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Improving the growth quality of the *Celosia argentea* plant using some synthetic hormones

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ABSTRACT

To improve the growth and quality of *Celosia argentea* (silver cockscomb), seeds were soaked for 2 hr before planting in a solution of thyroxine, progesterone, testosterone and cortisone, at different concentrations and distilled water as control. After germination, seedlings were transplanted into pots containing clay soil. The results showed clear superiority of treatments involving with all synthetic hormones in terms of all assessed parameters: vegetative, floral and biochemical, compared to the control. The results of our study have shown that the optimal treatments for growth and flowering were achieved with medium concentrations of the following hormones tested: thyroxine at 100 μg · L^{-1}, progesterone at 200 mg · L^{-1} and testosterone at 500 mg · L^{-1}. It should be noted that in the above-mentioned thyroxine treatment, the best growth parameters of the plant vegetative parts and flowers were obtained. In the case of cortisone, higher growth parameters were obtained when the hormone was used at the highest tested concentration of 1.5 mg · L^{-1}. Our results demonstrate that low-to-medium concentrations of thyroxine, progesterone and testosterone applied via seed priming are effective strategies for improving *C. argentea* growth and flowering enhancing biochemical components such as chlorophylls, carotenoids and carbohydrates.

Keywords: *Celosia argentea*, cortisone, progesterone, testosterone, thyroxine

INTRODUCTION

Celosia argentea is one of the food and medicinal plants that are used as vegetables and as dietary supplements to combat micronutrient deficiencies (Gupta et al., 2013). The silver cockscomb is an annual herbaceous plant of tropical origin from the Amaranthaceae family. It is commonly used in gardens and pots and is grown for the beauty of its colourful red, yellow and white flowers, which can be used as cut flowers. The plant can also be used as dried flowers that last a long time, so it can be used in a floral arrangement. Hence, it has great economic value as a cut flower and pot plant (Surse et al., 2014). Due to the economic importance of this species, many studies have been conducted to improve the quality of the plant by using fertilisers or improving

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growth environments and resistance to biotic and abiotic stress (Ahmed et al., 2022).

There are few studies on the effect of thyroid hormone on plants; however, an old study was conducted on the effect of thyroxine on plant growth, and it was concluded that its effect is probably to increase the rate of metabolism (Davis, 1934).

Cortisone is one of the steroid hormones that have been proven to be present in plants (Tarkowská, 2019). Genetic studies showed that steroids promote the accumulation of sugars and proteins in plant tissues (Sedaghathoor et al., 2024). It also has a significant effect on plant growth at all stages of growth, and the effect varies depending on the dose (Geuns, 1978).

Synthetic sex hormones, such as testosterone or progesterone, or their precursors influenced plant development: cell division, root and shoot growth, embryo development, flowering, pollen tube growth and callus proliferation and caused an increase in the contents of sugar and proteins (Janeczko and Skoczowski, 2005). It is noteworthy that sterols, such as progesterone, testosterone and cortisone, can be found in all eukaryotes (plants and animals), where they play many irreplaceable roles, including maintaining membrane semi-permeability, regulating its fluidity and serving as biosynthesis precursors of steroid hormones and act as important signalling molecules (Tarkowská, 2019). A typical representative of natural sterols produced by plant and animal cells is cholesterol. Progesterone, cortisone and testosterone can be found in varying quantities in a large number of plants, and that they have a certain regulatory role in plant growth and development, which affects vegetative and reproductive growth in a dose-dependent manner. The growth of shoots and roots is generally promoted by progesterone used at low concentrations and inhibited at high concentrations. The optimal concentrations vary between species and at different growth stages. Progesterone also plays an important role in photosynthesis, which leads to a significant increase in plant productivity. It contributes significantly to protecting the plant from biotic and abiotic stress (Li et al., 2022).

This study aims to improve the growth and quality of *C. argentea* plants by soaking the seeds in different concentrations of thyroxine, progesterone, testosterone and cortisone, which have been shown in previous studies by many researchers to have a positive effect on plant growth.

