially maintenance of plant water condition and availability of assimilates, without causing significant growth retardation. On the other hand, increased concentrations could have increased ABA-mediated growth restraint or hormonal imbalance and negated any possible positive effects[28].

Another notable interaction was found between quinabactin concentration and irrigation regime (Table 4), which means that quinabactin depended on the severity of stress. It is worth noting that the positive impact of 40 µmol L^{-1} was most evident in harsh conditions (FC80) whereby the number of kernels per row rose tremendously, which was 20.27 kernels in the untreated control to 72.81 kernels with foliar application. This remarkable enhancement underscores the ability of the most appropriate concentration of quinabactin to alleviate the effect of reproductive failure even in severe conditions of droughts. When plants are subjected to extreme stress, they are increasingly dependent on effective hormonal signaling cascades; thus, further strengthening of the ABA-SnRK2 signaling pathway can have a stronger protective impact than when the plants are under mild stress conditions[29].

The findings in Table 4 have shown considerable impacts of water deficit levels, quinabactin concentrations, as well as the interaction of water deficit levels and quinabactin concentrations on the number of kernels per row. The development of water stress intensity led to a severe and serious decrease in the number of kernels per row. FC50 treatment had the highest mean (64.65 kernels row^{-1}), then FC65 (56.28 kernels row^{-1}) and FC80 had the lowest mean (41.99 kernels row^{-1}). The extreme reduction in the presence of severe water deficit can be explained by the fact that the number of kernels per row is mainly established during the flowering and the initial grain set, which are the most drought-sensitive maize developmental stages. Water scarcity at these phases interferes with emergence of silk and pollination, high rates of floral and young kernel abortion and lower levels of carbohydrates to the growing reproductive organs because of hampered photosynthesis and hormonal system distortion. In turn, the kernel number is commonly referred to as one of the strongest yield elements that are correlated with drought severity in maize[27].

Regarding the use of quinabactin, the differences between the concentrations were very high. The overall mean of 40 µmol L^{-1} treatment (74.89 kernels row^{-1}) was significantly greater in comparison to the other concentrations. Conversely, the lowest values were obtained with the untreated control (0 µmol L^{-1}) and treatment 60 µmol L^{-1} (40.58 and 41.44 kernels row^{-1}, respectively), and an intermediate mean was obtained with 20 µmol L^{-1} (60.31 kernels

Table (4): Effect of water stress and Quinabactin on number of grains per row (grains row^{-1})

Water Depletion Levels	**Quinabactin Concentrations (µmol L^{-1})**				**Stress Mean**
	0	**20**	**40**	**60**	
FC50	64.56	75.91	80.27	37.86	64.65^{a}
FC65	36.91	62.65	71.59	53.95	56.28^{b}
FC80	20.27	42.37	72.81	32.50	41.99^{c}
Quinabactin Mean	40.58^{c}	60.31^{b}	74.89^{a}	41.44^{c}	54.31
LSD (0.05): Stress = 6.58, Concentration =4.24, Interaction = 8.09					

5. 500-Kernel Weight (g)

The results of the analysis in Table 5 show that there are strong major effects of water deficit, quinabactin concentration, and their interaction on the weight of 500 kernels .

The intensity of water-stress increased, which decreased the weight of 500-kernel significantly. FC50 treatment produced the best mean (74.25g) and the next treatment was FC65 (70.00g) and the last treatment was FC80 (62.75g). This is caused by the lack of water during the grain-filling phase that curtails photosynthetic rates, decreases translocation of assimilates to growing kernels, increases the rate of leaf senescence and subsequently shortens the period of effective grain-filling; all of which directly reduce the mass of the individual kernels. This is a classical response to drought, which causes a reduction in the grain weight of maize [30].

Regarding quinabactin, differences between concentrations were found to be statistically significant. The highest mean 500 71.67 2L treatment resulted in the 40 µmol L^{-1} treatment, which was significantly higher than the others. Conversely, there was no statistically significant difference in the 0, 20, and 60 µmol L^{-1} treatments with means of 67.67, 68.67, and 68.00g, respectively. These findings suggest that foliar application at 40 µmol L^{-1} optimized grain -filling efficiency, but the same could not be said of the other doses. The excellence of 40 µmol L^{-1} is likely to denote optimal physiological states during grain filling, preventive undue development retardation or metabolic disequilibrium [31].

Quinabactin also showed major interaction with water deficit. The beneficial action of 40mmol/L -1 was even more marked in the presence of severe stress (FC80) whereby the weight of 500kernels in the untreated control (60.00g) went up to 68.00g. This efficiency highlights the increased utility of quinabactin in optimizing water-use efficiency and allocate assimilate under water-limiting extreme conditions[32].

