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The combined effects of gibberellic acid and kinetin on growth, yield and quality in globe artichoke (*Cynara scolymus* L.)

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ABSTRACT:

The globe artichoke cv. 'Balady' is considered one of the most important cultivars in Egypt due to the earliness of its flowering compared with other cultivars, but the size of its head is small. Two field experiments were conducted during 2019-2020 and 2020-2021 growing seasons to assess the effects of gibberellic acid (GA_3) and kinetin (KN) alone or in various combinations on the growth, earliness, productivity, and head quality of globe artichokes. The results showed that plants treated with combination of GA_3 (20 ppm) and KN (50 ppm) had superior effects on growth, number of early heads feddan^{-1}, total number of heads feddan^{-1}, fresh weight of head, and head size as measured by length, and diameter of the head. Comparison with the control, the foliar spraying of 20 ppm GA_3 + 50 ppm KN raised the percentages of number of early head feddan^{-1} by 180 %, total number of head feddan^{-1} by 24 %, head fresh weight by 8%, head length by 21% and head diameter by 21%, in both seasons. Also, the same treatment recorded the highest values for the leaf minerals and chlorophyll contents as well as head quality traits (minerals, protein, inulin and ascorbic acid content). However, only the content of total phenolic compounds in heads was reduced with all exogenous hormone applications. Therefore, the combined treatment with 20 ppm GA_3 and 50 ppm KN might be considered as an optimal treatment to produce the highest yield with good quality of globe artichoke cv. 'Balady'.

Keywords: Globe artichoke, Gibberellic acid, Cytokinin, Kinetin, Yield, Chemical constituents

1. INTRODUCTION:

Globe artichoke (*Cynara scolymus* L.) is a major vegetable crop in the *Asteraceae* family. It is a perennial rosette crop that is planted all over the globe for its nutritious and juicy heads (Mauromicale et al. 2003; Anido et al. 2005). Artichoke is also regarded as one of the most important medicinal plants due to its high content of phenolic components such as flavonoids, inulin, fibers, and vitamins, as well as the fact that it has essential nutritional value. Cynarin, for example, has an impact on hyperlipidemia, hepatitis, dropsy, cholesterol metabolism, and rheumatism (Mauromicale et al. 2003).

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The artichoke is extensively grown across the Mediterranean area, including Egypt. In Egypt, the overall artichoke cultivation area was 16103 hectares, yielding around 308844 tons (FAO, 2019). The largest amount of globe artichoke production in Egypt occurs in March and April, whereas the best season for export to European nations is from December to February. Because of the high demand and pricing, the earlier production at this time is seen as crucial. To fulfill export needs, shifting the yield distribution would be of tremendous importance. Environmental conditions, cultivar features, soil management practices, nutritional strategies, and propagation techniques all impact artichoke yield and head emergence (Elsharkawy and Ghoneim, 2019).

To generate generative stems and flowers, artichoke production needs a low temperature and a prolonged photoperiod (Mauromicale and Ierna, 1995) . It is well established that artichoke cultivars need verbalization to transition from the vegetative to the reproductive stage, which begins quite early in the colder climates (during autumn). The optimum temperature for vernalization was between 2 and 7°C (Harwood and Markarian, 1968) . Out-of-season production most often happens during the warm period of the year; thus, plants frequently do not have enough times of low temperature to stimulate blooming; thus, foliar treatment of gibberellic acid (GA_3) might be an alternate solution.

Gibberellic acid, a naturally occurring hormone, is known as a growth hormone for plant development, and it is added exogenously to accelerate the flower initiation process that leads to head production in globe artichoke, particularly between December and February. In unfavorable photoperiod conditions, Basnizki et al. (1994) discovered that gibberellic acid triggered generative stems in artichoke plants. Furthermore, gibberellic acid reduced the time between planting and harvesting and enhanced yield (Venere et al. 2000) . According to Soliman et al., (2019) , GA_3 is widely used in Egypt and other countries to boost the development and production of several crops such as tomatoes, globe artichokes, cabbages, and cauliflower. Furthermore, much research has been reported on the influence of gibberellic acid (GA_3) on globe artichoke growth, yield, and quality.

Other plant hormones, such as cytokinins (CKs), were discovered from the extracted DNA of autoclaved herring sperm and were an efficient stimulator of tobacco pith cell development in culture (Miller and Skoog,1953) .They identified the active form as 6-furfurylaminopurine, an adenine derivative, and named it kinetin (Haberer and Kieber, 2002) . Zeatin was subsequently discovered to be the first naturally occurring CK in immature maize endosperm and the most frequent CK in coconut milk (Haberer and Kieber, 2002; Kieber and Schaller, 2014). Cytokinins discovered in nature are adenine derivatives with distinct N6 adenine ring substitutions. The list of chemicals that meet the CK criteria has grown to include a diverse variety of natural and synthetic compounds, including adenine and phenylurea derivatives. Cytokinins have a variety of physiological functions in plant development, including seed germination, shoot growth, blooming, fruit ripening and seed set development (Lomin et al. 2020) . Their effectiveness as agrochemicals in field studies, where they boost the development and yields of a broad variety of plants, including horticulture crops, is particularly noteworthy (Haberer and Kieber, 2002; Werner and Schmülling , 2009). However, there is little evidence on the impact of Ck hormones on artichoke growth, yield, earliness, and quality.

