sustainability

Article

The Potential Effects of Kinetin Implementation on Hybrid Rice Seed Production under Water Deficit

Hassan Sh. Hamad [1], Eman M. Bleih [1], Elsayed E. Gewaily [1], Khadiga Alharbi [2] and Medhat Rehan [3,4,*]

1 Rice Research and Training Department, Field Crops Research Institute, Agricultural Research Center, Kafrelsheikh 33717, Egypt
2 Department of Biology, College of Science, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia
3 Department of Plant Production and Protection, College of Agriculture and Veterinary Medicine, Qassim University, Buraydah 51452, Saudi Arabia
4 Department of Genetics, Faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh 33516, Egypt
* Correspondence: m.rehan@qu.edu.sa or medhat.rehan@agr.kfs.edu.eg

Abstract: Drought is one of the main abiotic stresses responsible for reducing crop yields worldwide. In hybrid rice production, cytoplasmic male sterility (CMS) displays an alternative plan for producing high-yielding hybrid rice depending on the hybrid vigor. Kinetin (Kin) has an essential role during the early phase of grain setting by regulating cell division, assimilate flow, and osmotic modification under water deficit. Growth, floral, and yield-related traits were evaluated in two CMS lines under five irrigation intervals and two concentrations of the phytohormone kinetin. Our study was conducted to explore the effects of irrigation intervals (continuous flooding (CF), irrigation every six (I_6), nine (I_9), twelve (I_{12}), and fifteen (I_{15}) days, and kinetin exogenously applied (control, 15 mg L^{-1}, and 30 mg L^{-1}) on growth, floral, and yield-related traits. Growth traits (i.e., number of leaves (NOL), days to complete leaf number (DCLN), days to heading (DTH, 50%), flag leaf area (FLA), and plant height (PH)), floral traits (i.e., duration of spikelet opening (DSO), panicle length (PL), spikelet opening angle (SOA), and panicle exertion (PE)), and seed yield traits (i.e., seed set (SS), panicle weight (PW), seed yield (SY), harvest index (HI), and number of fertile panicles per hill (NFP)) in two CMS lines. Implementation of kinetin displayed the highest significant and positive values for all growth, floral, and yield-related traits when compared to the control (average of applied irrigation intervals). Applying 30 mg L^{-1} kinetin positively enhanced the growth traits (i.e., NOL, FLA, and PH with 4.1%, 5%, and 3%, respectively), floral traits (i.e., PL, PE, SOA, and DSO with 5.4, 5.7, 5.9, and 5.4%, respectively), and yield-related traits (i.e., PW, SS, SY, HI, and NFP with 22%, 17%, 14%, 14.5%, and 15%, with the same sequence) compared to non-treated plants. Consequently, exogenous foliar spray of kinetin could be an effective process in minimizing the harmful effects (the reduction in PW, SS, SY, HI, and NFP recorded 41%, 61%, 45%, 30%, and 48%, respectively, under I_{15} conditions when compared to CF) of water deficit in hybrid rice and increasing seed production.

Keywords: CMS lines; physiological stress; kinetin; sustainability; floral traits; yield traits; rice plant

Citation: Hamad, H.S.; Bleih, E.M.; Gewaily, E.E.; Alharbi, K.; Rehan, M. The Potential Effects of Kinetin Implementation on Hybrid Rice Seed Production under Water Deficit. *Sustainability* **2023**, *15*, 5623. https://doi.org/10.3390/su15075623

Academic Editors: Yong Zhou, Xiaolei Fan and Jianping Liu

Received: 14 February 2023
Revised: 16 March 2023
Accepted: 20 March 2023
Published: 23 March 2023

1. Introduction

Rice (*Oryza sativa* L.) is the most important cereal food for humans. It provides the population of the world with 20% of its calories and 13% of its protein [1]. Rice is considered the first consumed crop and recorded as the second crop in production; otherwise, it is estimated to be the third cultivated food crop with 164 million hectares worldwide [1,2]. Hybrid rice technology yields 20% higher than traditional rice varieties. Success and sustainability of hybrid rice depend on efficient and economic seed production technology, besides the higher level of heterosis, which is a primary prerequisite. Moreover, Egypt is considered one of the earliest countries that introduced hybrid rice technology [3–5].

Drought stress is a severely reducing factor for crop yield that seriously minimizes the productivity of non-irrigated rice [6,7]. Drought can happen at any stage of rice cultivation. Under prolonged or severe drought stress, there is a flagrant disruption in photosynthesis and metabolism that will eventually lead to plant death. In addition, it restricts cell enlargement and, subsequently, plant growth. The shortage in plant growth will affect different biochemical and physiological processes such as photosynthesis, respiration, ion uptake, growth promoters, the source–sink relationship, carbohydrate metabolism, and nutrient metabolism [8,9]. Water scarcity leads to morphological, biochemical, and physiological changes in plants and affects their overall growth and yield. During the germination process, water deficiency inhibits water uptake and minimizes the seedling's strength. It damages the metabolic process at the cell level, reduces the ATP production, and causes trouble in the water balance that leads to poor seed germination [10,11]. At the vegetative stage, drought decreases leaf formation, leaf size, number of stomata, and tillering, subsequently reducing panicles per plant and losses in yield, whereas drought stress at the reproductive stage increases grain sterility, decreases the number of grains per panicle, and reduces grain filling and weight [10–13]. As an outcome of climate change, global warming, water shortages, and the increase in world population, enhancing crop performance under conditions of water deficit is a main purpose in agriculture to cover the world's food needs [14].

Growing drought-tolerant and water-saving rice varieties with acceptable yields in water shortage conditions is important to ensure food security worldwide [15]. Under stress conditions, plant growth regulators and osmoprotectants played a main role in the incorporation of the expressed responses. Cells in plants undergo many metabolic changes in response to drought stress, some of which may have adaptive significance [1,16,17].

Plant growth hormones perform the main role in arranging different responses during the stress period to regulate growth and development [18]. Auxins (i.e., IAA), cytokinins, ethylene, gibberellins, abscisic acid, and new groups such as jasmonates, strigolactones, and brassionosteriods significantly improve the metabolic mechanisms and contribute to organizing spikelet degeneration in cereals under water deficit. In addition, the interactions between plant hormones could be involved in altering cellular processes such as elongation of cells and spikelet degeneration with a highly significant role [18–22].

Cytokinins (CKs) play a significant role in regulating plant growth and development and, furthermore, enhance plant tolerance to drought stress. They stimulate cell division, enhance sink strength, and promote photosynthesis [23,24]. Kinetin (Kn) is a synthetic cytokinin that regulates cell growth and division in plants. It is often used in plant tissue culture for inducing callus formation and generating shoot tissues [25]. It performs a serious task in stress tolerance across a wide range of abiotic stresses and can retard leaf senescence directly [26]. Applying kinetin improves chlorophyll contents through the synthesis of photosynthetic proteins in plants, activates cell division, and changes the plant's apical dominance [26,27]. In cereals, grain yield depends upon the plant source/sink association. The contribution of the photosynthesis process in the emerging panicles is limited to grain formation, so grain formation in rice is significantly reliant on the source of leaves. During the early stage of grain formation, kinetin is involved in active cell growth and plays a central role in source/sink variations [28].

External implementation and assessing the role of phytohormones in rice under water deficit stress are relatively cheaper and quicker ways. The objectives of current research were to: (1) estimate the effect of exogenously applied kinetin on growth, floral, yield, and root traits under water deficit conditions; (2) evaluate the interaction between irrigation intervals, kinetin application, and two CMS lines; and (3) assess CMS lines that could be used in hybrid rice seed production under water shortage conditions.

2. Materials and Methods

2.1. Plant Materials and Experimental Site

The present experiment was performed at the experimental farm (31°08′ N and 30°58′ E) of the Rice Research and Training Center, Sakha, Kafr El-Sheikh, Egypt. Two seasons (2020 and 2021) were achieved to study the effects of exogenously kinetin implementation in combination with irrigation intervals on growth-related traits, floral and seed yield traits, and the production of F1 seeds in two lines of hybrid rice. Two cytoplasmic male sterile (CMS) lines (IR69625A and G46A), in addition to one restorer parental line (Giza 178R), were chosen for the present study (the pedigree of the utilized lines is shown in Table 1 depending on their variable genetics). Five irrigation intervals (i.e., continuous flooding (CF), irrigation every six (I_6), nine (I_9), twelve (I_{12}), and fifteen (I_{15}) days under the exogenous application of kinetin (control, 15 mg L^{-1} and 30 mg L^{-1}) were combined.

Table 1. Cytoplasmic male sterile (CMS) lines and restorer parental lines used for producing the hybrid seeds used for the study.

Code	Genotypes	Genotype Code	Days to Heading	Cytoplasmic Source	Origin
CMS Lines					
L1	IR69625A	A1	104.5	Wild abortive (WA) CMS line	IRRI
L2	G46A	A2	88.9	Gambiaca CMS line	China
Restorer line					
Variety	Giza 178R	R	100.7	Giza175/ Milyang 49 Indica/Japonic type	Egypt

2.2. Experimental Design and Agricultural Practices

The experiment was conducted in a strip-split plot design with three replications. The five irrigation intervals, namely, CF, I_6, I_9, I_{12}, and I_{15}, were located in the horizontal plots. While the vertical plots were occupied by two CMS lines (A1 and A2). Meanwhile, the three treatments of kinetin were located in split vertical plots. The horizontal plots were surrounded by deep ditches to control and prevent any lateral movement of irrigation.

Rice seeds at the rate of 20 kg ha^{-1} (15 kg from the CMS lines (IR69625A and G46A) and 5 kg from the restorer line (Giza 178 R) were soaked in fresh water for 24 h, then drained and incubated for 48 h to hasten early germination. The CMS line IR69625A (A1) was sown on May 1st, and G46A (A2) was sown on 20 May. The restorer line Giza 178 (R) was sown over three sowing dates to get a proper synchronization of flowering. The first sowing date (S_1) was when the number of leaves in CMS line A1 was 2.5; the second sowing date (S_2) was when the number of leaves recorded was 3.5 in CMS line A1; and the third sowing date (S_3) was implemented when the number of leaves estimated was 5 in the same CMS line. In permanent fields, monosuperphosphate (P_2O_5, 15.5%) was utilized before tillage at the rate of 240 kg ha^{-1}. Zinc sulfate ($ZnSO_4$, 22%) was applied after puddling and before planting at a rate of 50 kg ha^{-1}. Furthermore, 165 kg ha^{-1} of urea (46% N) was implemented as a nitrogen source (1/3 as basal dressing and 2/3 at panicle initiation). Seedlings thirty days old were transplanted with 3–4 and 2 seedlings per hill in R and A lines, respectively. The rowing direction was perpendicular to the wind direction.

The maintained distances between rows were 20, 30, and 15 cm for R-R, R-A, and A-A lines, respectively. R and A lines were kept 15 cm apart in hill spacing, with an isolation distance of 100 m recorded. Moreover, an additional 20 rows of R lines were cultivated to surround the experimental location, and all pots were isolated by a plastic barrier (2.5 m in height) to avoid cross-pollination and pollen grain movement among treatments. Regular gibberellic acids (GA_3) were applied twice: the first spray (40% of GA3) was applied when heading at A line and recorded 15–20%, whereas the second spray (60%) was applied when A line was at 35–40% heading (five days after heading). Shaking the pollen parents (R line) with bamboo sticks provided supplementary pollination. This operation was performed 2–3 times from 9 to 11.30 a.m. for a period of 10 days.