MATERIALS AND METHODS

Experimental site and layout

A pot experiment was conducted under open-field conditions at the Experimental Farm of Ornamental Plants and Landscape Gardening, Research Department, Horticulture Research Institute (HRI), Agricultural Research Centre (ARC), Giza, Egypt, during the 2022 and 2023 growing seasons. Each season spanned from 1st April to 1st November to evaluate the effects of specific human synthetic hormones on plant growth and development of *C. argentea* L.

The seeds of *C. argentea* silver cockscomb were obtained from Land Green International Company, Egypt, and soaked in the water solutions for 2 hr:

1. Control (distilled water).
2. Synthetic thyroxine hormone (levothyroxine sodium) was used at concentrations of 50, 100 and 150 μg · L^{-1}. The hormone was obtained from the commercial drug (Eltroxin) manufactured by Aspen Bad Oldesloe Gmbh Co., Egypt; each tablet contains: levothyroxine sodium 56 μg, equal thyroxine 50 μg.
3. Progesterone (≥98% purity) was applied at concentrations of 100, 200, and 300 mg · L^{-1}. The compound was sourced from commercially available progesterone tablets (PROGEST®; Pharco Pharmaceuticals, Egypt), with each tablet containing 50 mg active progesterone.
4. Testosterone was applied at concentrations of 250, 500 and 750 mg · L^{-1}. The compound was sourced from commercially available Cidoteston® ampoules (Chemical Industries Development Co., Egypt), with each 1 mL ampoule containing 250 mg testosterone as the active pharmaceutical ingredient.
5. Cortisone was applied at concentrations 0.5, 1.0 and 1.5 mg · L^{-1}. The compound was sourced from commercial dexamethasone tablets (DEXAZONE™; Kahira Pharmaceuticals & Chemical Industries Co., Cairo, Egypt), where each tablet contained 0.5 mg dexamethasone.

The seeds were then sown directly into trays filled with sand and clay until germination occurred. Seedlings of equal length (8–10 cm) were selected on April 1st and were planted into 25 cm plastic pots in a soil composed of sand and clay in a 1:1 volume ratio. Routine maintenance included manual removal of weeds and irrigation as required to sustain soil moisture near field capacity. Nutrient supply was provided through fertigation once per week using a balanced, water-soluble NPK fertiliser (Cristalon® 19:19:19, ASA Spezialdünger GmbH, Germany; distributed by Yara International ASA). The fertiliser solution was prepared at a concentration of 1 g · L^{-1} in municipal water with an electrical conductivity of 0.9 dS · m^{-1}. The nutrient solution was administered through the irrigation system during scheduled watering events to ensure homogeneous distribution. The experiment ended on 1st November. Physical and chemical properties of the field soil are shown in Table 1.

A factorial experiment on the open field, based on a completely randomised design, replicated thrice with four plants per replicate, was accomplished in seasons 2022 and 2023 according to Gomez and Gomez (1984).

Table 1. Physical and chemical analyses of the used soil.

Soil type	Particle size distribution (%)			S.P.	E.C. ($ds \cdot m^{-1}$)	pH	Cations ($meq \cdot L^{-1}$)				Anions ($meq \cdot L^{-1}$)		
	Sand	Silt	Clay				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3	Cl^{-}	SO_4^{-}
Loamy	48.0	35.5	16.5	44.0	1.36	8.28	3.5	2.5	6.63	0.65	0.5	7.5	5.28

Observations and measurements

Observations regarding plant growth and flowering were carried out in two growing seasons, while the biochemical parameters were assessed in the second season.

Growth parameters of the above-ground vegetative parts of the plant

The following parameters were evaluated: plant height (from above the surface of the pot to the base of the terminal flower), number of leaves/plant, diameter of the stem (from the top of the soil surface), number of branches per plant, fresh and dry weights of vegetative part, root length and roots fresh and dry weights by the end of the growing season.

Flowering assessment

Assessment concerned the number of days from planting to flowering, the number of flowers per plant, the length and diameter of the longest flower and the weight of the longest flower.

Carbohydrates and photosynthetic pigments

At the conclusion of the second growing season, the following biochemical parameters were analysed. The total carbohydrate content was determined according to Dubois et al. (1956). Photosynthetic pigment concentrations (chlorophyll *a*, chlorophyll *b* and carotenoids) were quantified using the methodology of Moran (1982).