Another vital factor in affecting the quality and quantity of a crop is the

cultivar (Abouelsaad et al. 2022; Brengi et al. 2021) . Numerous studies have shown significant differences between artichoke cultivars in
several traits, including early flowering, yield, and quality. The globe artichoke cv. 'Balady' is one of the most widely cultivated cultivars under the Egyptian conditions, but it produces heads of poor quality that are not suitable for exportation purposes. Overall, the objectives of this study are to determine the effects of foliar sprayings including GA_3, KN, or its combinations on the growth, yield, and head quality of globe artichokes cv. 'Balady'.

2. MATERIAL AND METHODS:

Experimental conditions

Two field experiments were carried out in 2019/2020 and 2020/2021 to investigate the effects of gibberellic acid (GA3) and kinetin (KN) alone or in combinations on the growth, earliness, and yield of artichoke cv. 'Balady'. The experiments were conducted in a private field in Sidi Ghazi, kafr El- Dawar region of Beheira Governorate, Egypt. This site is located between latitude 31.21 °N, and longitude 31.02 °E. A month before the beginning of the field experiment, soil samples of 30 cm depth were collected for analysis. For both seasons, soil physical and chemical properties for the experimental site were analyzed according to Jackson (1973) and Gupta et al. (2007) (Table 1).

Table 1. Physical and chemical analysis of soil in the two growth seasons.

Soil properties	Item	1st Season	2nd Season
Particle size distribution (%)	Sand	23.3	21.4
	Silt	34.2	37.2
	Caly	42.5	41.4
	Soil texture	Caly	Caly
Chemical properties	PH	8.12	8.19
	EC (dsm^{-1})	1.12	1.31
	O. M (%)	1.67	1.81
Soluble ions (meq/L)	$CaCO_3$ %	20.13	21.65
	Na^+	5.42	5.31
	Ca^{++}	5.23	5.3
	Mg^{++}	4.76	4.82
	K^+	0.14	0.13
	Cl^-	8.9	9.12
	SO_4^{--}	3.6	3.82

Planting and treatments application

From the old crown of a previous cv. 'Balady' globe artichoke plant, cuttings of stumps (crown pieces) were made for propagation purposes. Before planting, the stumps were treated with the fungicide Topspin M-70 (2 g/l for 20 minutes). The August 15 was the date of planting in both seasons. On one side of the ridge, stumps of relatively uniform weight (160 g/stump) were planted.

The experiment included nine treatments; each treatment included three replicates. The treatments were arranged in the Randomized Complete Block Design (RCBD). Each experimental unit (30 m^2) consisted of 3 ridges (10 meters long and 1 meter wide), and crown pieces were sown at 1m apart. The foliar spraying treatments included the application of Gibberellic acid-GA3 (10 and 20 ppm), kinetin- KN (25 and 50 ppm) and their combinations (10 ppm GA_3 + 25 ppm KN, 10 ppm GA_3 + 50 ppm KN, and 20 ppm GA_3 + 25 ppm KN and 20 ppm GA_3 + 50 ppm KN) as well as the control treatment (tap water), were applied at 30, 60 and 90 days after planting. To prevent the side effects, one guard row was placed between each pair of neighboring experimental units. The spraying solutions were applied to the plant's leaves until it began to drip. Foliar treatment was performed immediately before sunset to prevent degradation caused by the impacts of high temperatures and other ambient atmospheres.

All experimental units received the same quantities of nitrogen (N), phosphorous (P), and potassium (K) fertilizers, in addition to organic manure (20 m^3 $feddan^{-1}$). Ammonium nitrate, 33.5% N (200 kg/fed) was equally divided, and side dressed eight, twelve, and sixteen weeks after planting. Calcium super phosphate, 15.5% P_2O_5 (250 kg/fed) was base dressed prior to planting. Potassium sulphate, 48% K_2O (100 kg/fed) was equally divided, and side dressed eight and twelve weeks after planting. Pest control and agricultural practices were applied whenever they were necessary in accordance with Egyptian Ministry of Agriculture recommendations for commercial globe artichoke growing. Harvesting began on November 20, 2019 and lasted at seven-day intervals until May 1, 2020. However, harvesting began on November 28, 2020, and lasted until April 30, 2021, in the second season.