2.3. Exogenously Applying Kinetin

Kinetin (in two concentrations, 15 and 30 mg per liter) was applied as a foliar spray twice at the mid-tillering and panicle initiation stages of CMS lines, while control plants were sprayed with distilled water. The irrigation intervals were imposed 15 days after transplanting.

2.4. Measured Traits

Growth, Floral, and Yield Characteristics

Data were collected for: number of leaves (NOL), days to complete leaf number (DCLN), days to heading 50% (DTH), flag leaf area (FLA, cm), plant height (PH, cm), panicle length (PL, cm), panicle exertion (PE, %), spikelet opening angle (SOA, °), duration of spikelet opening (DSO, min), number of fertile panicles per hill^{-1} (NFP), panicle weight (PW, g), panicle exertion (PE, %), seed set (SS, %), seed yield (SY, t ha^{-1}), and harvest index (HI, %). The seeds are harvested when 80% of them turn a golden yellow color. After harvest, seeds dried naturally under the sun's rays, and the moisture content was adjusted up to 14% to estimate seed yield.

Panicle exertion percentage was estimated according to the following formula:

$$\text{Panicle exertion } \% = \frac{\text{Exerted panicle length (cm)}}{\text{Panicle length (cm)}} \times 100$$

The seed set percentage was calculated according to the following formula:

$$\text{Seed set } \% = \frac{\text{Number of filled grains/panicle}}{\text{Total Spikelet number/panicle}} \times 100$$

According to the Standard Evaluation System of IRRI (2014), data were collected for all traits under study, and agronomic applications were performed as recommended.

2.5. Statistical Analysis

A strip-split plot design with three replications was performed. Following the ANOVA technique, the data were analyzed, and the mean differences were compared by the Duncan's Multiple Range Test [29] using COSTAT (a statistical computer package).

3. Results

3.1. Effects of Drought Stress, Kinetin Application, and Their Interaction on Growth Traits

The performance of CMS lines, IR69625A (L1) and G46A (L2), under irrigation intervals and kinetin application as well as their interactions on the traits, number of leaves (NOL), days to complete leaf number (DCLN), days to heading (DTH, 50%), flag leaf area (FLA), and plant height (PH), are presented in Table 2. The effect of irrigation intervals was highly significant and negative for all traits. Continuous flooding (CF) recorded the highest values for all evaluated traits under both seasons, whereas the lowest values were assigned to the I_{15} treatment, with reductions of 14.9%, 15.2%, and 11.9% in NOL, FLA, and PH, respectively.

Furthermore, the assessed L1 displayed the highest values for NOL, DCLN, DTH, FLA, and PH with averages of 18.2, 99.3, 104.0, and 110.4 cm in the two assessed seasons, while, the increment in FLA was assigned to L2. In the case of kinetin application, 30 mg L^{-1} kinetin had significant or highly significant and positive effects on all evaluated traits in comparison with untreated plants. The average growth traits in the two seasons of study, i.e., NOL, DCLN, DTH, FLA, and PH, increased to 17.1, 90.7, 96.6, 30.2 cm, and 110.9 cm, respectively, under 30 mg L^{-1} of kinetin in comparison to untreated plants.

Table 2. Effect of irrigation intervals, two CMS lines, and kinetin application as well as their interactions on plant traits during the 2020 and 2021 seasons.

Studied Factors	NOL		DCLN		DTH (50%)		FLA (cm)		PH (cm)	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Irrigation intervals (I)										
CF	17.89 a	18.47 a	90.74 a	92.31 a	97.30 a	98.28 a	31.52 a	32.86 a	115.64 a	117.83 a
I_6	17.08 b	17.66 b	89.90 b	91.46 b	95.90 b	96.88 b	29.52 b	30.86 b	110.77 b	112.96 b
I_9	16.48 c	17.06 c	89.32 c	90.88 c	95.32 c	96.30 c	28.53 c	29.87 c	107.52 c	109.71 c
I_{12}	16.24 c	16.82 c	88.70 d	90.26 d	94.70 d	95.68 d	27.70 d	29.04 d	104.79 d	106.98 d
I_{15}	15.19 d	15.77 d	87.59 e	89.15 e	93.59 e	94.57 e	26.62 e	27.96 e	101.73 e	103.92 e
F-test	**	**	**	**	**	**	**	**	**	**
CMS Lines										
L1	17.93 a	18.51 a	98.49 a	100.05 a	103.55 a	104.53 a	27.12 b	28.46 b	109.33 a	111.52 a
L2	15.22 b	15.80 b	80.02 b	81.58 b	87.17 b	88.16 b	30.43 a	31.77 a	106.84 b	109.04 b
F-test	**	**	**	**	**	**	**	**	**	**
Kinetin application (K)										
Control	16.12 b	16.69 b	88.71 c	90.26 c	94.74 c	95.72 c	28.02 c	29.36 c	106.49 c	108.68 c
15 mg L^{-1}	16.79 a	17.41 a	89.19 b	90.75 b	95.29 b	96.27 b	28.77 b	30.11 b	108.02 b	110.22 b
30 mg L^{-1}	16.83 a	17.37 a	89.86 a	91.43 a	96.06 a	97.04 a	29.54 a	30.88 a	109.76 a	111.95 a
F-test	*	*	**	**	**	**	**	**	**	**
Interactions										
I × L	*	*	*	*	NS	NS	**	**	**	**
L × K	NS	NS	NS	NS	NS	NS	NS	NS	*	*
K × I	NS	NS	*	*	NS	NS	**	**	**	**
I × L × K	NS	NS	NS	NS	NS	NS	**	**	**	**

*, ** Significant, and highly significant at the 1% level of probability. NS, not significant at the 1% level of probability. a, b, c, d, and e: values in the same treatment, column, and season not sharing similar letters are significantly different ($p > 0.05$).

The interaction between the irrigation periods and the two CMS lines (I × L) showed a significant or highly significant effect for all characteristics except DTH. Going forward, the extent of irrigation intervals and kinetin application (K × I) interaction and irrigation intervals, two CMS lines, and kinetin (I × L × K) interaction was superior and increased FLA and PH.

The analysis of results implied significant and highly significant impacts of interaction between irrigation times and CMS lines (I × L) on NOL, DCLN, FLA, and PH under both seasons (Table S1). The best values for NOL, DCLN, and PH were recorded by L1 under continuous flooding (CF) with averages of 19.8, 101.1, and 119.1 cm in the two seasons, while L2 exhibited the best FLA value (34.5 cm) in average. Otherwise, water deficit stress caused shortages in all growth traits compared to normal irrigation, as clearly exhibited by irrigation every 15 days (I_{15}) treatment in the two genotypes.

The results in Table 3 represent the interaction between CMS lines and kinetin treatment (L × K). When kinetin was applied with 30 mg L^{-1}, L1 plants displayed a considerable increase in plant height with an average of 112.03 cm in comparison to the control (108.89 cm). Likewise, L2 under the same treatment exhibited the same trend.

Exploring the interaction between irrigation periods and kinetin implementation (K × I) revealed positively significant or highly significant increments in DCLN, FLA, and PH during both seasons of study (Table 4). Days to complete leaf number (DCLN), flag leaf area (FLA), and plant height (PH) under all irrigation intervals and 30 mg L^{-1} from kinetin had the highest mean values in the two seasons of assessment when compared to control in each treatment.

Table 3. Effect of interactions between the CMS lines and kinetin application on plant height during the 2020 and 2021 seasons.

CMS Lines	Kinetin Application	PH (cm)	
		2020	**2021**
L1	Control	107.79 d	109.98 d
	15 mg L^{-1}	109.28 b	108.96 e
	30 mg L^{-1}	110.93 a	113.12 a
L2	Control	105.18 f	107.37 f
	15 mg L^{-1}	106.77 e	108.96 e
	30 mg L^{-1}	108.59 c	110.78 c

a, b, c, d, e and f: values in the same column and season not sharing similar letters are significantly different ($p > 0.05$).

Table 4. Effect of interactions between irrigation intervals and kinetin application on plant traits during the 2020 and 2021 seasons.

Irrigation Intervals	Kinetin Application	DCLN		FLA (cm)		PH (cm)	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**
CF	Control	90.33 b	91.89 b	30.05 c	31.39 c	114.95 c	117.15 c
	15 mg L^{-1}	90.58 b	92.15 b	31.64 b	32.98 b	115.42 b	117.61 b
	30 mg L^{-1}	91.32 a	92.88 a	32.88 a	34.22 a	116.54 a	118.74 a
I_6	Control	89.32 cd	90.88 cd	28.98 e	30.32 e	108.93 g	111.13 g
	15 mg L^{-1}	89.64 c	91.20 c	29.53 d	30.87 d	110.72 e	112.92 e
	30 mg L^{-1}	90.74 b	92.30 b	30.06 c	31.40 c	112.66 d	114.85 d
I_9	Control	88.86 de	90.42 de	28.02 g	29.87 f	105.73 j	107.92 j
	15 mg L^{-1}	89.38 cd	90.94 cd	28.53 f	29.87 f	107.52 h	109.72 h
	30 mg L^{-1}	89.73 c	91.29 c	29.03 e	30.37 e	109.33 f	111.52 f
I_{12}	Control	88.30 f	89.86 f	26.89 j	28.23 j	103.05 m	105.24 m
	15 mg L^{-1}	88.37 ef	89.93 ef	27.68 h	29.02 h	104.74 k	106.93 k
	30 mg L^{-1}	89.44 c	91.00 c	28.52 f	29.86 f	106.58 i	108.77 i
I_{15}	Control	86.70 g	88.26 g	26.19 k	27.53 k	99.78 o	101.97 o
	15 mg L^{-1}	87.98 f	89.54 f	26.45 k	27.79 k	101.73 n	103.92 n
	30 mg L^{-1}	88.11 f	89.66 f	27.13 i	28.55 i	103.67 l	105.86 l

a, b, c, d, e, f, g, h, i, j, k, l, m, n and o: values in the same column and season not sharing similar letters are significantly different ($p > 0.05$).

In the same manner, doing interaction analysis among irrigation intervals, CMS lines, and kinetin spray (I × L × K) demonstrated a highly significant enhancement in FLA and PH (Table 5). Under 30 mg L^{-1} from kinetin, L2 recorded the uppermost values in flag leaf area (FLA) under all treatments of water deficit stress. Meanwhile, plant height (PH) increased under well-watered conditions, and L1 gave the highest values with continuous flooding (CF) coupled with kinetin treatment (30 mg L^{-1}). Contrary, L1 and L2 were negatively affected by water limitation since FLA and PH decreased to their lowest values with irrigation intervals (I_{15}) under control (without kinetin application).

Table 5. Effect of interactions among the irrigation intervals, two CMS lines, and kinetin application on plant traits during the 2020 and 2021 seasons.