Statistical analysis

All obtained data were statistically analysed according to the technique of analysis of variance (ANOVA) for a complete randomised block design in a factorial experiment as published by Gomez and Gomez (1984) by using 'MSTAT-C' computer software package (MSTAT Development Team, 1989). Means of all treatments were compared using Duncan's multiple range tests at 5% level of probability as described by Duncan (1955).

RESULTS

Vegetative growth parameters

The results presented in Table 2 indicated a clear superiority in the effect of treatment with all tested hormones, as plant height, number of branches and number of leaves per plant significantly increased compared to the control. The treatments with thyroxine at a concentration of 100 $\mu g \cdot L^{-1}$ and progesterone at 200 $mg \cdot L^{-1}$ increased plant height by approximately two-fold and the number of leaves by three-fold.

Also, results in Table 2 showed that plants treated with the hormones gave a significant increase in stem diameter when compared to control in both seasons. The level of increase of stem diameter varied between approximately 1.4- and 3-folds in both seasons. The largest shoot diameters, similar in both seasons, ranging from 1.50 cm to 1.60 cm, were observed under the treatments with thyroxine at 100 $\mu g \cdot L^{-1}$, progesterone at 200 $mg \cdot L^{-1}$, testosterone at 500 $mg \cdot L^{-1}$ and cortisone at 1.5 $mg \cdot L^{-1}$, while in the control, the stem diameter was three times smaller. Root length increased significantly with 750 $mg \cdot L^{-1}$ testosterone treatment and was higher by 1.7- and 2.0-folds in the first and second seasons, respectively, when compared with the control. The treatment with the hormone thyroxine at concentration of 100 $\mu g \cdot L^{-1}$ came in second place, as roots of the plants ≈ 1.5- and 1.9-folds in the first and second seasons, respectively. Furthermore, the results indicate a significant positive correlation between root growth parameters and vegetative growth traits, except under progesterone treatment.

The results in Table 3 indicated that when the seeds were treated with the tested hormones, a significant increase in fresh and dry weight of vegetative plant parts was observed. The best treatment was with the hormone thyroxine at a concentration of 100 $\mu g \cdot L^{-1}$, as it resulted in the highest fresh weight of vegetative part (82.18 g and 91.20 g) and vegetative dry weight (13.39 g and 14.80 g), in the first and second seasons, respectively. However, in the control, the values of fresh and dry mass of vegetative parts were more than 2.5 times and about 3 times lower, respectively.

It was also found that treating plants with thyroxine and testosterone increased the root fresh and dry weight compared to other treatments (Table 3). The highest values of fresh root weight (9.00 g and 8.67 g) and dry root weight (3.52 g and 3.43 g), in the first and second seasons, respectively, were recorded for the thyroxine treatment at 100 $\mu g \cdot L^{-1}$, while in the control, the values of root fresh and dry weights were two times and almost three times lower, respectively. In turn, the treatments with progesterone gave results with lower values for fresh weight of roots compared to other hormone treatments; in contrast, the vegetative growth characteristics were relatively high, comparable to other hormone treatments.

Flowering parameters

As an expected result, the increased vegetative growth ultimately led to a higher flower yield and stronger floral characteristics compared to the control (Table 4). Almost all hormone treatments significantly improved flowering parameters. Only in a few cases, e.g. testosterone treatment at 250 $mg \cdot L^{-1}$ in the first season

Table 2. Effect of synthetic hormones on plant height, number of branches per plant, number of leaves per plant, stem diameter and root length of *Celosia argentea* during the 2022 and 2023 seasons.