Growth and yield parameters

In both seasons, a representative sample of five plants from each experimental unit was obtained at 120 and 116 days following planting, respectively. The following growth measurements were recorded: plant height (cm), number of branches $plant^{-1}$, number of leaves $plant^{-1}$, root fresh weight (g), leaves fresh weight (g), stem fresh weight (g), plant fresh weight (g), plant dry weight (g) and Leaf area $plant^{-1}$ (cm^2) using the weight method as reported by Pandey and Singh (2011).

At harvest, five plant heads from each experimental unit were randomly selected and measured for the yield traits. Early yield was recorded as the number of all harvested heads $plant^{-1}$ and $feddan^{-1}$ during the four months of Nov., Dec., Jan. and Feb. Meanwhile, total yield $plant^{-1}$ was estimated as the number of all harvested heads $plant^{-1}$ and $feddan^{-1}$ during the full harvesting season (Ghoneim, 2005) . At the peak of the harvesting season (March), head quality traits were evaluated, and the fresh head weight (g), length (cm), and diameter (cm) were measured on average.

Chemical constituents of leaves and heads

The relative chlorophyll contents of globe artichoke leaves were measured using the SPAD-502 chlorophyll meter device (Konica Minolta Sensing, Japan) (Brengi and Abouelsaad, 2019; Hassan and Ali, 2019) . Methods previously published by Page et al. (1982) , John (1970) , and Cottenie et al. (1982) were used to measure nitrogen (N), phosphorous (P), and potassium (K) contents

(% D.W.), respectively, in heads and leaves from each treatment. Also, total crude protein (%) was calculated by multiplying N % by 6.25 as described by Mariotti et al. (2008) .Total phenols (% D.W.) and vitamin C (mg100 g^{-1}) were estimated using the methods described by Okasha et al. (1968) and Srivastava et al. (1988) , respectively. Head inulin content (%) was measured by a simplified spectrophotometric method outlined by Araya et al. (2011).

Statistical Analysis

All the data undergone statistical analysis using the analysis of variance (ANOVA) and the experimental design was Randomized Complete Block Design (RCBD). When comparing the means, the Duncan's multiple range test with a significance level of $P \leq 0.05$ was used in the COSTAT software.

3. RESULTS AND DISCUSSION:

Vegetative growth

According to the results in Tables 2 and 3, the foliar application treatments of GA_3, KN, and their combinations significantly increased the growth of globe artichoke compared to the foliar control in most of the cases. Plants treated with 10 ppm GA_3 + 50 ppm KN, 20 ppm GA_3 + 25 ppm KN, and 20 ppm GA_3 + 50 ppm KN had the greatest plant height and number of branches in both seasons (Table 2). Furthermore, plants given 20 ppm GA_3 + 25 ppm KN and 20 ppm GA_3 + 50 ppm KN treatments had the largest number of leaves in both seasons. In the same manner, the double applications of GA_3 (20 ppm) and KN (50 ppm) gave the highest values for the leaf area, total plant fresh and dry weights as well as their components (e.g., root weight, stem weight and leaves weight) in both seasons (Tables 2 and 3).

Table 2. Vegetative growth characters of globe artichoke plants as affected by foliar applications of gibberellic acid (GA_3), KN (kinetin) or their combinations in two growing seasons.

Treatments	Plant height (cm)		Number of leaves plant $^{-1}$		Leaf area plant^{-1} (cm^2)		No. of branches plant^{-1}	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Control (tap water)	88.33 e	85.37 d	32.67 e	34.00 e	9524.54 f	9931.64 f	5.78 f	5.56 d
GA_3 (10 ppm)	97.93 cd	98.33 bc	34.00 de	34.67 de	10594.09 e	10873.19 e	6.67 e	6.33 d
GA_3 (20 ppm)	101.17 bc	99.00 bc	35.00 d	36.00 d	11288.58 d	11644.02 cd	7.67 d	7.33 c
KN (25 ppm)	94.83 d	96.33 c	39.00 bc	37.67 c	11476.66 cd	11390.08 d	8.22 cd	7.67 bc
KN (50 ppm)	97.83 cd	98.00 bc	38.00 c	38.67 abc	11330.51 cd	11626.02 cd	8.44 c	8.33 ab
GA_3 (10 ppm) + KN (25 ppm)	102.17 b	99.67 b	40.00 ab	39.33 ab	12095.55 b	11996.76 bc	8.67 bc	8.33 ab
GA_3 (10 ppm) + KN (50 ppm)	109.50 a	105.40 a	39.33 bc	38.33 bc	11842.96 bc	11692.74 cd	8.78 abc	8.67 a
GA_3 (20 ppm) + KN (25 ppm)	106.83 a	104.40 a	39.67 ab	40.00 a	12392.78 b	12399.69 ab	9.22 ab	8.67 a
GA_3 (20 ppm) + KN (50 ppm)	109.00 a	106.70 a	41.00 a	40.00 a	13249.45 a	12830.24 a	9.44 a	8.67 a

The means in each column (trait), followed by comparable letter(s), are not significantly different (5% probability level), as showed by Duncan's Multiple Range Test.