Irrigation Intervals	CMS Lines	Kinetin Application	FLA (cm)		PH (cm)	
			2020	2021	2020	2021
CF	L1	Control	28.10 jk	29.45 jk	114.16 c	119.34 c
		15 mg L^{-1}	29.12 hi	30.46 hi	117.91 b	120.10 b
		30 mg L^{-1}	30.43 f	31.77 f	119.05 a	121.24 a
	L2	Control	31.99 c	33.33 c	112.75 e	114.94 e
		15 mg L^{-1}	34.16 b	35.50 b	112.93 e	115.12 e
		30 mg L^{-1}	35.34 a	36.68 a	114.04 d	116.23 d
I_6	L1	Control	27.25 l	28.59 l	110.57 h	112.76 h
		15 mg L^{-1}	27.75 k	29.09 l	112.17 f	114.36 f
		30 mg L^{-1}	28.25 j	29.59 j	114.04 d	116.23 d
	L2	Control	30.71 ef	32.05 ef	107.31 lm	109.49 lm
		15 mg L^{-1}	32.32 d	32.65 d	109.28 j	111.21 j
		30 mg L^{-1}	31.87 c	33.22 c	111.28 g	113.47 g
I_9	L1	Control	26.03 o	27.37 o	106.44 n	108.63 n
		15 mg L^{-1}	26.53 mn	27.87 mn	108.03 k	110.22 k
		30 mg L^{-1}	27.03 l	28.37 l	109.64 i	111.84 i
	L2	Control	30.02 g	31.35 g	105.02 p	107.21 p
		15 mg L^{-1}	30.53 f	31.87 f	107.02 m	109.21 m
		30 mg L^{-1}	31.04 de	32.37 de	109.02 j	111.21 j
I_{12}	L1	Control	25.59 p	26.93 p	104.28 q	106.47 q
		15 mg L^{-1}	26.61 m	27.95 m	105.78 o	105.89 r
		30 mg L^{-1}	27.72 k	29.06 k	107.48 l	107.88 o
	L2	Control	28.19 j	29.53 j	101.81 u	104.00 u
		15 mg L^{-1}	28.76 i	30.10 i	103.70 r	105.83 r
		30 mg L^{-1}	29.32 h	30.66 h	105.69 o	107.88 o
I_{15}	L1	Control	25.15 q	26.48 q	100.54 w	102.73 w
		15 mg L^{-1}	25.20 q	26.60 q	102.54 t	104.73 t
		30 mg L^{-1}	26.14 no	27.47 no	104.43 q	106.62 q
	L2	Control	27.24 l	28.58 l	99.02 x	101.20 x
		15 mg L^{-1}	27.76 k	29.10 k	100.92 v	103.11 v
		30 mg L^{-1}	28.29 j	29.63 j	102.92 s	105.11 s

a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, u, v, w and x: values in the same column and season not sharing similar letters are significantly different ($p > 0.05$).

3.2. *Performance of Floral Traits*

Effects of irrigation intervals, CMS lines, and kinetin application as well as their interaction on panicle length (PL), panicle exertion (PE), spikelet opening angle (SOA), and duration of spikelet opening (DSO) characteristics are given in Table 6. The assessed traits in two lines of interest manifested a wide variation between treatments of irrigation. As expected, a positive and significant effect was observed under CF treatment, with a decrease in floral trait values when water deficit increased. The CMS lines displayed highly significant effects for panicle length (PL), spikelet opening angle (SOA), and duration of spikelet opening (DSO) otherwise, no significant impact on panicle exertion (PE) was detected. L1 exhibited the best values for PL, whereas SOA and DSO were assigned to L2.

When the plant hormone kinetin was implemented, 30 mg L^{-1} positively improved the floral traits and exhibited the highest PL, PE, SOA, and DSO values when compared to the control (non-treated plants). Exploring the interaction between the irrigation and CMS lines (I × L) revealed highly significant differentiations in PL, PE, and DSO. Likewise, L × K interactivity exposed a remarkable impact on PE and DSO, while I × K interplay exhibited visible changes in all floral traits except SOA. By going forward and exploring the reaction among I × L × K, a tangible change in PL and DSO was observed based on variance analysis.

Table 6. Effect of irrigation intervals, CMS lines, and kinetin application as well as their interactions on plant floral traits during the 2020 and 2021 seasons.

Main Effect and Interaction	PL (cm)		PE (%)		SOA (°)		DSO (min)	
	2020	2021	2020	2021	2020	2021	2020	2021
Irrigation intervals (I)								
CF	23.30 a	23.35 a	71.74 a	73.99 a	25.89 a	27.87 a	166.34 a	166.47 a
I_6	22.22 b	22.27 b	67.40 b	69.65 b	24.14 b	26.12 b	160.20 b	160.91 b
I_9	22.05 b	22.11 b	63.02 d	65.26 d	24.25 b	26.23 b	154.34 c	156.55 c
I_{12}	20.91 c	20.96 c	65.04 c	67.29 c	23.21 c	25.19 c	147.47 d	147.87 d
I_{15}	20.64 d	20.69 d	63.06 d	65.31 d	22.35 d	24.33 d	135.76 e	137.16 e
F-test	**	**	**	**	**	**	**	**
CMS lines (L)								
L1	22.50 a	22.55 a	66.70 a	68.95 a	22.52 b	24.50 b	149.09 b	148.28 b
L2	21.15 b	21.20 b	65.40 a	67.65 a	25.42 a	27.41 a	156.56 a	159.30 a
F-test	**	**	NS	NS	**	**	**	**
Kinetin application (K)								
Control	21.23 c	21.27 c	64.05 c	66.30 c	23.22 c	25.20 c	148.63 c	149.65 c
15 mg L^{-1}	21.84 b	21.89 b	66.08 b	68.33 b	23.97 b	25.95 b	152.57 b	153.65 b
30 mg L^{-1}	22.42 a	22.47 a	68.02 a	70.26 a	24.72 a	26.70 a	157.27 a	158.06 a
F-test	*	*	**	**	**	**	**	**
Interactions								
I × L	**	**	**	**	NS	NS	**	**
L × K	NS	NS	**	**	NS	NS	**	**
I × K	**	**	**	**	NS	NS	**	**
I × L × K	**	**	NS	NS	NS	NS	**	**

*, ** Significant, and highly significant at the 1% level of probability. NS is not significant at the 1% level of probability. a, b, c, d, e: values in the same treatment, column, and season not sharing similar letters are significantly different ($p > 0.05$).

In detail, the feasibility of the interconnection between irrigation and CMS lines (I × L) displayed the best values of PL and PE in L1, while L2 had good numbers of DSO under well-watered conditions (CF). The lowest numbers in PL and PE were assigned to L2 and DSO for L1 under severe water shortage (I_{15}) (Table S2).

The interrelationship between L × K regarding PE and DSO showed a highly significant increase in the case of 30 mg L^{-1} kinetin implementation. A percentage of 6.6 and 10.0 increase in PE and DSO, respectively, were detected in L1 in comparison to untreated plants (Table 7). The same orientation was observed with L2.

Table 7. Effect of interactions between CMS lines and kinetin application on plant floral traits in both seasons.

CMS Lines	Kinetin Application	PE (%)		DSO (min)	
		2020	2021	2020	2021
L1	Control	64.47 e	66.72 e	144.59 f	143.65 f
	15 mg L^{-1}	65.38 d	69.04 c	148.78 e	148.11 e
	30 mg L^{-1}	68.85 a	71.10 a	153.88 a	163.04 a
L2	Control	63.64 f	65.88 f	152.66 d	155.66 c
	15 mg L^{-1}	65.38 d	67.63 d	156.36 b	159.19 b
	30 mg L^{-1}	67.18 b	69.43 b	160.65 a	163.05 a

a, b, c, d, e and f: values in the same column and season not sharing similar letters are significantly different ($p > 0.05$).

Applying the interplay between I × K significantly increased the PL, PE, and DSO traits. Continued flooding (CF) combined with 30 mg L^{-1} kinetin enhanced the floral characteristics, followed by 15 mg L^{-1} when compared to the control (Table 8). Otherwise, the water deficit (I_{15}) showed the minimum values for all traits under control (without K treatment). In conclusion, application of kinetin improved the floral traits under all water-stressed conditions.

Table 8. Effect of interactions between irrigation intervals and kinetin application on plant floral traits during the 2020 and 2021 seasons.

Irrigation Intervals	Kinetin Application	PL (cm)		PE (%)		DSO (min)	
		2020	2021	2020	2021	2020	2021
CF	Control	22.82 c	22.87 c	70.50 c	72.75 c	165.61 c	169.46 c
	15 mg L^{-1}	23.14 b	23.19 b	71.77 b	74.02 b	166.32 b	164.67 b
	30 mg L^{-1}	23.94 a	24.00 a	72.95 a	75.20 a	167.08 a	169.28 a
I_6	Control	21.70 e	21.84 e	65.24 f	67.49 f	156.45 g	157.77 g
	15 mg L^{-1}	22.21 d	22.31 d	67.42 e	69.67 e	159.95 e	160.77 f
	30 mg L^{-1}	22.74 c	22.82 c	69.53 d	71.78 d	164.20 d	169.17 d
I_9	Control	21.55 e	21.60 e	60.96 h	63.21 h	149.51 j	151.83 j
	15 mg L^{-1}	22.05 d	22.11 d	62.95 g	65.22 g	154.00 h	156.33 g
	30 mg L^{-1}	22.55 c	22.61 d	65.11 f	67.36 f	159.50 f	161.48 e
I_{12}	Control	20.09 h	20.00 h	62.97 g	65.22 g	141.64 l	141.97 m
	15 mg L^{-1}	21.13 f	21.18 f	65.05 f	67.30 f	147.14 k	147.62 k
	30 mg L^{-1}	21.65 e	21.70 e	67.12 e	69.37 e	153.64 i	154.02 i
I_{15}	Control	19.95 h	20.15 h	60.59 h	62.84 h	129.93 n	131.25 o
	15 mg L^{-1}	20.63 g	20.69 g	63.23 g	65.48 g	135.43 m	136.86 n
	30 mg L^{-1}	21.19 f	21.24 f	65.36 f	67.61 f	141.93 l	143.36 l

a, b, c, d, e, f, g, h, i, j, k, l, m, n and o: values in the same treatment, column, and season not sharing similar letters are significantly different ($p > 0.05$).

Performing the same work, the I × L × K interaction displayed a positive and highly significant raise in PL and DSO in the two CMS lines under all irrigation times coupled with kinetin treatments when compared to non-treated plants (Table 9). With regard to PL, the best values were recorded with L1 under 30 mg L^{-1} and CF, while the highest numbers related to DSO were observed with L2 under the same previous conditions (30 mg L^{-1} and CF). Furthermore, continuous exposure of L1 and L2 to an insufficient amount of water led to the lowest values of DSO and PL, respectively, under the control of I_{15}.

Table 9. Effect of interactions among irrigation intervals, CMS lines, and kinetin application on plant floral traits during the 2020 and 2021 seasons.