Treatments		Plant height (cm)		Number of branches per plant		Number of leaves per plant		Stem diameter (cm)		Root length (cm)	
		2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Control		45.00 g	51.20 h	5.33 e	6.33 g	45.30 i	41.70 i	0.53 e	0.57 g	6.30 f	5.70 g
Thyroxine	50 µg · L^{-1}	57.30 f	61.70 fg	9.00 d	10.33 f	57.00 h	51.00 h	0.77 d	0.81 f	6.2 fg	6.20 f
	100 µg · L^{-1}	103.30 a	108.00 a	19.33 a	22.33 a	118.00 a	121.00 a	1.53 a	1.61 a	9.73 b	10.80 b
	150 µg · L^{-1}	84.30 cd	86.70 c	14.33 bc	15.33 d	85.00 cd	80.30 e	0.97 c	1.13 b	7.30 de	6.50 f
Progesterone	100 mg · L^{-1}	86.330 bcd	83.70 cd	8.67 d	10.67 f	62.70 gh	64.00 g	0.80 d	0.77 f	5.60 g	5.20 g
	200 mg · L^{-1}	91.00 b	92.70 b	18.00 a	21.70 ab	101.70 b	115.30 b	1.57 a	1.57 a	4.40 h	3.90 h
	300 mg · L^{-1}	61.30 f	64.00 g	13.00 c	14.67 e	73.30 ef	70.30 f	1.03 c	1.00 cd	4.20 h	3.47 h
Testosterone	250 mg · L^{-1}	71.00 e	75.30 f	9.33 d	10.33 f	59.30 h	63.70 g	0.80 d	0.87 ef	7.80 d	7.37 e
	500 mg · L^{-1}	87.70 bc	80.30 def	18.00 a	20.67 b	89.30 c	95.00 c	1.53 a	1.60 a	9.27 bc	9.97 c
	750 mg · L^{-1}	62.70 f	64.00 g	15.00 b	16.67 d	56.70 h	63.00 g	1.00 c	0.95 de	11.20 a	11.70 a
Cortisone	0.5 mg · L^{-1}	73.30 e	78.30 ef	8.33 d	10.33 f	67.30 fg	72.00 f	0.70 d	0.82 f	7.10 e	6.37 f
	1.0 mg · L^{-1}	74.00 e	81.70 cde	12.67 c	15.00 e	79.00 de	87.70 d	1.20 b	1.10 bc	6.80 ef	7.20 e
	1.5 mg · L^{-1}	80.30 d	85.00 cd	15.67 b	18.67 c	82.00 d	97.00 c	1.50 a	1.55 a	8.70 c	9.17 d

Means having the same letter are not significantly different at the 0.05 level of probability according to Duncan's multiple range test (Duncan, 1955).

Table 3. Effect of synthetic hormones on fresh and dry weights of plant vegetative parts and roots of *Celosia argentea* during the 2022 and 2023 seasons.

Treatments		Fresh weight of vegetative part (g)		Dry weight of vegetative part (g)		Root fresh weight (g)		Root dry weight (g)	
		Season 2022	Season 2023	Season 2022	Season 2023	Season 2022	Season 2023	Season 2022	Season 2023
Control		31.60 h	37.08 k	4.87 f	4.37 i	4.50 g	4.17 e	1.35 g	1.24 i
Thyroxine	50 µg · L^{-1}	42.83 g	49.93 j	6.30 e	5.78 h	6.80 cd	5.83 d	1.90 ef	1.78 g
	100 µg · L^{-1}	82.17 a	91.20 a	13.39 a	14.80 a	9.00 a	8.67 a	3.52 a	3.43 a
	150 µg · L^{-1}	61.27 cd	68.27 de	7.71 d	8.36 e	8.02 b	8.00 b	2.23 d	2.34 e
Progesterone	100 mg · L^{-1}	62.97 c	70.78 d	7.53 d	8.11 e	3.73 h	3.60 f	1.90 ef	1.50 h
	200 mg · L^{-1}	72.34 b	79.77 b	10.57 b	10.86 c	4.43 g	4.43 e	2.27 d	2.38 e
	300 mg · L^{-1}	52.30 f	54.67 i	8.48 c	9.00 d	3.57 hi	3.52 f	1.75 f	1.64 gh
Testosterone	250 mg · L^{-1}	58.63 d	62.50 g	7.51 d	7.90 ef	7.27 c	7.40 c	2.50 c	2.62 d
	500 mg · L^{-1}	64.07 c	64.67 fg	10.64 b	11.43 b	8.30 b	8.43 ab	2.91 b	3.10 b
	750 mg · L^{-1}	50.60 f	53.50 i	7.84 cd	8.17 e	6.26 e	5.90 d	2.10 de	2.27 e
Cortisone	0.5 mg · L^{-1}	55.50 e	58.40 h	6.21 e	7.40 g	3.13 i	2.93 g	1.52 g	1.55 h
	1.0 mg · L^{-1}	61.83 c	65.63 ef	7.11 d	7.65 fg	5.53 f	5.97 d	1.98 e	2.11 f
	1.5 mg · L^{-1}	72.17 b	76.00 c	10.00 b	10.67 c	6.67 de	7.12 c	2.59 c	2.79 c