Table 3. Vegetative growth characters of globe artichoke plants as affected by foliar applications of gibberellic acid (GA3), KN (kinetin) or their combinations in two growing seasons.

Treatments	Root weight plant^{-1} (g)		Stem weight plant^{-1} (g)		Leaves weight plant^{-1} (g)		Plant fresh weight (g)		Plant dry weight (g)	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Control (tap water)	303.80 h	292.35 g	1005.79 f	947.85 c	837.76 f	843.58 f	2147.34 h	2083.78 f	313.15 g	299.55 e
GA_3 (10 ppm)	375.34 g	338.59 f	1128.15 e	1113.68 b	960.74 e	989.91 e	2464.23 g	2442.18 e	342.92 f	331.09 d
GA_3 (20 ppm)	456.28 f	426.28 e	1273.70 d	1191.26 ab	1044.83 d	1077.98 d	2774.82 f	2695.52 d	362.08 e	348.06 c
KN (25 ppm)	495.77 e	435.56 de	1361.61 bc	1290.18 a	1083.92 c	1075.99 d	2941.30 e	2801.74 cd	421.08 c	384.38 b
KN (50 ppm)	584.80 c	463.37 c	1324.03 cd	1308.38 a	1103.57 c	1132.50 c	3012.40 cd	2904.25 bc	431.73 bc	416.16 a
GA_3 (10 ppm) + KN (25 ppm)	479.20 ef	448.33 cd	1352.20 bc	1271.66 a	1145.63 b	1136.38 bc	2977.03 de	2856.37 bc	391.20 d	373.56 b
GA_3 (10 ppm) + KN (50 ppm)	531.67 d	464.70 c	1361.33 bc	1294.09 a	1160.01 b	1145.37 bc	3053.01 c	2904.15 bc	393.81 d	378.97 b
GA_3 (20 ppm) + KN (25 ppm)	635.88 b	531.64 b	1383.23 ab	1274.12 a	1176.24 b	1177.59 ab	3195.35 b	2983.35 ab	439.07 b	416.17 a
GA_3 (20 ppm) + KN (50 ppm)	721.37 a	561.75 a	1419.30 a	1275.22 a	1257.64 a	1217.69 a	3398.31 a	3054.65 a	456.33 a	423.39 a

The means in each column (trait), followed by comparable letter(s), are not significantly different (5% probability level), as showed by Duncan's Multiple Range Test.

In the current study, the effect of GA_3 on the vegetative growth parameters may be connected to how it prompts cell growth and division. Gibberellins also affect the activity of many enzymes as well as plant photosynthetic capabilities (Venere et al. 2000) . Sm et al. (2021) reported that foliar treatment of GA_3 (60 ppm) on globe artichoke French cv. resulted in greater mean values of plant height, leaf area, number of leaves, number of branches, fresh and dry weights. Furthermore, Elsharkawy and Ghoneim, (2019) demonstrated that plants sprayed once or twice with GA_3 had the greatest vegetative growth (leaf length and breadth, plant height, and leaf dry matter) when compared to untreated plants. Ezzo et al. (2019) studied the effect of GA_3 on globe artichoke and found that foliar application at 50 ppm significantly increased the vegetative growth parameters and chlorophyll content at 70 and 110 days after transplanting compared to untreated control.

On the other hand, Aremu et al. (2020) emphasized the significance of CKs as agrochemicals for improving shoot proliferation and growth pattern in a variety of horticulture plants. The beneficial effect of CKs on plant development is certainly due to their ability to induce cell proliferation (Abouelsaad, 2016; Lomin et al. 2020; Gabr et al. 2022) . Furthermore, apical dominance prevents the production of lateral shoots, enabling the plant to grow vertically. When CKs lose apical dominance, plants begin to grow longer, with side buds developing into new shoots. Furthermore, the treatment of CKs may increase chlorophyll content in leaf tissues by decreasing chlorophyll breakdown and prolonging the aging process (Aremu et al. 2020) . SM et al. (2021) showed that the foliar application of N-6-benzyle amino purine on globe artichoke increased the vegetative growth (e.g., plant height, leaf area, number of branches and dry weight) compared to the control treatment. In another study, Abouelsaad and Brengi, (2022) reported a considerable improvement in vegetative growth of potato plants in response to different types of CKs.

Yield and its components

Usually over both seasons, the treatments with GA_3 or KN, and their combinations had a significant impact on artichoke yield and its components (Tables 4 and 5). The combined treatments at the various doses produced the maximum total numbers of heads plant^{-1} and total number of heads feddan^{-1} among the different treatments in both seasons (Table 4). For instance, the application of 20 ppm GA_3 + 50 ppm KN treatment raised the percentages of total number of heads feddan^{-1} by around 24 %, as an average for both seasons, in comparison to the control. The results also showed that plants treated with 20 ppm GA_3 + 25 ppm KN or 20 ppm GA_3 + 50 ppm KN exhibited the highest values for the number of early head plant^{-1} and the number of early head feddan^{-1} in both seasons. For instance, in comparison to the control, the increment reached 180 % of the number of early head feddan^{-1} after the application of 20 ppm GA_3 + 50 ppm KN, as an average in both seasons (Table 4).