Irrigation Intervals	CMS Lines	Kinetin Application	PL (cm)		DSO (min)	
			2020	2021	2020	2021
CF	L1	Control	23.50 b	23.55 b	160.18 h	160.04 h
		15 mg L^{-1}	23.61 b	23.66 b	161.09 f	161.29 g
		30 mg L^{-1}	24.84 a	24.53 a	162.13 e	162.38 f
	L2	Control	22.14 gh	22.19 gh	171.05 b	170.87 b
		15 mg L^{-1}	22.67 ef	22.72 ef	171.54 ab	172.04 a
		30 mg L^{-1}	23.40 bc	23.45 bc	172.03 a	174.19 a

Table 9. *Cont.*

Irrigation Intervals	CMS Lines	Kinetin Application	PL (cm)		DSO (min)	
			2020	2021	2020	2021
I_6	L1	Control	22.42 fg	22.47 fg	152.37 l	153.23 l
		15 mg L^{-1}	22.95 de	23.00 de	156.37 j	156.23 j
		30 mg L^{-1}	23.50 b	23.55 b	160.87 fg	160.23 h
	L2	Control	20.98 jk	21.01 jk	160.53 gh	162.32 f
		15 mg L^{-1}	21.48 i	21.03 jk	163.53 d	165.32 e
		30 mg L^{-1}	21.98 h	22.03 h	167.53 c	168.12 c
I_9	L1	Control	22.58 e	22.63 ef	145.93 o	144.79 p
		15 mg L^{-1}	23.08 cd	23.13 cd	150.93 o	150.79 m
		30 mg L^{-1}	23.58 b	23.63 b	156.93 i	156.59 j
	L2	Control	20.53 lm	20.58 lm	153.08 k	158.87 i
		1 g L^{-1}	21.03 jk	21.03 j	157.08 i	161.87 f
		2 g L^{-1}	21.53 i	21.58 i	162.08 e	166.37 d
I_{12}	L1	Control	19.66 n	19.71 n	137.23 t	135.09 u
		15 mg L^{-1}	21.52 i	21.75 i	143.23 q	141.09 r
		30 mg L^{-1}	22.05 gh	22.11 gh	150.23 n	148.09 o
	L2	Control	20.24 m	20.29 m	146.06 o	148.84 n
		15 mg L^{-1}	20.74 lm	20.79 lm	151.06 m	154.15 k
		30 mg L^{-1}	21.25 ij	21.30 ij	157.06 i	159.94 h
I_{15}	L1	Control	20.96 jk	21.01 jk	127.27 v	125.13 w
		15 mg L^{-1}	21.54 i	21.59 i	132.28 u	131.13 v
		30 mg L^{-1}	22.10 gh	22.11 gh	139.25 r	138.15 s
	L2	Control	19.23 o	19.28 o	132.59 u	137.38 t
		15 mg L^{-1}	19.73 n	19.78 n	138.59 s	142.60 q
		30 mg L^{-1}	20.28 m	20.33 m	144.59 p	148.60 n

a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, u, v and w: values in the same column and season not sharing similar letters are significantly different ($p > 0.05$).

3.3. Grain Yield in the Two Hybrids under Drought, Kinetin, and Their Interaction

The assessed yield traits in the two CMS lines as a result of stressed conditions, kinetin application, and their interactions revealed a wide variation for all measured traits. The effects on panicle weight (PW), seed set (SS), seed yield (SY), harvest index (HI), and number of fertile panicles per hill (NFP) characteristics were evaluated. A highly significant and negative effect with reductions in PW, SS, SY, HI, and NFP reaching 41%, 61%, 45%, 30%, and 48%, respectively, was observed under drought stress intervals when compared to continuous flooding (CF) in the two seasons of study (Table 10). In addition, the two lines (IR69625A × Giza 178R and G46A × Giza 178R) had highly significant reductions in PW, SS, SY, HI, and NFP, with more losses in L2 (G46A × Giza 178R) than L1 (IR69625A × Giza 178R). In addition, the yield-related traits (PW, SS, SY, HI, and NFP) displayed a positive effect with a highly significant increase in yield traits under kinetin application. Applying 30 mg L^{-1} kinetin exhibited the highest values for PW, SS, SY HI, and NFP with 22%, 17%, 14%, 14.5%, and 15% increments, respectively, in comparison with the control. All the interactions among treatments displayed significant and highly significant effects for PW, SS, SY, HI, and NFP during the 2020 and 2021 seasons.

Table 10. Effect of irrigation periods, two hybrids, and kinetin application as well as their interactions on panicle traits and yield during the 2020 and 2021 seasons.

Main Effect and Interaction	PW (g)		SS (%)		SY (t ha^{-1})		HI (%)		NFP	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Irrigation intervals (I)										
CF	3.15 a	3.24 a	31.96 a	37.26 a	1.728 a	1.839 a	18.98 a	19.94 a	19.53 a	20.45 a
I_6	2.78 b	3.05 b	25.89 b	28.71 b	1.395 b	1.503 b	17.38 b	18.67 b	18.02 b	18.71 b
I_9	2.47 c	2.73 c	21.70 c	24.44 c	1.289 c	1.371 c	16.25 c	17.42 c	16.79 c	17.65 c
I_{12}	2.13 d	2.39 d	19.37 d	22.02 d	1.194 d	1.264 d	15.00 d	16.15 d	15.11 d	15.89 d
I_{15}	1.75 e	2.02 e	12.16 e	14.68 e	0.939 e	1.021 e	12.85 e	14.06 e	9.88 e	10.81 e
F-test	**	**	**	**	**	**	**	**	**	**
CMS lines (L)										
L1 × R	2.49 a	2.73 a	23.05 a	26.68 a	1.354 a	1.439 a	16.45 a	17.61 a	17.06 a	17.97 a
L2 × R	2.42 b	2.63 b	21.38 b	24.16 b	1.264 b	1.361 b	15.64 b	16.89 b	14.67 b	15.44 b
F-test	*	**	*	**	**	**	**	**	**	**
Kinetin application (K)										
Control	2.21 c	2.34 c	19.82 c	23.52 c	1.222 c	1.298 c	14.81 c	15.74 c	14.47 c	15.29 c
15 mg L^{-1}	2.37 b	2.64 b	22.10 b	25.25 b	1.281 b	1.384 b	16.28 b	17.47 b	15.98 b	16.85 b
30 mg L^{-1}	2.78 a	3.07 a	24.73 a	27.51 a	1.425 a	1.517 a	17.18 a	18.53 a	17.14 a	17.97 a
F-test	**	**	**	**	**	**	**	**	**	**
Interactions										
I × L	*	**	**	**	**	**	*	**	**	**
L × K	**	**	**	**	**	**	**	**	*	*
I × K	**	**	**	**	**	**	**	**	**	**
I × L × K	**	**	**	*	**	**	**	**	**	**

*, ** Significant, and highly significant at the 1% level of probability. NS is not significant at the 1% level of probability. a, b, c, d, and e: values in the same treatment, column, and season not sharing similar letters are significantly different ($p > 0.05$).

In Table S3, the panicle weight (PW), seed set (SS), seed yield (SY), harvest index (HI), and number of panicles fertile hill^{-1} (NPF) declined when combined between irrigation periods and hybrids. L1 and L2 (IR69625A × Giza 178R and G46A × Giza 178R) exhibited highly significant decreases, with percentages of 41, 60.7, 47.2, 30.8, and 47.4 for L1 (under I_{15} vs. CF) and 40.9, 61.8, 42.7, 30.9, and 49.2 for L2 (I_{15} vs. CF) in the same previous sequences.

Applying the interaction between the two CMS lines (IR69625A × Giza 178R and G46A × Giza 178R) and kinetin implementation showed a highly positive and significant increase in PW, SS, SY, HI, and NPF, which recorded 23.4%, 16.7%, 14.7%, 14.5%, and 12.7%, respectively, with L1 (IR69625A × Giza 178R) and 21.2%, 17.5%, 14.0%, 14.4%, and 18.2% with L2 (G46A × Giza 178R) under 30 mg L^{-1} kinetin (Table 11).

When the interaction between irrigation durations and kinetin treatments was studied, an enhancement in panicle and yield traits was observed in comparison to the control (Table 12). Highly significant and positive enhancements in panicle weight (PW), seed set (SS), seed yield (SY), harvest index (HI), and number of panicle fertile hill^{-1} (NPF) were detected under 30 mg L^{-1} from kinetin hormone in all irrigation intervals when compared at control (in each treatment).

Likewise, Table 13 represents the obtained results from the correlation among the irrigation times, two CMS lines, and kinetin employment (I × L × K). PW, SS, SY, HI, and NPF traits had highly significant excesses under kinetin treatment (30 mg L^{-1}) in both hybrids under all water irrigation intervals.

Table 11. Effect of interactions between two CMS lines, and kinetin application on panicle traits and yield during the 2020 and 2021 seasons.

CMS Lines	Kinetin Application	PW (g)		SS (%)		SY (t ha^{-1})		HI (%)		NFP	
		2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
L1 × R	Control	2.21 e	2.37 e	20.29 e	25.00 c	1.262 d	1.331 e	15.21 d	16.02 e	15.76 c	16.87 c
	15 mg L^{-1}	2.43 c	2.69 c	23.06 c	26.49 b	1.320 c	1.424 c	16.85 b	17.85 c	17.09 b	18.02 b
	30 mg L^{-1}	2.84 a	3.14 a	25.80 a	28.55 a	1.479 a	1.562 a	17.59 a	18.95 a	18.34 a	19.02 a
L2 × R	Control	2.20 e	2.31 f	19.34 f	22.03 e	1.180 f	1.265 f	14.41 e	15.46 f	13.17 e	13.71 e
	15 mg L^{-1}	2.33 d	2.95 d	21.14 d	24.00 d	1.242 e	1.3455 d	15.72 c	17.10 d	14.88 d	15.69 d
	30 mg L^{-1}	2.73 b	2.99 b	23.66 b	26.46 b	1.372 b	1.472 b	16.79 b	18.11 b	15.94 c	16.91 c

a, b, c, d, e and f: values in the same treatment, column, and season not sharing similar letters are significantly different ($p > 0.05$).

Table 12. Effect of interactions between irrigation intervals and kinetin application on panicle traits and yield during the 2020 and 2021 seasons.

Irrigation Intervals	Kinetin Application	PW(g)		SS (%)		GY (t ha^{-1})		HI (%)		NFP	
		2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
CF	Control	2.97 d	2.66 f	28.8 d	36.65 c	1.687 b	1.753 c	18.36 d	18.44 d	18.64 d	19.10 c
	15 mg L^{-1}	2.97 d	3.24 d	32.0 b	37.17 b	1.694 b	1.861 b	18.99 b	20.23 b	19.07 c	20.13 b
	30 mg L^{-1}	3.49 a	3.82 a	34.96 a	37.95 a	1.803 a	1.904 a	19.58 a	21.15 a	20.87 a	22.13 a
I_6	Control	2.24 fg	2.50 h	22.0 g	24.80 g	1.233 h	1.325 g	15.57 g	16.64 f	16.28 g	16.99 e
	15 mg L^{-1}	2.75 e	3.06 e	25.09 e	27.89 e	1.329 e	1.423 e	17.90 d	19.23 c	18.20 e	19.08 c
	30 mg L^{-1}	3.35 b	3.58 b	30.54 c	33.44 d	1.623 c	1.762 c	18.66 c	20.15 b	19.58 b	20.08 b
I_9	Control	2.13 i	2.36 j	19.60 i	22.30 i	1.189 i	1.262 h	14.46 i	15.55 h	15.03 i	16.20 f
	15 mg L^{-1}	2.25 f	2.52 g	21.7 gh	24.52 gh	1.281 g	1.380 f	16.50 f	17.52 e	17.24 f	17.99 d
	30 mg L^{-1}	3.03 c	3.30 c	23.72 f	26.50 f	1.398 d	1.472 d	17.79 e	19.18 c	18.09 e	18.76 c
I_{12}	Control	2.00 j	2.25 k	17.12 j	19.78 j	1.110 k	1.182 j	13.49 j	14.65 i	13.57 j	14.21 g
	15 mg L^{-1}	2.16 h	2.41 i	19.45 i	21.98 i	1.167 i	1.237 i	15.16 h	16.30 g	15.42 h	16.15 f
	30 mg L^{-1}	2.23 g	2.51 gh	21.54 h	24.28 h	1.305 f	1.374 f	16.35 f	17.50 e	16.33 g	17.32 e
I_{15}	Control	1.69 m	1.94 n	11.4 m	14.04 m	0.888 n	0.96 m	12.16 l	13.42 k	8.82 m	9.96 j
	15 mg L^{-1}	1.73 l	1.97 m	12.09 l	14.65 l	0.93 m	1.023 l	12.86 k	14.10 j	10.00 l	10.91 i
	30 mg L^{-1}	1.84 k	2.14 l	12.9 k	15.35 k	0.966 l	1.072 k	13.52 j	14.68 j	10.48 k	11.56 g

a, b, c, d, e, f, g, h, i, j, k, l, m and n: values in the same treatment, column, and season not sharing similar letters are significantly different ($p > 0.05$).