Table (5): Effect of water stress and Quinabactin on 500-grain weight (GW500) (g)

Water Depletion Levels	Quinabactin Concentrations (µmol L^{-1})				Stress Mean
	0	20	40	60	
FC50	74.00	74.00	75.00	74.00	**74.25^{a}**
FC65	69.00	70.00	72.00	69.00	**70.00^{b}**
FC80	60.00	62.00	68.00	61.00	**62.75^{c}**
Quinabactin Mean	**67.67^{b}**	**68.67^{b}**	**71.67^{a}**	**68.00^{b}**	69.00
LSD (0.05): Stress = 1.95, Concentration =1.42, Interaction = 2.58					

6. Grain Yield (t ha^{-1})

Table 6 gives results that show that the water deficit, quinabactin concentration and water deficit and quinabactin concentration have substantial effects on yields of grains and e.g. their interaction. The level of water stress intensity was positively linked with a heavy decrease in the grain yield as it increased progressively. FC50 treatment achieved the maximum mean grain output (7.63 t. ha^{-1}) and the other two treatments (FC65, and FC80) had lesser outputs (6.68 t. ha^{-1} and 2.91 t. ha^{-1}). This extreme degradation may be described by the accruing effects of water stress on the crucial development phases, i.e. flowering, kernel set, and grain filling. Water shortage at these stages increased the anthesis silking interval (ASI), and reduced the number of rows of kernels and weight—dimensions that were negatively impacted in extreme stress in the current study[28].

Application of quinabactin showed a significant enhancement in grain yield with the highest mean yield of 7.06 t. ha^{-1} obtained in quinabactin application of 40 µmol L^{-1}compared to 0 and 60 µmol L^{-1}which recorded the lowest yields of 5.10 and 5.00 t. ha^{-1}, respectively. An intermediate yield (5.80 20 t. ha^{-1}) was obtained. It means that the 40 moles per liter per liter was the strongest to transform the physiological gains into the actual gain in yield, with subsequent doses being ineffective to boost the yield, which could be explained by overstimulation of the ABA signaling or metabolic imbalance [12].

Water deficit had a significant interaction with quinabactin. The positive influence of 40 µmol L^{-1} was the most pronounced under extreme stress (FC80), as the grain yield started at 2.00 t. ha^{-1}in the unstimulated control, and the yield under treatment was 4.74 t. ha^{-1}, proving that this concentration can overcome the negative impact of drought on the grain yield. Stressed plants are more dependent on effective hormonal and physiological mechanisms, and therefore, the ABA-SnRK2 signaling can be improved in a highly effective manner [26].

Table (6): Effect of water stress and Quinabactin on grain yield (GY) (t ha⁻ ¹)

Water Depletion Levels	**Quinabactin Concentrations (µmol L⁻ ¹)**				**Stress Mean**
	0	**20**	**40**	**60**	
FC50	7.40	7.90	8.52	6.70	**74.25^{a}**
FC65	5.90	6.80	7.92	6.10	**70.00^{b}**
FC80	2.00	2.70	4.74	2.20	**62.75^{c}**
Quinabactin Mean	5.10^{c}	5.80^{b}	7.06^{a}	5.00^{c}	69.00
LSD (0.05): Stress = 0.57, Concentration =0.58, Interaction = 2.58					

7. Irrigation Water Use Efficiency (IWUE) (kg m⁻ ³)

Quinabactin application led to statistically significant improvement of IWUE. The highest average IWUE was 1.66 kg m^{-3}, which occurred at the concentration of 40 µmol L⁻ ¹, with the undosed (0 µmol L⁻ ¹) and the 60 µmol L⁻ ¹ treatment giving the lowest results (1.14 -1 and 1.32 kg m^{-3}). This was accomplished with the dose that optimized water-use efficiency without causing too much stomatal closure or metabolic dysfunction, thus maintaining growth and photosynthetic potential [34].

The association between irrigation treatment and foliar quinabactin application was high with the associating of FC65 and 40 µmol L⁻ ¹ at a maximum of IWUE of 2.01 kg.m^{-3}. Foliar quinabactin application enhanced IWUE in comparison to the control at severe stress level (FC80); nevertheless, the physiological limitations caused by the high water deficit were not completely compensated [29].

As shown in Table 7, water deficit, quinabactin, and their interaction significantly affected IWUE.

The highest instantaneous water-use efficiency (IWUE) of 1.69 kg m^{-3} was recorded with the FC65 (moderate irrigation deficit) which was statistically superior to the IWUE values of FC50 (1.37 kg m^{-3}) and FC80 (0.88 kg m^{-3}). It is also known that moderate water-addition limitation will effectively increase water-use-efficiency by reducing non-productive transpiration without adversely affecting photosynthetic performance, kernel establishment, and grain filling. Conversely, extreme irrigation deficit triggers a strong reduction in yield, which cannot be compensated by lowering irrigation, thus lowering aggregate IWUE. These findings support the current physiological paradigm according to which maximum IWUE is achieved when the irrigation is moderate, and not total or severe drought [33].