In addition, the combined treatment of GA_3 (20 ppm) and KN (50 ppm) showed the highest values for the average head fresh weight, while the combined treatments of 20 ppm GA_3 + 50 ppm KN, 20 ppm GA_3 + 25 ppm KN and 10 ppm GA_3 + 50 ppm KN exhibited the largest values for the head weight plant^{-1} in both seasons. Moreover, the highest values of head length and diameter were remained in the combined treatments of 20 ppm GA_3 + 50 ppm KN or 20 ppm GA_3 + 25 ppm KN (Table 5).

Table 4. Globe artichoke yield and its components as affected by foliar applications of gibberellic acid (GA_3), KN (kinetin) and their combinations in two growing seasons.

Treatments	Early yield				Total yield			
	Number of early head plant^{-1}		Number of early head feddan^{-1}		Total number of head plant^{-1}		Total number of head feddan^{-1}	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Control (tap water)	1.44 d	1.89 f	7200.00 d	9450.00 f	11.11 d	11.11 c	55533.33 d	55550.00 c
GA_3 (10 ppm)	2.44 c	2.89 de	12216.67 c	14450.00 de	11.44 d	11.22 c	57216.67 d	56116.67 c
GA_3 (20 ppm)	3.22 b	3.67 bc	16116.67 b	18333.33 bc	13.00 abc	12.78 ab	65000.00 abc	63883.33 ab
KN (25 ppm)	2.22 c	1.89 f	11100.00 c	9450.00 f	12.22 cd	11.44 bc	61100.00 cd	57216.67 bc
KN (50 ppm)	2.33 c	2.33 ef	11666.67 c	11666.67 ef	12.89 bc	13.00 a	64433.33 bc	65016.67 a
GA_3 (10 ppm) + KN (25 ppm)	3.11 b	3.33 cd	15550.00 b	16666.67 cd	13.33 abc	12.89 ab	66666.67 abc	64433.33 ab
GA_3 (10 ppm) + KN (50 ppm)	3.00 b	3.33 cd	15000.00 b	16666.67 cd	13.45 ab	13.11 a	67233.33 ab	65550.00 a
GA_3 (20 ppm) + KN (25 ppm)	4.11 a	4.33 ab	20550.00 a	21666.67 ab	14.00 ab	13.11 a	69983.33 ab	65566.67 a
GA_3 (20 ppm) + KN (50 ppm)	4.22 a	4.67 a	21100.00 a	23333.33 a	14.11 a	13.22 a	70550.00 a	66116.67 a

The means in each column (trait), followed by comparable letter(s), are not significantly different (5% probability level), as showed by Duncan's Multiple Range Test.

Table 5. Globe artichoke yield and its components as affected by foliar applications of gibberellic acid (GA_3), KN (kinetin) and their combinations in two growing seasons.

Treatments	Head fresh weight g)		Heads weight (g) plant^{-1}		Head Length (cm)		Head diameter (cm)	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Control (tap water)	284.00 g	286.30 g	3154.41 f	3180.89 c	8.97 f	8.87 f	7.39 g	7.32 f
GA_3 (10 ppm)	286.93 f	288.23 fg	3283.43 ef	3235.18 c	10.25 e	10.33 e	7.93 f	7.95 e
GA_3 (20 ppm)	288.90 ef	289.93 ef	3756.20 cd	3704.98 ab	10.35 de	10.53 d	8.06 ef	8.13 d
KN (25 ppm)	291.13 e	292.50 e	3559.27 de	3347.62 bc	10.45 cd	10.63 cd	8.17 de	8.33 c
KN (50 ppm)	295.63 d	296.60 d	3810.75 cd	3856.79 a	10.61 bc	10.70 cd	8.30 cd	8.50 b
GA_3 (10 ppm) + KN (25 ppm)	298.07 cd	297.73 cd	3973.88 bc	3836.65 a	10.76 ab	10.77 bc	8.43 bc	8.50 b
GA_3 (10 ppm) + KN (50 ppm)	303.48 b	303.13 b	4080.99 abc	3974.28 a	10.70 b	10.73 bc	8.40 bc	8.53 ab
GA_3 (20 ppm) + KN (25 ppm)	300.27 c	300.67 bc	4202.43 ab	3943.39 a	10.77 ab	10.90 ab	8.47 ab	8.63 ab
GA_3 (20 ppm) + KN (50 ppm)	307.59 a	308.37 a	4340.36 a	4077.65 a	10.90 a	11.07 a	8.60 a	8.67 a

The means in each column (trait), followed by comparable letter(s), are not significantly different (5% probability level), as showed by Duncan's Multiple Range Test.