Table 13. Effect of interactions among irrigation intervals, two CMS lines, and kinetin application on panicle and yield traits during the 2020 and 2021 seasons.

Irrigation Intervals	CMS Lines	Kinetin Application	PW (g)		SS (%)		SY (t ha^{-1})		HI (%)		NFP	
			2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
CF	L1 × R	Control	2.89 g	2.70 j	26.44 f	39.26 ab	1.783 c	1.851 c	18.36 d	18.81 e	19.13 de	19.88 c
		15 mg L^{-1}	3.04 e	3.28 e	32.53 bc	39.11 b	1.815 b	1.953 b	19.5 ab	20.64 b	20.02 c	20.96 b
		30 mg L^{-1}	3.58 a	3.96 a	36.81 a	39.82 a	1.952 a	1.998 a	19.77 a	21.85 a	22.02 a	23.33 a
	L2 × R	Control	3.06 de	2.62 k	26.44 f	34.04 e	1.560 f	1.655 g	18.36 d	18.08 f	18.14 gh	18.32 fg
		15 mg L^{-1}	2.92 g	3.19 g	31.66 cd	25.25 d	1.604 e	1.766 e	18.43 d	19.81 d	18.10 gh	19.29 d
		30 mg L^{-1}	3.41 b	3.68 b	33.11 b	36.08 c	1.654 d	1.810 d	19.39 b	20.44 c	19.73 c	20.93 b

Table 13. *Cont.*

Irrigation Intervals	CMS Lines	Kinetin Application	PW (g)		SS (%)		SY (t ha^{-1})		HI (%)		NFP	
			2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
I_6	L1 × R	Control	2.288 j	2.55 l	23.76 g	26.53 i	1.256 l	1.347 k	16.15 g	16.90 i	14.47 l	18.97 de
		15 mg L^{-1}	2.81 h	3.15 h	26.66 f	29.49 g	1.343 i	1.445 i	18.41 d	19.67 d	19.24 d	20.21 c
		30 mg L^{-1}	3.42 b	3.66 b	31.44 d	34.34 e	1.674 d	1.819 d	19.08 c	20.67 b	18.56 fg	21.02 b
	L2 × R	Control	2.20 k	2.65 mno	20.35 j	23.08 k	1.211 m	1.302 l	15.00 i	16.38 j	14.47 l	15.00 l
		15 mg L^{-1}	2.70 i	2.97 i	23.51 hi	26.29 i	1.314 jk	1.400 j	17.40 e	18.78 e	17.17 i	17.96 gh
		30 mg L^{-1}	3.28 c	3.50 c	29.63 e	32.54 f	1.572 f	1.704 f	18.24 d	19.62 d	18.56 fg	19.14 d
I_9	L1 × R	Control	2.16 l	2.43 o	20.86 j	23.58 k	1.201 m	1.278 m	15.07 h	15.87 k	13.19 n	18.45 efg
		15 mg L^{-1}	2.30 j	2.57 l	22.67 i	25.42 j	1.307 k	1.398 j	17.34 e	17.82 g	15.81 k	19.07 d
		30 mg L^{-1}	3.08 d	3.35 d	24.59 g	27.38 h	1.426 g	1.498 h	18.25 d	19.62 d	16.64 j	19.99 c
	L2 × R	Control	2.10 m	2.31 q	18.34 k	21.02 l	1.176 n	1.246 n	13.28 l	15.24 l	13.19 n	13.96 m
		15 mg L^{-1}	2.20 k	2.47 m	20.86 j	23.62 k	1.255 l	1.362 k	15.85 g	17.23 h	15.81 k	16.37 j
		30 mg L^{-1}	2.97 f	3.25 f	22.85 hi	25.62 j	1.371 h	1.446 i	17.34 e	18.72 e	16.64 j	17.53 h
I_{12}	L1 × R	Control	2.02 n	2.27 q	18.41 k	21.08 l	1.139 o	1.197 o	13.94 k	14.89 m	15.42 k	16.37 j
		15 mg L^{-1}	2.19 k	2.44 no	20.64 j	23.03 k	1.205 m	1.276 m	15.85 g	16.74 i	17.08 ij	17.98 gh
		30 mg L^{-1}	2.27 j	2.55 l	22.61 i	25.36 j	1.334 ij	1.396 j	16.91 f	17.82 i	17.84 h	18.80 def
	L2 × R	Control	1.98 o	2.24 s	15.84 l	20.95 l	1.080 p	1.166 p	13.03 l	14.42 op	11.72 o	12.04 n
		15 mg L^{-1}	2.12 m	2.39 p	18.26 k	23.02 k	1.129 o	1.197 o	13.94 k	15.86 k	13.75 m	14.32 m
		30 mg L^{-1}	2.18 kl	2.46 mn	20.46 j	23.19 k	1.277 l	1.353 k	15.79 h	17.17 h	14.82 l	15.84 k
I_{15}	L1 × R	Control	1.71 s	1.94 w	12.00 no	14.56 p	0.902 s	0.981 t	12.53 m	13.65 q	9.30 r	10.71 o
		15 mg L^{-1}	1.76 r	2.00 v	12.81 mn	15.38 no	0.962 r	1.045 r	13.28 l	14.37 p	10.42 p	11.85 n
		30 mg L^{-1}	1.87 p	2.19 t	13.55 m	15.85 n	1.010 q	1.097 q	13.82 k	14.76 mn	11.73 o	11.98 n
	L2 × R	Control	1.66 t	1.94 w	10.96 p	13.51 q	0.875 t	0.955 u	11.81 n	13.18 r	8.33 s	9.22 q
		15 mg L^{-1}	1.71 s	1.95 w	11.36 op	13.92 q	0.905 s	1.001 s	12.45 m	13.83 q	9.57 qr	9.97 p
		30 mg L^{-1}	1.83 q	2.09 u	12.28 no	14.86 op	0.983 r	1.046 r	13.22 l	14.59 no	9.96 q	11.15 o

a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, u, v and w: values in the same column and season not sharing similar letters are significantly different ($p > 0.05$).

3.4. Correlation between Indices

To assess the correlation between the two CMS lines and both kinetin and drought treatments, a principal component analysis was conducted. Both PCA1 and PCA2 presented the most variability, with 96.23% of the total variation (Figure 1). Exploring the PC-biplot, PCA2 displayed lower variation, counting 22.79%, while PCA1 evaluated 73.45%, reflecting higher variability, and looked to correspond with L1 and its hybrid. In general, continuous flooding (CF), I_6, and kinetin treatments were presented on the extremely PCA1 positive side.

There is a strong positive relationship between the measured growth, floral, and yield-related traits as located on the positive side of PC1, especially for 30 mg L^{-1} from kinetin, continuous flooding, and L1 (IR69625A × G178R, yield traits) performance. On the contrary, severe water deficits (I_9, I_{12}, and I_{15}) are located on the opposite side, presenting lower-evaluated traits. Otherwise, the traits of floral, growth, and yield displayed a highly significant and positive correlation by adjacent vectors except for the traits: days to complete leaf number (DCLN), days to heading (DTH, 50%).

Applying correlation by heatmap depicted the measured vegetative, floral, and yield characteristics in the two CMS lines under water shortage and kinetin implementation into two main groups (Figure 2). Approximately, continuous flooding, irrigation every 6 days (I_6), kinetin spray (30 mg L^{-1}), and L1 grouped together, whereas I_9, I_{12}, I_{15}, L2, and kinetin treatments (control and 15 mg L^{-1}) located in another cluster. A strong positive and significant association was detected among all studied traits in the first cluster except SOA, FLA, and DSO in L1, while the same traits were positive in L2.

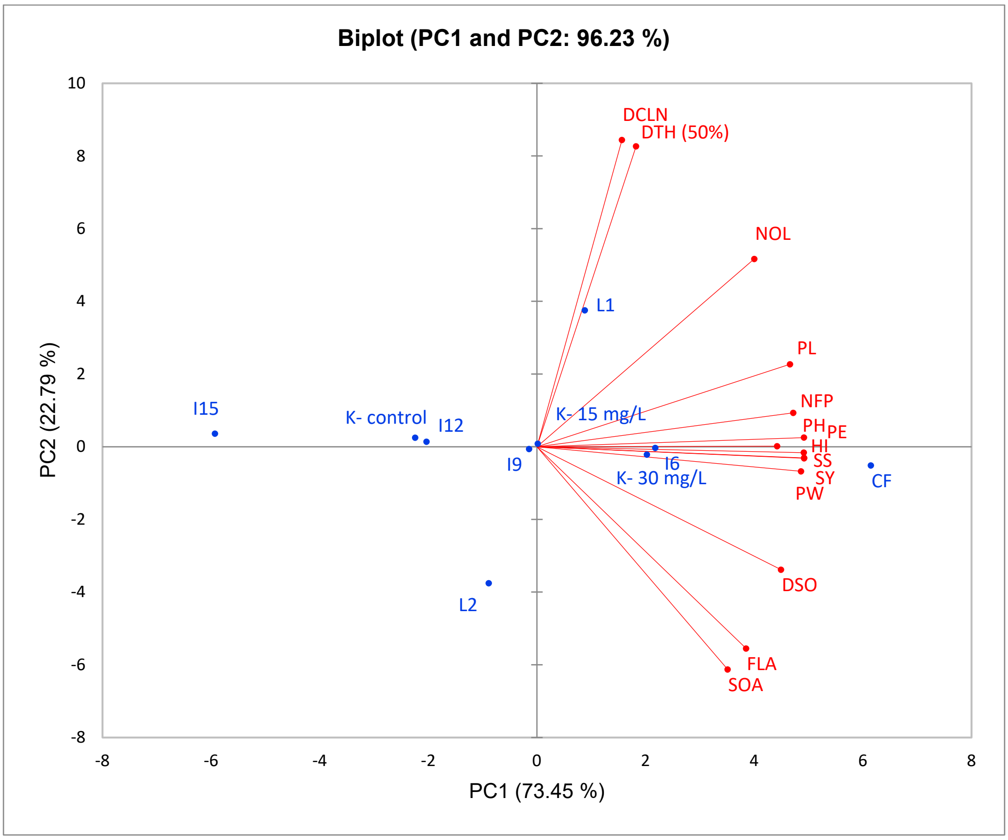

Figure 1. PC-biplot for the applied kinetin treatments coupled with irrigation intervals with two CMS lines based on evaluated growth traits (number of leaves (NOL), days to complete leaf number (DCLN), days to heading (DTH, 50%), flag leaf area (FLA), and plant height (PH)), floral traits (panicle length (PL), panicle exertion (PE), spikelet opening angle (SOA), and duration of spikelet opening (DSO)), and seed yield traits (panicle weight (PW), seed set (SS), seed yield (SY), harvest index (HI), and number of fertile panicles per hill (NFP)).