Means having the same letter are not significantly different at the 0.05 level of probability according to Duncan's multiple range test (Duncan, 1955).

Table 4. Effect of synthetic hormones on the number of days to flowering, the number of flowers per plant, flower length, flower weight and flower diameter of *Celosia argentea* plants during the 2022 and 2023 seasons.

Treatments		Number of days to flowering		Number of flowers per plant		Flower length (cm)		Flower weight (g)		Flower diameter (cm)	
		Season 2022	Season 2023	Season 2022	Season 2023	Season 2022	Season 2023	Season 2022	Season 2023	Season 2022	Season 2023
Control		142.00 ab	151.00 a	6.30 i	7.00 f	2.77 i	3.07 i	0.55 i	0.82 h	2.20 g	2.10 f
Thyroxine	50 μg · L^{-1}	129.00 d	137.30 c	8.30 ghi	8.67 e	5.87 g	5.60 fg	1.19 h	1.45 g	2.73 e	2.9 c
	100 μg · L^{-1}	115.00 f	112.33 f	23.00 a	21.30 a	9.57 a	10.10 a	4.70 a	5.43 a	3.27 a	3.60 a
	150 μg · L^{-1}	133.30 c	137.00 bc	12.30 ef	13.67 c	6.47 ef	5.97 ef	2.47 e	2.96 d	2.93 cd	3.00 c
Progesterone	100 mg · L^{-1}	129.30 cd	125.00 de	10.30 fg	12.00 d	4.80 h	5.33 gh	2.73 de	2.39 e	2.20 g	2.43 e
	200 mg · L^{-1}	111.67 f	115.00 f	18.30 b	17.30 b	8.97 b	9.00 b	3.70 b	3.15 cd	3.20 ab	3.37 b
	300 mg · L^{-1}	130.00 cd	134.70 c	9.67 g	10.70 d	7.17 d	6.83 d	1.27 gh	1.61 fg	2.17 g	2.40 e
Testosterone	250 mg · L^{-1}	145.30 a	141.30 b	7.30 hi	8.67 e	4.70 h	4.97 h	1.70 f	2.15 e	2.17 g	2.40 e
	500 mg · L^{-1}	140.70 b	135.30 c	16.00 b	14.00 c	8.33 c	9.13 b	3.73 b	4.10 b	2.80 de	2.63 d
	750 mg · L^{-1}	130.30 cd	125.30 de	14.67 cd	14.00 c	8.77 bc	9.27 b	1.51 fg	1.83 f	2.33 g	2.40 e
Cortisone	0.5 mg · L^{-1}	119.30 e	120.33 ef	8.67 gh	10.67 d	6.00 fg	6.30 e	3.17 c	3.82 b	2.53 f	2.70 d
	1.0 mg · L^{-1}	121.30 e	125.70 d	12.67 de	14.30 c	7.03 de	7.50 c	3.02 cd	3.33 c	2.77 de	2.93 c
	1.5 mg · L^{-1}	130.30 cd	136.00 c	16.00 b	18.30b	8.63 bc	8.90 b	3.54 b	4.03 b	3.00 bc	3.00 c

Means having the same letter are not significantly different at the 0.05 level of probability according to Duncan's multiple range test (Duncan, 1955).

Table 5. Effect of synthetic hormones on total chlorophyll *a*, chlorophyll *b*, carotenoids and total carbohydrates of *Celosia argentea* plants during the 2023 season.