These findings are consistent with George et al. (2008) , who found that spraying GA_3 increased the number of globe artichoke heads due to its effect on primordia development promotion. Also, this study concluded that is crucial for increasing early yield. (Firpo et al. 2000; Anido et al. 2005) showed that using GA_3 in artichoke cv. "Violet de Provence" increased the early production of artichoke buds by 115%. The early blooming of globe artichoke plants may have occurred because of GA_3 treatments that enhance vegetative development, resulting in the transport of synthesized assimilates to other plant tissues and perhaps facilitating early flowering (heads production) (Soliman et al. 2019) . The transformation from vegetative to reproductive growth, or the floral transformation, is regulated by both endogenous and exogenous signals such as physiological factors related to the maturity level of propagation methods (explants), temperature, photoperiod, hormone levels, and a group of genes that promote flowering growth (Riahi et al. 2020). On the other hand, studies on different artichoke cultivars produced from seeds revealed that the frequency of GA_3 treatments, the susceptibility of each cultivar to GA_3, and the planting dates all affect how successful GA_3 is in promoting earliness (Elia and Santamaria, 1994).

In addition, CKs could speed up plant growth by increasing cells division, break bud dormancy, and help the formation of lateral bud (Berngi and Abouelsaad, 2019; Kieber and Schaller, 2018) . Exogenous use of synthesized CKs such as N-(2-chloropyridin-4-yl)-N'-phenylurea (CPPU), 6-benzylaminopurine (BAP) can enhance growth of plants, fruit set, and development in vegetable crops such as snap beans and watermelon (Hayata et al. 1995; Zaki et al. 2014). Also, according to Khalil et al., (2006), the use of kinetin led to an increase in both the number of blooms and quantity of fruits produced in lentil plant. It also led to an increase in earliness and total yield production of cucumber, tomato, and pepper (Papadopoulos et al. 2006) . The effects of employing CKs (6-N benzyl adenine purine at 20 and 30) on the yield of globe artichoke varieties known as 'French' and 'Balady' were investigated and analyzed by SM et al. (2021). The results obtained from two growing seasons showed that spraying treatments had significantly greater effects on total yield (number of heads plant^{-1}, number of heads feddan^{-1}, and weight of edible plant^{-1}) and early yield (number of early heads plant^{-1} and number of early heads feddan^{-1}), compared with control treatment.

Leaf chemical characteristics

Table 6 shows the impact of foliar treatments of GA_3, KN, and its combinations on leaves chemical composition. The acquired data revealed significant changes in chemical composition across the various treatments as compared to the control. In both seasons, the combined treatment of GA_3 (20 ppm) + KN (50 ppm) produced the greatest mean values of K content, whereas the combination treatment of GA_3 (20 ppm) + KN (25 or 50 ppm) produced the highest mean values of N, P, and protein (Table 4). On the other hand, the greatest values for the total chlorophyll content, were seen with KN (25 and 50 ppm), as well as with the combination treatment of GA_3 and KN in both seasons (Table 6).

Table 6. Leaf chemical characteristics as affected by foliar applications of gibberellic acid (GA_3), KN (kinetin) and their combinations in two growing seasons.

Treatments	Relative chlorophyll content (SPAD value)		N (%)		P (%)		K (%)		Protein (%)	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Control (tap water)	56.78 c	57.67 bc	2.68 e	2.77 d	0.69 d	0.68 d	4.09 e	4.08 e	16.75 e	17.31 d
GA_3 (10 ppm)	56.55 c	57.00 c	2.80 d	2.84 d	0.71 bcd	0.69 d	4.17 de	4.13 de	17.50 d	17.77 d
GA_3 (20 ppm)	56.89 c	56.67 c	2.94 bc	2.96 c	0.71 bcd	0.70 cd	4.17 de	4.15 d	18.38 bc	18.52 c
KN (25 ppm)	58.67 ab	59.33 a	2.87 cd	2.96 c	0.69 d	0.70 cd	4.22 d	4.17 d	17.96 cd	18.50 c
KN (50 ppm)	59.44 ab	59.67 a	2.94 bc	3.05 abc	0.70 cd	0.73 ab	4.33 abc	4.25 c	18.38 bc	19.06 abc
GA_3 (10 ppm) + KN (25 ppm)	58.33 b	58.67 ab	2.85 d	3.01 bc	0.72 bc	0.71 bc	4.31 c	4.27 c	17.82 d	18.83 bc
GA_3 (10 ppm) + KN (50 ppm)	59.00 ab	59.67 a	2.95 b	3.03 abc	0.71 bcd	0.72 b	4.32 bc	4.28 c	18.43 b	18.96 abc
GA_3 (20 ppm) + KN (25 ppm)	59.55 ab	59.67 a	2.98 ab	3.09 ab	0.73 ab	0.73 ab	4.40 ab	4.36 b	18.64 a	19.31 ab
GA_3 (20 ppm) + KN (50 ppm)	60.00 a	59.67 a	3.03 a	3.13 a	0.74 a	0.74 a	4.41 a	4.43 a	18.96 a	19.54 a

The means in each column (trait), followed by comparable letter (s), are not significantly different (5% probability level), as showed by Duncan's Multiple Range Test.