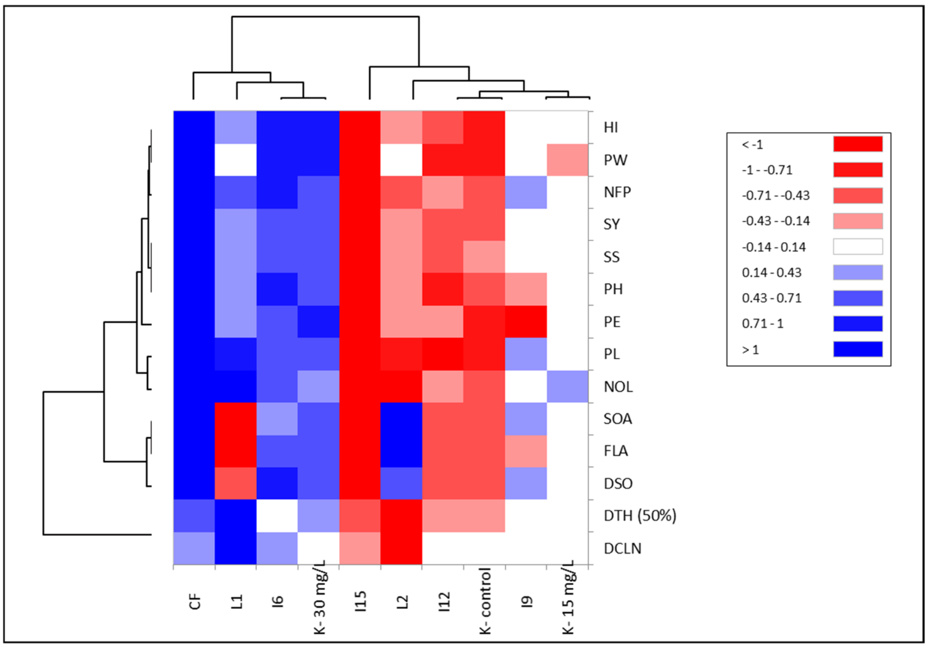

Figure 2. Correlation heatmap of the evaluated growth, floral, and yield traits of two CMS lines under kinetin and drought conditions.

4. Discussion

Hybrid rice systems provide an excellent choice for attaining a potential high yield under favorable conditions; meanwhile, hybrid rice seed production under drought stress has not yet been fully evaluated [30]. Irrigation intervals had a highly negative and significant effect on all growth traits. Under severe water deficit (I_{15} treatment), the number of leaves (NOL), flag leaf area (FLA), and plant height (PH) reduced up to 14.9%, 15.2%, and 11.9%, respectively, in comparison to control (CF). Accordingly, kinetin application (30 mg L^{-1}) displayed significant or highly positive significant effects on NOL, FLA, and PH, with increments measuring 4.1%, 5%, and 3%, respectively. In addition, I × L × K interaction revealed a highly significant increase in FLA and PH. These increments in NOL, FLA, and PH are due to the effect of kinetin, which promotes cell division, regulates shoot meristem size and leaf primordia number, stimulates axillary bud break and leaf and shoot growth, and subsequently improves the plant's growth and development, leading to an increase in plant height and leaf area [31,32].

Assessment of seventeen rice genotypes under water deficit caused considerable reductions in days to heading (DTH), flag leaf area (FLAR), plant height (PH), flag leaf angle (FLA), relative water content (RWC), chlorophyll content (CHC), grain yield (GY), and its related traits [13,33,34]. The use of phytohormones such as abscisic acid, indole-3-carboxylic acid, gibberellic acid (GA_3) and jasmonic acid led to leaf and root tolerance in rice plants [35]. Abscisic acid (ABA), the most critical hormone produced in response to a water deficit) accumulates in guard cells, reduces turgor pressure, causes stomata closure, and decreases transpirational water loss. Exogenous implementation of ABA on plant leaves improves cell wall extensibility, root hydraulic transmission, tissue turgidity, and total chlorophyll contents [36]. In addition, gibberellins (GAs) stimulate many aspects of plant growth, such as flowering time, flower development, elongation growth, and germination [37]. Reguera et al. [38] indicated that the stress-induced cytokinin synthesis enhanced sink strengthening via regulation of nitrogen and carbon assimilation and promoted tolerance to water shortages in the rice transgenic plants. The phytohormone kinetin plays an important role in controlling various processes during the cycle of plant life and improves photosynthesis performance in plants by stimulating enzymes involved in photosynthesis, light capture, leaf area, and enhancing the nutrients efficacy. Moreover, it promotes flowering and seed set in plants [21,39]. Cytokinin promotes cell division and acts with other plant hormones in both synergy and antagonistic manners, influencing a wide range of events during plant growth and development [40–43]. Plant growth is completed via cell division, differentiation, and enlargement, which involve morphological, genetic, physiological, and ecological events in addition to their complex interactivity [44,45]. Furthermore, cytokinin (i.e., kinetin) plays an important role in the nutrient metabolic pathway of crop plants during stress. It improved the contents of Zn, Mn, S, and Fe in cereal seeds, which led to an increase in the cytokine dehydrogenase enzyme, resulting in an improvement of the root system, water absorption, and scavenging nutrients from the soil under drought stress [32].

Based on the literature, varied concentrations of kinetin were applied to a variety of crops. Glycine betaine (100 mM) and kinetin (1 mM) in combination were applied to rice at the flowering stage as a foliar spray under water stress to enhance proline and soluble sugar concentrations in leaves [46]. Koprna et al. [47] applied three cytokinin derivatives, with 10 μM concentration in field trial experiments by foliar spraying in winter wheat and spring barley at the tillering stage. On the other hand, Sawan et al. [48] used kinetin (0–10 mg/L) on Egyptian cotton with three different application methods to improve seed viability and seedling vigor, whereas Li et al. [49] implemented (0–40 mg/L) with two *Pteris* species under arsenate stress.

At the floral stage, water deficit affects panicle length (PL), panicle exertion (PE), spikelet opening angle (SOA), and duration of spikelet opening (DSO) (Table 6). As expected, negative and significant decreases in all floral traits were detected with prolonged water scarcity. The CMS lines displayed highly significant effects for panicle length (PL), duration of spikelet opening (DSO), and spikelet opening angle (SOA). Remarkably, the plant hormone kinetin (30 mg L^{-1}) positively improved floral traits such as PL, PE, SOA, and DSO values when compared to non-treated plants. Nahar et al. [50] reported the morphological and physiological responses under water limitation in rice that involve a lower chlorophyll content, a lower rate of photosynthesis, slower growth rate, low root and shoot length, inhibition of seed germination, stomatal closure, and a reduction in yield. Exogenous application of plant growth hormones was employed for reducing the effects of drought stress and improving drought tolerance through increasing growth, development, and plant productivity. Phytohormones such as cytokinins (i.e., kinetin) are essential for the growth of plants via participation in the germination of seeds, floral development, photomorphogenesis, leaf senescence, vascular development, and development of the shoot apical meristem. Notably, cytokinin assists plants to stimulate adaptive responses to water deficits and adverse ecological conditions [21,51,52]

The assessed yield traits in the two CMS lines under stressed conditions and kinetin application exhibited a highly significant and negative effect, with reductions in panicle weight (PW), seed set (SS), seed yield (SY), harvest index (HI), and number of fertile panicles per hill (NFP) reaching 41%, 61%, 45%, 30%, and 48%, respectively (Table 10). Applying 30 mg L^{-1} of kinetin improved PW by 22%, SS by 17%, SY by 14%, HI by 14.5%, and NFP by 15%. Yang et al. [53] estimated grain yield under water deficit in two rice cultivars under two water treatments. They recorded reductions in yield of 23.2% for YLY6 and 24.0% for HY113, in addition to decreases in all physiological traits under water stress, with no reversion to normal levels at the grain filling stage.

Drought stress caused various structural and functional perturbations in reproductive organs, leading to failure of fertilization or abortion of premature seed formation [54]. Early senescence, a shortened grain-filling period, photosynthesis reduction, and increasing soluble sugar remobilization from grains to other vegetative parts are detected when water deficit occurs at the reproductive stage [55]. The reduction in grain yield is largely attributed to limited source activity and sink size. In crop plants, improving the leaf structure, root system, osmotic balance, stomatal adjustment, and water contents are the most prominent features against drought stress.

In the present study, growth, floral, and yield-related traits that were adversely affected by drought were ameliorated by foliar spraying of kinetin. The results showed the highest number of leaves (NOL), days to complete leaf number (DCLN), days to heading (DTH), flag leaf area (FLA), and plant height (PH) in non-treated plants. Floral characteristics, i.e., panicle length (PL), panicle exertion (PE), spikelet opening angle (SOA), and duration of spikelet opening (DSO), declined with a continuous reduction in water. Otherwise, kinetin spray application (15 mg L^{-1} and 30 mg L^{-1}) enhanced these growth traits under water deficit conditions. Drought stress has a strong influence on rice at the flowering stage, physiological traits, and yield [22,56]. In the susceptible rice genotypes, water shortage during the vegetative stage induces leaf rolling, reduces plant height and chlorophyll content, and minimizes the number of tillers/plants. The grain yield reduction, 100 grain weight, number of panicles/plant, and high sterility percentage resulted from drought at the flowering and ripening stages. Drought at vegetative, flowering, and panicle initiation over the season minimized the grain yield by 28%, 40%, 34%, and 22%, respectively, when compared to control in rice [53,57,58].

Jalal-ud-Din et al. [46] evaluated the effect of exogenous application of kinetin (KIN) and glycine betain (GB) at the flowering stage on some yield attributes of two rice varieties (*Oryza sativa* L.) under water stress. Proline content in leaves and panicles, soluble sugar in the leaves and panicles, starch concentration in leaves and panicles, paddy yield, the number of seeds per panicle were significantly increased by KIN and GB spray. The same trend was observed in both yield-related traits. These traits (panicle weight, seed set, seed yield, harvest index, and number of fertile panicles per hill) decreased with increasing irrigation intervals. Rice lines irrigated with 12 day intervals and 15 day intervals had the highest negative effects on all traits. Yield under three drought stress levels (well-watered, moderate, and severe) exhibited 54%, 77%, and 89% reductions in yield, respectively [34,59].

Additionally, grain yield was significantly reduced by 23.2% for YLY6 and 24.0% for HY113 under drought stress [48].