Treatments		Chlorophyll *a* (mg · g^{-1} FW)	Chlorophyll *b* (mg · g^{-1} FW)	Carotenoids (mg · g^{-1} FW)	Total carbohydrates (% d.w.)
Control		1.153 h	0.330 j	0.454 e	24.66 i
Thyroxine	50 µg · L^{-1}	1.274 d	0.349 hi	0.461 e	25.45 g
	100 µg · L^{-1}	1.484 a	0.569 a	0.617 a	33.57 a
	150 µg · L^{-1}	1.325 c	0.426 d	0.505 b	29.18 c
Progesterone	100 mg · L^{-1}	1.215 ef	0.372 fg	0.490 cd	26.20 f
	200 mg · L^{-1}	1.449 a	0.512 b	0.615 a	32.00 b
	300 mg · L^{-1}	1.357 bc	0.436 d	0.509 b	27.17 e
Testosterone	250 mg · L^{-1}	1.176 gh	0.332 ig	0.424 f	24.78 i
	500 mg · L^{-1}	1.336 c	0.385 ef	0.460 e	27.45 d
	750 mg · L^{-1}	1.237 e	0.355 gh	0.452 e	24.98 h
Cortisone	0.5 mg · L^{-1}	1.187 fgh	0.346 hij	0.480 d	25.33 g
	1.0 mg · L^{-1}	1.204 efg	0.339 ef	0.514 b	27.45 d
	1.5 mg · L^{-1}	1.384 b	0.476 c	0.600 a	32.14 b

Means having the same letter are not significantly different at the 0.05 level of probability according to Duncan's multiple range test (Duncan, 1955).
FW, fresh weight.

did not significantly influence days to flowering, number of flowers and flower diameter.

The data recorded in Table 4 showed that treatment with thyroxine at a concentration of 100 µg · L^{-1} and progesterone at a concentration of 200 mg · L^{-1} resulted in significantly shorter periods of vegetative growth until flowering, which were reduced by 27–39 days compared to the control (142 days and 151 days in the first and second season, respectively). The largest numbers of flowers per plant (23.00 and 21.3) and the longest flowers (9.57 cm and 10.10 cm) were for treatment with thyroxine at 100 µg · L^{-1} in both seasons, respectively, while in the control, these values were more than three times lower.

The data in Table 4 also indicate that compared to the rest of the treatments, a significant increase in flower weight and diameter for plants treated with thyroxine at a concentration of 100 µg · L^{-1} was observed, where flower weight reached (4.70 g and 5.43 g) and flower diameter reached (3.27 cm and 3.60 cm) in both seasons, respectively. In comparison to this thyroxine treatment, in the control, flower weights were 8.5 and 6.6 times smaller and flower diameters 1.5 and 1.7 times smaller in the first and second season, respectively. It can be noted that treatment with progesterone at a concentration of 200 mg · L^{-1}, testosterone at a concentration of 500 mg · L^{-1}, and cortisone at a concentration of 1.5 mg · L^{-1} also resulted in high flowering parameters, but lower than in the case of thyroxine treatment at 100 µg · L^{-1}.

Biochemical composition

The data listed in Table 5 show that the contents of chlorophyll *a*, chlorophyll *b*, carotenoid contents and total carbohydrates were increased with all hormone treatments in varying proportions. The concentration of chlorophyll *a*, chlorophyll *b*, carotenoids and total carbohydrates in plants treated with thyroxine at the concentration of 100 µg · L^{-1} increased by approximately 30%, 72%, 35% and 36%, respectively, compared to the control. It can be noted that progesterone, at a concentration of 200 mg · L^{-1} and thyroxine at a concentration of 100 µg · L^{-1}, gave the highest content of chlorophyll *a* and carotenoids in the leaves. The plants treated with cortisone at a concentration of 1.5 mg · L^{-1} also reached high contents of chlorophyll, carotenoids and carbohydrates, which were similar or slightly lower compared to the mentioned above thyroxine and progesterone treatments.