Gibberellic acid and KCs are responsible for regulating a plant's capacity to a wide variety of nutrients from its surrounding environment, including N, P, and K. As a result, the nutritional status of a plant may influence the plant's rate of growth and development (Argueso et al. 2009; Brengi et al. 2018). Sm et al. (2021) found that spraying globe artichoke cv. 'French' and 'Balady' with GA_3 or N-6-benzyle amino purine significantly affected the leaf contents of N, P, K, and protein compared to control treatment in two growing seasons. Also, Moatshe et al. (2011) reported that the leaf mineral content of Morula tree sprayed with BA had considerably greater levels than the plants that served as controls. The exogenous application of CKs increase the photosynthetic pigments content in the leaves of global artichoke Sm et al. (2021) wheat (Malibari, 1993) , and maize (Kaya et al. 2010) . Cytokinins increasing the quantity of carotenoid pigments and prevent chlorophylls from being degraded by the photo-oxidation process (Petrenko and Biryukova, 1977) . Therefore, because CKs slows down the process of aging and reduces the rate at which chlorophyll is degraded, cytokinin treatment might potentially result in an increase in the amount of chlorophyll in leaf tissues (Dwelle and Hurley, 1984; Kieber and Schaller, 2014).

Head quality

According to the findings shown in Table 7, the application of plant hormone treatments had a noticeable and positive impact on the quality of the global artichoke heads (the content of minerals, inulin, protein, ascorbic acid and total phenolic compounds). However, GA_3, KN and their combinations significantly decreased the content of total phenolic compounds compared with control plants. In general, the control plants produced the lowest mean values for the content of N, P, K, protein, inulin and ascorbic acid, but also showed the highest content of total phenolic compounds. On the other hand, the various combination treatments of GA_3 and KN demonstrated the greatest content of N, K, protein, and ascorbic acid contents in the two growing seasons. Also, the combination treatment of GA_3 (20 ppm) and KN (25 or 50 ppm) showed the greatest amount of P, while the combined treatment of GA_3 (20 ppm) and KN (50 ppm) showed the highest level of inulin in both seasons (Table 7).

Table 7. Head quality as affected by foliar applications of gibberellic acid (GA_3), KN (kinetin) and their combinations in two growing seasons.

Treatments	N (%)		P (%)		K (%)		Inulin (%)		Protein (%)		Ascorbic acid (mg/100g)		Total phenolic compounds (mg g^{-1}dw)	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Control (tap water)	3.05 f	3.04 f	0.43 e	0.40 e	3.23 c	2.96 d	1.57 d	1.75 e	19.06 f	18.98 f	17.10 d	17.20 e	22.92 a	24.07 a
GA_3 (10 ppm)	3.11 e	3.11 e	0.44 de	0.42 d	3.40 a	3.21 c	2.13 c	2.04 d	19.44 e	19.44 e	17.52 c	17.49 d	19.13 b	19.80 b
GA_3 (20 ppm)	3.16 d	3.21 d	0.45 cd	0.43 cd	3.44 a	3.36 a	2.23 bc	2.24 c	19.77 d	20.06 d	17.65 bc	17.68 cd	17.83 c	17.57 c
KN (25 ppm)	3.22 c	3.24 cd	0.46 b	0.44 bcd	3.30 bc	3.27 bc	2.16 bc	2.25 bc	20.15 c	20.27 cd	17.68 b	17.76 bcd	16.43 de	16.43 de
KN (50 ppm)	3.27 abc	3.32 ab	0.46 b	0.45 abc	3.43 a	3.34 ab	2.32 ab	2.32 b	20.42 abc	20.75 ab	17.76 b	17.77 bc	15.67 e	14.97 f
GA_3 (10 ppm)+ KN (25 ppm)	3.25 bc	3.28 bc	0.47 ab	0.43 cd	3.36 ab	3.31 ab	2.27 abc	2.28 bc	20.29 bc	20.50 bc	18.11 a	17.98 ab	16.40 de	17.00 cd
GA_3 (10 ppm)+ KN (50 ppm)	3.26 abc	3.29 abc	0.46 b	0.44 bcd	3.37 ab	3.36 a	2.32 ab	2.31 bc	20.38 abc	20.52 abc	18.06 a	18.17 a	17.27 cd	16.80 d
GA_3 (20 ppm)+ KN (25 ppm)	3.28 ab	3.30 ab	0.47 ab	0.46 ab	3.35 ab	3.33 ab	2.25 abc	2.28 bc	20.52 ab	20.63 ab	18.06 a	18.08 a	16.47 de	15.83 e
GA_3 (20 ppm)+ KN (50 ppm)	3.30 a	3.33 a	0.48 a	0.47 a	3.41 a	3.37 a	2.42 a	2.41 a	20.60 a	20.83 a	18.14 a	18.19 a	16.67 cde	16.54 de

The means in each column (trait), followed by comparable letter (s), are not significantly different (5% probability level), as showed by Duncan's Multiple Range Test.