The interaction between irrigation treatments and genotypes affected the flag leaf area significantly in both seasons. Zubaer et al. [60] reported significant interaction effects of different levels of moisture and rice genotypes on leaf area/hill at all stages of growth. In addition, the development of the number of tillers plant^{-1} was severely affected by the stress. These results demonstrate the most obvious effect of the water shortage on the number of tillers in the two seasons. This may be due to reduced nutrient uptake under water stress as a result of reduced demand for new tillage development. Ndebe et al. [61], Kasim et al. [62] recorded that there was no significant difference ($p \leq 0.05$) in panicle length among the tested rice varieties, whereas panicle length was positively correlated to grain yield in upland varieties. Otherwise, days to 50% flowering correlated significantly with number of panicles, number of tillers, and plant height. Additionally, plants watered daily have longer panicles than plants watered every 2, 4, and 6 days.

Applying the PCA-biplot is a suitable method to evaluate the correlation between the traits under study. Our obtained results coming from this approach reinforced the above-mentioned results. Robust positive associations were detected among all measured floral, growth, and yield-related traits in CMS line L1 under CF, I_6, and kinetin treatments. Our results involved in the present study revealed that the kinetin application treatment with promising CMS lines such as L1 enhances floral traits, plant growth and development, plant yield, and hence increases the CMS lines outcrossing rate and hybrid seed production. Kamara et al. [63], Sakran et al. [56] found positive and significant associations between F1 hybrid performance and specific combining ability (SCA) for characteristics and grain yield per plant traits in maize and between grain yield and each of relative water content, number of filled grains per panicle, 1000 grain weight, chlorophyll content, and number of panicles per plant in rice under water shortage.

5. Conclusions

Increasing the water deficit (irrigation every 6, 9, 12, and 15 days) causes severe harm to rice plants and affects the growth, floral, and yield traits. Exogenous application of the phytohormone kinetin (30 mg L^{-1}) minimized the harmful effects of water shortage and positively enhanced the yield traits, panicle weight, seed set, seed yield, harvest index, and fertile panicle per hill by 22%, 17%, 14%, 14.5%, and 15%, respectively, in two CMS lines (IR69625A and G46A). The hereby study showed that L1 (IR69625A) was more tolerant to drought stress than L2 (G46A) under kinetin implementation through an increase in plant biomass. Briefly, applying the exogenous kinetin with the CMS line (IR69625A) enhanced the growth, floral, and seed-related traits that recommend implementing it under water shortage conditions.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15075623/s1, Table S1. Effect of interaction between irrigation intervals and CMS lines on plant traits during the 2020 and 2021 seasons; Table S2. Effect of interaction between irrigation intervals and CMS lines on plant floral traits in both seasons; Table S3. Effect of interaction between CMS lines and irrigation periods on panicle traits and yield during the 2020 and 2021 seasons.

Author Contributions: Conceptualization, H.S.H., E.M.B. and K.A.; methodology, H.S.H., E.M.B. and E.E.G.; formal analysis, H.S.H., E.M.B.; investigation, H.S.H. and E.M.B.; funding publication, K.A. and M.R.; writing—original draft preparation, E.M.B. and M.R.; writing—review and editing, E.M.B. and M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2023R188), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors are grateful to all members at RRTC, Field Crops Research Institute, and ARC, Egypt, for the support provided whilst conducting this research. The authors extend their appreciation to Princess Nourah bint Abdulrahman University Researchers Supporting Project Number (PNURSP2023R188), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Statista. *Worldwide Production of Grain in 2021/22, by Type*; Statista: London, UK, 2022.
2. Bhavsar, S.; Solanki, T.; Amin, S.; Jain, N. Assessment of genetic purity of parental lines of hybrid rice using DNA-based markers. *Online J. Biol. Sci.* **2015**, *15*, 59–69. [CrossRef]
3. Abo-Yousef, M. Application for Hybrid Rice Technology at Egypt. *Ann. Agric. Sci. Moshtohor* **2018**, *56*, 3–16. [CrossRef]
4. Virmani, S.; Hossain, M.; Bayarsaihan, T. *Policy Support Needs of Hybrid Rice Technology in Asia*; International Rice Research Institute (IRRI): Los Baños, Philippines, 2006.
5. Virmani, S.S. Hybrid Rice: The Future of Rice Cultivation. *Asia-Pac. Biotech News* **2002**, *06*, 942–949. [CrossRef]
6. Raza, A.; Mubarik, M.S.; Sharif, R.; Habib, M.; Jabeen, W.; Zhang, C.; Chen, H.; Chen, Z.-H.; Siddique, K.H.M.; Zhuang, W.; et al. Developing drought-smart, ready-to-grow future crops. *Plant Genome* **2023**, *16*, e20279. [CrossRef]
7. Fahad, S.; Bajwa, A.A.; Nazir, U.; Anjum, S.A.; Farooq, A.; Zohaib, A.; Sadia, S.; Nasim, W.; Adkins, S.; Saud, S.; et al. Crop Production under Drought and Heat Stress: Plant Responses and Management Options. *Front. Plant Sci.* **2017**, *8*, 1147. [CrossRef]
8. Pantuwan, G.; Fukai, S.; Cooper, M.; Rajatasereekul, S.; O'Toole, J.C. Yield response of rice (*Oryza sativa* L.) genotypes to different types of drought under rainfed lowlands: Part 1. Grain yield and yield components. *Field Crops Res.* **2002**, *73*, 153–168. [CrossRef]
9. Oladosu, Y.; Rafii, M.Y.; Samuel, C.; Fatai, A.; Magaji, U.; Kareem, I.; Kamarudin, Z.S.; Muhammad, I.; Kolapo, K. Drought Resistance in Rice from Conventional to Molecular Breeding: A Review. *Int. J. Mol. Sci.* **2019**, *20*, 3519. [CrossRef]
10. Panda, D.; Mishra, S.S.; Behera, P.K. Drought Tolerance in Rice: Focus on Recent Mechanisms and Approaches. *Rice Sci.* **2021**, *28*, 119–132. [CrossRef]
11. Swain, P.; Raman, A.; Singh, S.P.; Kumar, A. Breeding drought tolerant rice for shallow rainfed ecosystem of eastern India. *Field Crops Res.* **2017**, *209*, 168–178. [CrossRef]
12. Torres, R.O.; Henry, A. Yield stability of selected rice breeding lines and donors across conditions of mild to moderately severe drought stress. *Field Crops Res.* **2018**, *220*, 37–45. [CrossRef]
13. El-Hashash, E.F.; Agwa, A.M. Genetic Parameters and Stress Tolerance Index for Quantitative Traits in Barley under Different Drought Stress Severities. *Asian J. Res. Crop Sci.* **2018**, *1*, 1–16. [CrossRef]
14. Raza, A.; Razzaq, A.; Mehmood, S.S.; Zou, X.; Zhang, X.; Lv, Y.; Xu, J. Impact of Climate Change on Crops Adaptation and Strategies to Tackle Its Outcome: A Review. *Plants* **2019**, *8*, 34. [CrossRef] [PubMed]
15. El-Hashash, E.; El-Agoury, R. Comparison of Grain Yield-Based Drought Tolerance Indices under Normal and Stress Conditions of Rice in Egypt. *J. Agric. Vet. Sci.* **2019**, *6*, 14. [CrossRef]
16. Lafitte, H.R.; Courtois, B. Interpreting cultivar X environment interactions for yield in upland rice: Assigning value to drought-adaptive traits. *Crop Sci.* **2002**, *42*, 1409–1420. [CrossRef]
17. Seleiman, M.F.; Al-Suhaibani, N.; Ali, N.; Akmal, M.; Alotaibi, M.; Refay, Y.; Dindaroglu, T.; Abdul-Wajid, H.H.; Battaglia, M.L. Drought Stress Impacts on Plants and Different Approaches to Alleviate Its Adverse Effects. *Plants* **2021**, *10*, 259. [CrossRef]
18. Ahmad, P.; Latef, A.A.A.; Hashem, A.; Abd Allah, E.F.; Gucel, S.; Tran, L.S.P. Nitric oxide mitigates salt stress by regulating levels of osmolytes and antioxidant enzymes in chickpea. *Front. Plant Sci.* **2016**, *7*, 347. [CrossRef]
19. Chhaya; Yadav, B.; Jogawat, A.; Gnanasekaran, P.; Kumari, P.; Lakra, N.; Lal, S.K.; Pawar, J.; Narayan, O.P. An overview of recent advancement in phytohormones-mediated stress management and drought tolerance in crop plants. *Plant Gene* **2021**, *25*, 100264. [CrossRef]
20. Ullah, A.; Manghwar, H.; Shaban, M.; Khan, A.H.; Akbar, A.; Ali, U.; Ali, E.; Fahad, S. Phytohormones enhanced drought tolerance in plants: A coping strategy. *Environ. Sci. Pollut. Res.* **2018**, *25*, 33103–33118. [CrossRef]
21. Iqbal, S.; Wang, X.; Mubeen, I.; Kamran, M.; Kanwal, I.; Díaz, G.A.; Abbas, A.; Parveen, A.; Atiq, M.N.; Alshaya, H.; et al. Phytohormones Trigger Drought Tolerance in Crop Plants: Outlook and Future Perspectives. *Front. Plant Sci.* **2022**, *12*, 799318. [CrossRef]
22. Ahmad, H.M.; Wang, X.; Ijaz, M.; Mahmood-Ur-Rahman; Oranab, S.; Ali, M.A.; Fiaz, S. Molecular Aspects of MicroRNAs and Phytohormonal Signaling in Response to Drought Stress: A Review. *Curr. Issues Mol. Biol.* **2022**, *44*, 3695–3710. [CrossRef]
23. Akhtar, S.S.; Mekureyaw, M.F.; Pandey, C.; Roitsch, T. Role of Cytokinins for Interactions of Plants with Microbial Pathogens and Pest Insects. *Front. Plant Sci.* **2020**, *10*, 1777. [CrossRef] [PubMed]
24. Novakova, M.; Dobrev, P.; Motyka, V.; Gaudinova, A.; Malbeck, J.; Pospisilova, J.; Haisel, D.; Storchova, H.; Dobra, J.; Mok, M.C.; et al. *Cytokinin Function in Drought Stress Response and Subsequent Recovery BT—Biotechnology and Sustainable Agriculture 2006 and beyond*; Xu, Z., Li, J., Xue, Y., Yang, W., Eds.; Springer Netherlands: Dordrecht, The Netherlands, 2007; pp. 171–174.