DISCUSSION

Our results indicated that treating *C. argentea* plants with four mammalian synthetic significantly influenced their growth and development, leading to notable improvements in vegetative and flowering parameters as well as in chemical composition. Many researchers obtained similar results to ours. Boiteau and Ratsimamanga (1958) found that treating *Lens culinaris* (lentil) plants with cortisone led to an increase in the seedlings' fresh weight, root length by 43% and shoot length by 34%. Bhattacharya and Gupta (1981) reported that treatment of sunflower (*Helianthus annuus*) with high concentration of progesterone (0.25 µg · plant^{-1}) led to the increase of shoot growth but inhibition of root development, while at low concentration (0.1 µg · plant^{-1}), it had the opposite effect. In turn, testosterone at 0.1–0.25 µg · plant^{-1} stimulated the formation of vegetative axillary buds.

This differential growth response may be attributed to progesterone's stimulatory effect on aerial biomass allocation, concomitant with reduced root development. According to Janeczko (2000), progesterone (1 μM) stimulated the growth of winter wheat seedling roots and leaves cultured *in vitro*. This steroid at 10-fold higher concentration inhibited the seedlings' growth by a few percent. Lino et al. (2007) showed that in *Arabidopsis thaliana,* root and vegetative growth were positively or negatively affected by progesterone in a dose-dependent manner.

Our research covers the effect of thyroxine on growth and development of *C. argentea*. Thyroxine at a medium dose improved plant growth, development and chemical composition the most, and these results corresponded with the findings of Calujac et al. (2024) on *Salvia hispanica* L. and *Triticum aestivum* L. In their study, levothyroxine sodium concentration exhibited a dose-dependent effect on seed germination and seedling growth, promoting or inhibiting these processes. Ozyigit (2012) reported that irrigation of cotton (*Gossypium hirsutum* L.) plants with levothyroxine sodium at low concentrations resulted in an increase in stem length and an enhancement of leaf and root growth compared to untreated plants. This hormone at low concentration also increased contents of iron, magnesium and zinc in plants. However, higher concentrations revealed the opposite effects. Progesterone's protective and growth-promoting effects point to its strong potential for agricultural use in managing stress and enhancing crop productivity (El-Beltagi et al., 2025). Supporting the role in stress tolerance, Erdal (2012) showed that treating wheat plants under salt stress with the hormone progesterone led to a significant increase in the plant's chlorophyll content and the dry weight of the plant. As mentioned, progesterone significantly increased osmoprotectant levels while stimulating both enzymatic and non-enzymatic antioxidant pathways (Li et al., 2022).

The results corresponding to ours were obtained by Sedaghathoor and Zakibakhsh-Mohammadi (2019) who reported that soaking the seeds of *Zinnia elegans* in progesterone at 10 mg $\cdot$ L^{-1} resulted in the highest plants, heaviest shoot fresh and dry weights, largest number of branches and leaves, the largest number of buds and the largest number of flowers per plant compared to the plants whose seeds were soaked only in distilled water or soaked in progesterone at 5 mg $\cdot$ L^{-1}. However, they also found that spraying with progesterone at 10 mg $\cdot$ L^{-1} 2 months after germination resulted in better findings compared to those obtained for soaking seeds and spraying in the four-leaf seedling phase. In addition, total chlorophyll increased when progesterone at 10 mg $\cdot$ L^{-1} was applied at any stage. Similar to our study, the role of progesterone in increasing the chlorophyll content in leaves was reported by Mohammad et al. (2020). Spraying strawberry plants with this hormone increased chlorophyll *a* and *b* contents. In addition, they showed that the number of inflorescences per plant, the number of flowers per inflorescence, the weight of the first fruit, the average weight of the fruit and the length and width of the first fruit of the strawberry were significantly increased by foliar application of progesterone. It is considered that due to its structural similarity to other steroid hormones, progesterone could bind to specific receptors in plant cells and thereby regulate various growth processes (Pinto et al., 2024).

