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Effects of Gibberellin and Melatonin Foliar Sprays on Basil Chemical Composition and Volatile Oil Yield under Water Stress

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Abstract

This study investigated the potential of exogenous gibberellic acid (GA_3) and melatonin (MT) to mitigate the adverse effects of drought stress on basil (*Ocimum basilicum* L.). Conducted in 2022 at the University of Baghdad, Iraq, the experiment employed a split-plot design within a completely randomized block design. Three irrigation intervals (3, 5, and 7 days) were assigned to the main plots, while subplots received a factorial combination of the plant growth regulator gibberellic acid (GA_3; 0, 100, and 200 mg/L) and melatonin (0, 20, and 40 mg/L). Results indicated that moderate water stress with a 5-day irrigation interval significantly enhanced leaf nitrogen, phosphorus, and potassium nutrient content, total phenolic content, and volatile oil yield compared with the 3-day and 7-day irrigation intervals. The application of 200 mg/L GA_3 and 40 mg/L melatonin consistently yielded the highest values for all physiological and chemical parameters. Significant double- and triple-interactions suggest that the synergistic application of GA_3 and melatonin effectively improved basil secondary metabolism under water-limited conditions. These findings highlight a strategic approach for optimizing essential oil production in arid environments.

Keywords: basil, growth regulator, irrigation interval, water stress

Introduction

The use of medicinal plants has become an urgent need with the increase in population size and the increase in awareness and knowledge in treating diseases that may affect humans, as well as their use and circulation is simple and can be used as concentrates or extracts or in the form of capsules and dry pills due to the presence of the active substance in them with a physiological effect, as attention turned in the late last century in developed countries towards alternative medicine instead of taking medical drugs that humans take (Al-Shahat, 2006). Medicinal plants have been used since ancient times to treat and cure diseases, and many countries still rely on them. The World Health Organisation also indicated that a large portion of the world's population relies on medicinal herbs as a primary form of treatment for many diseases (Mamedov, 2012).

Basil belongs to the mint family, which includes a variety of aromatic plants found worldwide. Its scientific name is *Ocimum basilicum* L., and it is believed to be native to Asia and Africa (Arya & Thakur, 2012; Zolfaghari et al., 2013). Basil is widely cultivated around the world due to its nutritional and medicinal importance, as it was used in ancient China and India to treat kidney and stomach problems (Leung & Foster, 1996; Manzoor et al., 2023), its oil has antioxidant, antibacterial, antifungal, and antimicrobial properties, and has medicinal and economic value for the production of cosmetics, perfumes, and pharmaceuticals. It is also used as a food preservative and flavour enhancer

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(Al-Shahat, 2006; Ru et al., 2024). Basil oil is characterised as a white-to-pale-yellow liquid with a pleasant odour (Al-Dajwi, 2004; Mounira et al., 2022). Agricultural production worldwide is affected by various stresses, both biotic and abiotic. Medicinal plants are among those directly affected by stress, including water stress, as this stress affects the development, formation, and growth stages of plant organs, and the occurrence and duration of these stages vary with accompanying environmental conditions (Jaleel et al., 2009). Water shortages or water stress are one of the biggest environmental challenges in basil-growing regions, especially in arid and semi-arid climates. Water shortages or water stress can lead to reduced relative water content of leaves and impaired physiological functions, such as poor growth and decreased total essential oil content. Water shortages reduce leaf area and crop dry weight, and plants sometimes respond by increasing glandular hair density or improving water-use efficiency (WUE), which helps maintain reasonable yields under stress. In these environments, careful irrigation management, the selection of drought-resistant varieties, and strategies such as microbial inoculation or the use of growth regulators are critical to enhance plant resilience. Integrating water stress management with crop quality is essential to ensuring sustainable basil production in a changing climate (Shahrajabian et al., 2021).

The physiological processes that occur in plants and are associated with water stress require further studies, especially the process of nutritional balance that plants perform to maintain their water content in harmony with climatic conditions and call for to seriously consider not wasting water and finding technologies that increase the efficiency of water use, such as spraying some antioxidant compounds such as melatonin, which is of great importance for growth and multiple physiological processes, including enhancing photosynthesis, regulating nitrogen metabolism, maintaining nutritional balance within plant tissues, protecting plant pigments, delaying leaf aging, and balancing oxidation and reduction processes (Ren et al., 2022). Melatonin also has essential functions in plant growth and development. Many studies have demonstrated the regulatory effects of melatonin on plant systems under various abiotic stress conditions, as melatonin has multiple physiological effects, including stimulating cells in the thin layer of plant tissue between the epidermis and the bark and increasing the activity and growth of root hairs, resulting in the emergence of new lateral roots and adventitious roots (Al-Janabi et al., 2024; Arnao & Hernández-Ruiz, 2018).

Plant growth regulators, specifically gibberellic acids (GA_3), are fundamental endogenous regulators of cell division and elongation (Davies, 2012; Taiz & Zeiger, 2010). Beyond their primary role in promoting growth, GAs significantly enhance plant adaptability to water deficits by facilitating stem and root elongation, thereby optimizing subsoil moisture acquisition. Furthermore, GAs modulate the antagonistic crosstalk between growth hormones (auxins) and stress hormones (abscisic acid), thereby mitigating the physiological constraints of drought. Previous research suggests that exogenous GA application improves cell wall elasticity, enhances nutrient uptake efficiency, and maintains photosynthetic pigments under moisture-limited conditions (Maghsoudi et al., 2018). Recently, melatonin has emerged as a synergistic signaling molecule that further bolsters antioxidant defenses. There are still limited studies on how plant growth regulators can improve oil yield of aromatic species under water stress. This study, therefore, evaluates the combined effects of foliar-applied gibberellins and melatonin on the volatile oil profile and chemical composition of basil (*Ocimum basilicum* L.) under stage-specific water stress.