25. Kaya, C.; Akram, N.A.; Ashraf, M. Kinetin and Indole Acetic Acid Promote Antioxidant Defense System and Reduce Oxidative Stress in Maize (*Zea mays* L.) Plants Grown at Boron Toxicity. *J. Plant Growth Regul.* **2018**, *37*, 1258–1266. [CrossRef]
26. Lazar, T.; Taiz, L.; Zeiger, E. Plant physiology. 3rd edn. *Ann. Bot.* **2003**, *91*, 750–751. [CrossRef]
27. Bielach, A.; Hrtyan, M.; Tognetti, V.B. Plants under stress: Involvement of auxin and cytokinin. *Int. J. Mol. Sci.* **2017**, *18*, 1427. [CrossRef]
28. Radchuk, V.; Radchuk, R.; Pirko, Y.; Vankova, R.; Gaudinova, A.; Korkhovoy, V.; Yemets, A.; Weber, H.; Weschke, W.; Blume, Y.B. A somaclonal line SE7 of finger millet (*Eleusine coracana*) exhibits modified cytokinin homeostasis and increased grain yield. *J. Exp. Bot.* **2012**, *63*, 5497–5506. [CrossRef] [PubMed]
29. Stern, R.D. Statistical Procedures in Agricultural Research, by K. A. Gomez and A. A. Gomez. New York, Chichester, etc.: Wiley (1984), 2nd edition, paperback, pp. 680, price not stated. *Exp. Agric.* **1986**, *22*, 313. [CrossRef]
30. Villa, J.E.; Henry, A.; Xie, F.; Serraj, R. Hybrid rice performance in environments of increasing drought severity. *Field Crops Res.* **2012**, *125*, 14–24. [CrossRef]
31. Werner, T.; Motyka, V.; Strnad, M.; Schmülling, T. Regulation of plant growth by cytokinin. *Proc. Natl. Acad. Sci. USA* **2001**, *98*, 10487–10492. [CrossRef]
32. Prasad, R. Cytokinin and Its Key Role to Enrich the Plant Nutrients and Growth Under Adverse Conditions—An Update. *Front. Genet.* **2022**, *13*, 883924. [CrossRef]
33. Gaballah, M.M.; Ghoneim, A.M.; Rehman, H.U.; Shehab, M.M.; Ghazy, M.I.; El-Iraqi, A.S.; Mohamed, A.E.; Waqas, M.; Shamsudin, N.A.; Chen, Y. Evaluation of Morpho-Physiological Traits in Rice Genotypes for Adaptation under Irrigated and Water-Limited Environments. *Agronomy* **2022**, *12*, 1868. [CrossRef]
34. Zhang, J.; Zhang, S.; Cheng, M.; Jiang, H.; Zhang, X.; Peng, C.; Lu, X.; Zhang, M.; Jin, J. Effect of Drought on Agronomic Traits of Rice and Wheat: A Meta-Analysis. *Int. J. Environ. Res. Public Health* **2018**, *15*, 839. [CrossRef] [PubMed]
35. Ubaidillah, M.; Safitri, F.; Jo, J.-H.; Lee, S.-K.; Hussain, A.; Mun, B.-G.; Chung, I.; Yun, B.-W.; Kim, K.-M. Roles of plant hormones and anti-apoptosis genes during drought stress in rice (*Oryza sativa* L.). *3 Biotech* **2016**, *6*, 247. [CrossRef] [PubMed]
36. Wilkinson, S.; Davies, W.J. ABA-based chemical signalling: The co-ordination of responses to stress in plants. *Plant. Cell Environ.* **2002**, *25*, 195–210. [CrossRef] [PubMed]
37. Schwechheimer, C. Gibberellin Signaling in Plants—The Extended Version. *Front. Plant Sci.* **2012**, *2*, 107. [CrossRef] [PubMed]
38. Reguera, M.; Peleg, Z.; Abdel-Tawab, Y.M.; Tumimbang, E.B.; Delatorre, C.A.; Blumwald, E. Stress-Induced Cytokinin Synthesis Increases Drought Tolerance through the Coordinated Regulation of Carbon and Nitrogen Assimilation in Rice. *Plant Physiol.* **2013**, *163*, 1609–1622. [CrossRef] [PubMed]
39. Pan, S.; Rasul, F.; Li, W.; Tian, H.; Mo, Z.; Duan, M.; Tang, X. Roles of plant growth regulators on yield, grain qualities and antioxidant enzyme activities in super hybrid rice (*Oryza sativa* L.). *Rice* **2013**, *6*, 9. [CrossRef]
40. Mohd Zain, N.A.; Ismail, M.R. Effects of potassium rates and types on growth, leaf gas exchange and biochemical changes in rice (*Oryza sativa*) planted under cyclic water stress. *Agric. Water Manag.* **2016**, *164*, 83–90. [CrossRef]
41. Zhao, D.L.; Atlin, G.N.; Amante, M.; Cruz, M.T.S.; Kumar, A. Developing aerobic rice cultivars for water-short irrigated and drought-prone rainfed areas in the tropics. *Crop Sci.* **2010**, *50*, 2268–2276. [CrossRef]
42. Abarshahr, M.; Rabiei, B.; Samizadeh Lahigi, H. Assessing Genetic Diversity of Rice Varieties under Drought Stress Conditions. *Not. Sci. Biol.* **2011**, *3*, 114–123. [CrossRef]
43. Sabagh, A.E.L.; Mbarki, S.; Hossain, A.; Iqbal, M.A.; Islam, M.S.; Raza, A.; Llanes, A.; Reginato, M.; Rahman, M.A.; Mahboob, W.; et al. Potential Role of Plant Growth Regulators in Administering Crucial Processes against Abiotic Stresses. *Front. Agron.* **2021**, *3*, 648694. [CrossRef]
44. Terra, T.G.R.; de Barros Leal, T.C.A.; Rangel, P.H.N.; Barros, H.B.; dos Santos, A.C. Tolerância à seca de cultivares de arroz no cerrado do estado do Tocantins, Brasil. *Acta Sci.-Agron.* **2010**, *32*, 715–719. [CrossRef]
45. Bozorgi, H.R.; Tarighi, F.; Moradi, M.; Azarpour, E. The study effect of drought stress on four native rice varieties in Iran. *World Appl. Sci. J.* **2011**, *13*, 410–414.
46. Din, J.-U.-D.; Khan, S.; Khan, A.; Naveed, S. Effect of Exogenously Applied Kinetin and Glycinebetaine on Metabolic and Yield Attributes of Rice (*Oryza sativa* L.) under Drought Stress. *Emir. J. Food Agric.* **2014**, *27*, 75–81. [CrossRef]
47. Koprna, R.; Humplík, J.F.; Špíšek, Z.; Bryksová, M.; Zatloukal, M.; Mik, V.; Novák, O.; Nisler, J.; Doležal, K. Improvement of Tillering and Grain Yield by Application of Cytokinin Derivatives in Wheat and Barley. *Agronomy* **2021**, *11*, 67. [CrossRef]
48. Sawan, Z.M.; Mohamed, A.A.; Sakr, R.A.; Tarrad, A.M. Effect of Kinetin Concentration and Methods of Application on Seed Germination, Yield Components, Yield and Fiber Properties of the Egyptian Cotton (*Gossypium barbadense*). *Environ. Exp. Bot.* **2000**, *44*, 59–68. [CrossRef] [PubMed]
49. Li, Q.; Wang, H.; Wang, H.; Zheng, W.; Wu, D.; Wang, Z. Effects of kinetin on plant growth and chloroplast ultrastructure of two *Pteris* species under arsenate stress. *Ecotoxicol. Environ. Saf.* **2018**, *158*, 37–43. [CrossRef] [PubMed]
50. Nahar, S.; Kalita, J.; Sahoo, L.; Tanti, B. Morphophysiological and molecular effects of drought stress in rice. *Ann. Plant Sci.* **2016**, *5*, 1409. [CrossRef]
51. Kamran, M.; Malik, Z.; Parveen, A.; Zong, Y.; Abbasi, G.H.; Rafiq, M.T.; Shaaban, M.; Mustafa, A.; Bashir, S.; Rafay, M. Biochar alleviates Cd phytotoxicity by minimizing bioavailability and oxidative stress in pak choi (*Brassica chinensis* L.) cultivated in Cd-polluted soil. *J. Environ. Manag.* **2019**, *250*, 109500. [CrossRef] [PubMed]

52. Safari, M.; Mousavi-Fard, S.; Rezaei Nejad, A.; Sorkheh, K.; Sofo, A. Exogenous salicylic acid positively affects morpho-physiological and molecular responses of *Impatiens walleriana* plants grown under drought stress. *Int. J. Environ. Sci. Technol.* **2022**, *19*, 969–984. [CrossRef]
53. Yang, X.; Wang, B.; Chen, L.; Li, P.; Cao, C. The different influences of drought stress at the flowering stage on rice physiological traits, grain yield, and quality. *Sci. Rep.* **2019**, *9*, 3742. [CrossRef]
54. Zaman, N.K.; Abdullah, M.Y.; Othman, S.; Zaman, N.K. Growth and Physiological Performance of Aerobic and Lowland Rice as Affected by Water Stress at Selected Growth Stages. *Rice Sci.* **2018**, *25*, 82–93. [CrossRef]
55. Zain, N.A.M.; Ismail, M.R.; Mahmood, M.; Puteh, A.; Ibrahim, M.H. Alleviation of Water Stress Effects on MR220 Rice by Application of Periodical Water Stress and Potassium Fertilization. *Molecules* **2014**, *19*, 1795–1819. [CrossRef] [PubMed]
56. Sakran, R.M.; Ghazy, M.I.; Rehan, M.; Alsohim, A.S.; Mansour, E. Molecular Genetic Diversity and Combining Ability for Some Physiological and Agronomic Traits in Rice under Well-Watered and Water-Deficit Conditions. *Plants* **2022**, *11*, 702. [CrossRef] [PubMed]
57. Kamara, M.M.; Rehan, M.; Mohamed, A.M.; El Mantawy, R.F.; Kheir, A.M.S.; Abd El-Moneim, D.; Safhi, F.A.; ALshamrani, S.M.; Hafez, E.M.; Behiry, S.I.; et al. Genetic Potential and Inheritance Patterns of Physiological, Agronomic and Quality Traits in Bread Wheat under Normal and Water Deficit Conditions. *Plants* **2022**, *11*, 952. [CrossRef]
58. Gaballah, M.M.; Abd Allah, A.A. Effect of Water Irrigation Shortage on Some Quantitative Characters at Different Rice Development Growth Stages. *World Rural Obs.* **2015**, *16*, 39–55. [CrossRef]
59. Gaballah, M.M.; Ghoneim, A.M.; Ghazy, M.I.; Mohammed, H.M.; Sakran, R.M.; Rehman, H.U.; Shamsudin, N.A.A. Root Traits Responses to Irrigation Intervals in Rice (*Oryza sativa*). *Int. J. Agric. Biol.* **2021**, *26*, 22–30. [CrossRef]
60. Zubaer, M.A.; Chowdhury, A.K.M.M.B.; Islam, M.Z.; Hasan, M.A.; Ahmed, T. Effects of Water Stress on Growth and Yield Attributes of Aman Rice Genotypes. *Int. J. Sustain. Crop Prod.* **2007**, *2*, 25–30.
61. Ndebe, A.K.; Asumanah, P.; Massaquo, M.; Ndaloma, P.G.; Lahai, S.; Kolleh, D.M.; Ahiakpa, K. Agronomic performance of four upland rice genotypes under rainfed condition. *Afr. J. Food Agric. Nutr. Dev.* **2018**, *18*, 13304–13316. [CrossRef]
62. Kasim, N.; Yao, T.; Namasivayam, P.; Mohd Yusoff, N.F.; Chai, L. Analyses of yield related agronomic traits of Malaysian rice varieties. *Asia Pac. J. Mol. Biol. Biotechnol.* **2020**, *28*, 59–74. [CrossRef]
63. Kamara, M.M.; Rehan, M.; Ibrahim, K.M.; Alsohim, A.S.; Elsharkawy, M.M.; Kheir, A.M.S.; Hafez, E.M.; El-Esawi, M.A. Genetic Diversity and Combining Ability of White Maize Inbred Lines under Different Plant Densities. *Plants* **2020**, *9*, 1140. [CrossRef]