In the research on *Petunia hybrida*, *Tagetes erecta* and *Calendula officinalis*, Mohsen et al. (2018) concluded that treatment with oestradiol increased leaf area, flower longevity, chlorophyll and carotenoid contents and peroxidase activity. Although progesterone was less effective than other steroid hormones, it had a significant effect on the plant growth of these three species compared to plants that were not treated with any hormones with *T. erecta* being more responsive compared to the other two species. Similarly, our study revealed that all hormone treatments significantly increased both the number of inflorescences per plant and the number of flowers per inflorescence compared to untreated control plants. The synthetic hormones could potentially influence plants through several physiological and biochemical pathways. Once internalised, these hormones could disrupt apoplastic transport (Horst, 1995), altering mineral nutrient mobility and adsorption to cell walls, thereby affecting ion homeostasis and physiological processes like germination and growth. Additionally, thyroxine implies that such hormones may interact with plant-specific signalling pathways, potentially through transport proteins like transthyretin homologues, which are present in plants and can bind thyroid hormones (Eneqvist et al., 2003).

In an experiment on the physiological effect of progesterone on gerbera growth, Metwally (2015) reported that spraying gerbera leaves with progesterone at the concentration of 20 ppm resulted in a significant increase in endogenous indole-3-acetic acid (IAA) content compared to the control group. However, at the lowest concentration of 10 ppm, progesterone had the strongest effect in increasing the plant's cytokinin content. Progesterone also increased the leaf protein content, reaching its highest value when applied at the highest concentration of 30 ppm. Progesterone can act in plants through receptor-mediated signalling, binding to membrane steroid binding protein in *Arabidopsis*, modulating root growth and stress responses (Yang et al., 2005), enhancing antioxidant defences via boosting superoxide dismutase (SOD), catalase (CAT) and ascorbate peroxidase (APX) activities to reduce oxidative stress markers, such as H_2O_2 and malondialdehyde (MDA) (Erdal, 2012; Pinto et al., 2024) and promoting osmoregulation (e.g. accumulating proline and glycine betaine to maintain cell turgor under salinity/drought) (Kopecká et al., 2023). They may also stabilise photosynthesis by protecting photosystem II integrity (Xue et al., 2017), regulate ion homeostasis through reducing Na^+/K^+ ratios (Sameeullah et al., 2021). However, their precise molecular mechanisms and signalling pathways require further elucidation (Li et al., 2022).

Turk (2021) pointed out that treating maize seeds with progesterone significantly increased gene expression levels of citrate synthase (CS), cytochrome c oxidase (COX19), pyruvate dehydrogenase (Pdh1) and ATP synthase (ATP6), enzymes involved in mitochondrial respiration. Progesterone also increased root length, total soluble proteins and total carbohydrates. This may indicate that progesterone stimulates mitochondrial respiration by stimulating biochemical and molecular processes and thus accelerating seed germination.

Further studies could investigate the long-term effects of these hormone treatments in the field, and comparative transcriptome analysis of hormone-treated and untreated plants could contribute to expanding knowledge of the mechanism of their action in plant organisms.

CONCLUSIONS

Pre-soaking *C. argentea* seeds in synthetic hormone solutions significantly enhance vegetative growth, floral development and biochemical characteristics compared to the control. Among the tested hormones, thyroxine at 100 µg · L^{-1} proved to be most effective, promoting the highest growth rate. Progesterone and testosterone also revealed the positive effect on the plant growth and flowering when applied at medium concentrations, 200 mg · L^{-1} and 500 mg · L^{-1}, respectively. In turn, cortisone exhibited a dose-dependent effect, with the highest concentration (1.5 mg · L^{-1}) yielding the most pronounced improvements.

Based on these findings, seed soaking in thyroxine (100 µg · L^{-1}) before planting is recommended to maximise *C. argentea* growth and plant quality, offering a practical approach for horticultural and agricultural applications.

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AUTHOR CONTRIBUTIONS

M.A.B. and M.A.E. contributed to methodology, formal analysis, investigation, software, data curation, writing original draft, writing review and editing, validation and visualisation. M.A.E. and S.D.I. supported the investigation, validation, visualisation, data curation and methodology. M.H. and M.A. were responsible for resources, data curation, editing, visualisation, formal editing and biochemical analysis. S.D.I., S.A., and M.A. assisted with investigation, software, data curation, methodology and validation. S.D.I., and S.A. contributed to investigation, software and review. M.A.B., M.A.E. and M.H. contributed to chemical analysis, editing and visualisation. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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