Similar results were obtained by Ezzo et al. (2019) who found that the levels of N, P, K, Ca, and Zn in globe artichoke increased after foliar spraying with GA_3 at the rate of 50 ppm, in comparison to the control plants. Also, Soliman et al. (2019) and Al-Barbary et al. (2022) showed that GA_3 enhanced the contents of nutrient (N, P, and K), inulin and protein of globe artichoke heads cv. 'Balady'. This result refers to GA3's positive mode of action on the nutritional status of globe artichoke heads cv. "Balady" for enhancing human health. The physiological function of inulin as a dietary fiber is to enhance intestinal flora, increase intestinal absorption of calcium and magnesium, and decrease blood levels of lipids and cholesterol. In non-food industrial applications, it is used as a source of carbohydrates for making ethanol, as a fat substitute and prebiotic factor, and in yoghurt and ice cream recipes, it makes a gel that has a similar texture to fat but a lot fewer calories (Raccuia et al. 2010; Soliman et al. 2019). In addition, the globe artichoke is an excellent source of flavonoids and phenolic acids, which are both types of polyphenols (Dabbou et al. 2017). But in contradictory to the results of the current study, Soliman et al. (2019) found that GA_3 application significantly increased the total phenolic compounds content. This variation might be related to the experimental conditions for the study and/or the complicated metabolic processes that occur throughout plant growth and development and blooming (Soliman et al. 2019). On the other hand, Sm et al. (2021) reported that spraying N-6-benzyle amino purine with different concentrations showed significant effects on the globe artichoke head contents of N, P, K and protein. In other vegetable crops such as okra, under high temperature conditions, the application of the three synthetic cytokinins (BAP, CPPU, and Kinetin) improved the growth and yield as well as the mineral content of both leaves and the fruits (Brengi, 2018).

CONCLUSION:

Globe artichoke cv. 'Balady' is one of the most extensively grown cultivars in Egypt, however it produces poor-quality heads that are unsuitable for exporting. The current study indicated that the combined foliar application of GA_3 and KN as a vernalized tool to enhance the heads' initiation (early yield) and increase the head quality could achieve potential high financial returns because of high prices.

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الملخص العربى

تأثيرات حمض الجبريليك والكينتين على النمو والمحصول والجودة في الخرشوف

يعتبر صنف الخرشوف البلدى من أهم الأصناف في مصر بسبب قدرتة على الازهار المبكر مقارنة بالأصناف الأخرى، لكن حجم الرؤوس أصغر. خلال تلك الدراسة تم إجراء تجربتين فى الحقل خلال موسمي النمو 2019-2020 و2020-2021 لتقييم آثار استخدام حمض الجبريليك (GA_3) والكينيتين (KN) بمفردهما وفي توليفات مختلفة على النمو، والازهار المبكر، والإنتاجية، وجودة الرؤوس. أظهرت النتائج أن النباتات المعاملة بمزيج منGA_3 (20 جزء في المليون) و KN (50 جزء في المليون) كان لها تأثير متفوق على النمو ، وعدد الرؤوس المبكرة للفدان، والعدد الرؤوس الإجمالي للفدان، وحجم الرأس، وزن وطول وقطر الرأس. بالمقارنة مع الكنترول، أدت المعاملة ب 20 جزء في المليونGA_3 + 50 جزء في المليون KN إلى رفع النسب المئوية لعدد الرأس المبكر للفدان بنسبة 180٪ ، إجمالي عدد الرأس للفدان بنسبة 24٪ ، متوسط وزن الرأس بنسبة 8٪، طول الرأس بنسبة 21٪، وقطر الرأس بنسبة 21٪، كمتوسط للموسمين. أيضًا، في معظم الحالات ، سجلت نفس المعاملة أعلى قيم لمحتوى الأوراق للعناصر و الكلوروفيل بالإضافة إلى مواصفات جودة الرأس (العناصر والبروتين والأنولين وحمض الأسكوربيك). ولكن فقط محتوى المركبات الفينولية الكلية في رأس الخرشوف انخفض معنويا مع جميع المعاملات الهرمونية. لذلك ، يمكن اعتبار المعاملة بGA_3 (20 جزء في المليون) و KN(50 جزء في المليون) بمثابة المعالمة المثلى فى تلك الدراسة الانتاجية عالية ذات نوعية جيدة في صنف الخرشوف البلدى.

الكلمات الدالة: الخرشوف، حمض الجبريليك ، سيتوكينين ، كينتين ، المحصول ، التركيب الكيميائي