Table (7): Effect of water stress and Quinabactin on irrigation water use efficiency (IWUE) (kg m^{-3})

Water Depletion Levels	Quinabactin Concentrations ($\mu mol\ L^{-1}$)				Stress Mean
	0	20	40	60	
FC50	1.33	1.42	1.54	1.21	1.37^{b}
FC65	1.49	1.72	2.01	1.54	1.69^{a}
FC80	0.61	0.82	1.44	0.67	0.88^{c}
Quinabactin Mean	1.14^{c}	1.32^{b}	1.66^{a}	1.14^{c}	1.32
LSD (0.05): Stress = 0.10, Concentration =0.06, Interaction = 0.12					

8. Relative Water Content (RWC) (%)

resulted in these significant values of 87.93% and 85.71 %respectively. Middle doses therefore alleviated the water status of leaves but excessive doses (60 μmolL^{-1}) can disequilibrate metabolism or cause further physiological stress [35].

The effect of interaction was also observed: the beneficial effect of 20 μmolL^{-1} was the greatest at moderate stress (FC -85, RWC - 91.55%), but not so noticeable at severe stress (FC -80) as the hormonal compensation to extreme drought was limited [25].

Table 8 shows significant effects of water deficit, quinabactin, and their interaction on leaf RWC.

The stress caused a significant reduction in the root water content, and it was found that the water content was 91.71% at FC 50, 86.19% at FC 65, and 73.53% at FC 80. This decrease has been explained by lower water level in the soil, a decrease in cell turgor, and a decrease in leaf water content, which makes RWC a perceptive indicator of cellular water stress [11].

The application of quinabactin by foliar with the concentration of 20 and 40 μmolL^{-1}

Table (8): Effect of water stress and Quinabactin on leaf relative water content (RWC) (%)

Water Depletion Levels	Quinabactin Concentrations (µmol L^{-1})				Stress Mean
	0	20	40	60	
FC50	92.93	92.68	89.82	91.41	91.71^{a}
FC65	80.01	91.55	87.04	86.16	86.19^{b}
FC80	69.57	79.55	80.27	64.73	73.53^{c}
Quinabactin Mean	80.84^{b}	87.93^{a}	85.71^{a}	80.77^{b}	83.81
LSD (0.05): Stress = 3.41, Concentration =3.41, Interaction = 5.66					

9.Total Chlorophyll Content (Chl, SPAD):

Table 9 shows that water stress, quinabactin, and water stress-quinabactin have the statistically significant impact on total chlorophyll content in terms of SPAD unit .

Water deficit lead to statistically significant decrease in the value of chlorophyll with FC50 treatment having the highest mean value (40.60 SPAD units), then FC65 (37.00 SPAD units) and FC80 being the lowest (33.60 SPAD units). This decrease can be explained by the fact that the water-stress-induced perturbation of the chloroplast structure, which triggers chlorophyll degradation and chlorophyll biosynthesis inhibition through the lowered nutrient uptake level and activity of enzymes enable the decrease in photosynthetic efficiency during drought conditions [12].

Application of quinabactin of 40 µmol L^{-1} concentration showed a significant increase in chlorophyll content of 40.17 SPAD units, which is higher when compared to an increased concentration (60 µmol L^{-1}).The observation suggests that moderate quinabactin doses are optimal to regulate physiologically and control photosynthesis, but supraphysiological doses have secondary stress potential or disbalance [35].

The interactions analysis also indicated that the positive influence of quinabactin was more intense when plants suffered moderate (FC65) and severe (FC80) drought stress, and the level of chlorophyll of treated plants was much higher than those of the untreated plants, whereas the moderate drought stress (FC50) revealed the absence of a definite outcome [36].

Table (9): Effect of water stress and Quinabactin on total chlorophyll content (Chl) (SPAD unit)

Water Depletion Levels	Quinabactin Concentrations (µmol L⁻ ¹)				Stress Mean
	0	**20**	**40**	**60**	
FC50	40.00	40.60	41.50	40.30	40.60^{a}
FC65	35.00	37.00	40.00	36.00	37.00^{b}
FC80	30.00	33.60	39.00	31.80	33.60^{c}
Quinabactin Mean	35.00^{c}	37.07^{b}	40.17^{a}	36.03^{c}	37.07
LSD (0.05): Stress = 1.33, Concentration =1.58, Interaction = 2.54					

Conclusions:

Foliar spraying of quinabactin at 40 µM level was able to increase maize resistance to water deficit with the maximum effect recorded in cases of severe stress. It is interesting to note that the dose produced important enhancements in grain production and irrigation water-use efficiency. In all the observed characteristics, the 40O -3 treatment was significantly better than other doses, and treatment with 60O -3 causes a significant decrease, which indicates that there is an optimal level of concentration. Additional experimental research in various environmental settings, and in seasonal settings is therefore justified especially on the concentration ranges that are close to 40 uM. The work of analysis of the underlying molecular mechanisms, an assessment of the economic feasibility, and combination of quinabactin use and overall crop management practices should also be included in the future research.

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