Materials and Methods

Experimental Site and Design

The study was conducted during the spring season of 2022 at the experimental field of the Faculty of Agricultural Engineering Sciences, University of Baghdad. The research evaluated the physiological and chemical responses of basil (*Ocimum basilicum* L.) to exogenous gibberellic

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acid (GA_3) and melatonin applications under varying water-stress regimes. The experiment was organized in a split-split plot design within a completely randomized block design with three replications. The irrigation intervals of 3, 5, and 7 days, reflecting water stress levels, was assigned as the main plot; sub-plots with GA_3 concentrations of 0, 100, and 200 mg/L; and sub-sub-plots with melatonin concentrations of 0, 20, and 40 mg/L.

Basil seeds were initially sown in seedling trays filled with a standardized growth medium (peat moss and perlite). After 2–4 true leaves emerged, the seedlings were thinned to ensure uniformity. At 21–28 days after sowing (DAS), the seedlings were transplanted into the experimental field. For the drought stress treatment, a standard irrigation was maintained during the initial establishment period to ensure successful root development. Water stress treatments were initiated 14–21 days post-transplantation, when the plants were approximately 35–45 days old. At this phenological stage, the plants had reached a stable vegetative state, allowing for a clear assessment of how and melatonin influence stress resilience and volatile oil synthesis.

Leaf nutrient analysis and secondary metabolite quantification were performed following standardized protocols. Nitrogen (N) content was determined using the semi-micro Kjeldahl method (AOAC, 1980). Phosphorus (P) was estimated colorimetrically via spectrophotometry, while potassium (K) was quantified according to AOAC (1980) guidelines. The total phenolic content (TPC) was evaluated using the spectrophotometric method described by Mahadevan and Sridhar (1986). Volatile oil content was extracted from fresh leaf material using a Clevenger-type apparatus for hydrodistillation (AOAC, 1980), and the volatile oil yield was subsequently calculated as the product of the fresh leaf weight and the oil percentage (g per plant).

Results and Discussion

Result

Effects of Irrigation Intervals and Growth Regulators on Leaf N, P, K

The mineral composition of basil leaves, specifically nitrogen (N), phosphorus (P), and potassium (K), was significantly influenced by irrigation frequency and the application of exogenous growth regulators (Tables 1, 2, 3, 4, 5, and 6). The three-way interaction among 5-day watering interval, GA_3 at 200 mg/L, and melatonin at 40 mg/L had the greatest positive impact on nutrient uptake. The maximum values recorded were 2.920% for N (Table 1), 0.811% for P (Table 3), and 1.793% for K (Table 5). Conversely, the lowest nutrient accumulation was consistently observed in the 7-day watering interval without growth regulators, resulting in 0.974% N (Table 1), 0.270% P (Table 3), and 0.598% K (Table 5), illustrating the severe limitations on mineral absorption imposed by prolonged water deficits without hormonal mitigation.

The moderate irrigation interval of 5 days consistently yielded the highest nutrient concentrations: N (2.153%, Table 1), P (0.598%, Table 3), and K (1.322%, Table 5). In contrast, extending the irrigation interval to 7 days resulted in the lowest recorded values across all mineral traits (Tables 1, 3, 5). respectively.

Regarding hormonal treatments, the high-concentration applications of GA_3 (200 mg/L) and melatonin (40 mg/L) significantly enhanced nitrogen accumulation compared to their respective controls (Table 2). Melatonin at 40 mg/L was particularly effective for nitrogen, achieving a peak of 2.016% (Table 2), while GA_3 at 200 mg/L recorded phosphorus and potassium peaks of 0.548% (Table 4) and 1.210% (Table 6). Significant two-way interactions were observed between all studied factors (Tables 2, 4, and 6). The combinations of 5-day watering intervals and GA_3 at 200 mg/L or melatonin at 40 mg/L produced the highest leaf N (Table 2), P (Table 4), and K (Table 6) concentrations. For instance, basil treated with 5-day watering intervals and

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melatonin at 40 mg/L had N and K concentrations of 2.399% (Table 2) and 1.473% (Table 6), respectively.

Total Phenolic Content (%)

Statistical analysis (Tables 7 and 8) revealed that the total phenolic content was significantly enhanced by moderate irrigation (5-day irrigation interval; 0.466%) and by the highest hormonal concentrations (200 mg/L GA_3: 0.415%; 40 mg/L melatonin; 0.428%). The synergistic effect of the three factors was most evident in the 5-day irrigation interval, 200 mg/L GA_3, and 40 mg/L melatonin combination, which achieved 0.679%, a significant increase over the 7-day irrigation interval without growth regulators (0.139%).

Leaf Oil Content

The volatile oil percentage exhibited a response pattern consistent with the leaf nutrient accumulation trends (Tables 9, 10). Statistical analysis revealed that irrigation intervals, GA_3 application, and melatonin treatments all exerted significant primary and interactive effects on these parameters (Tables 9, 10).

The moderate irrigation frequency of 5 days achieved a maximum oil yield of 7.421 g per plant, significantly outperforming the severe drought condition of 7 days, which reduced yield to 5.062 g per plant (Table 11). Among the growth regulators, the highest concentrations of GA_3 (200 mg/L) and melatonin (40 mg/L) resulted in peak individual yields of 6.509 g per plant and 6.744 g per plant, respectively (Table 12). These results confirm that exogenous GA_3 and melatonin act as potent biostimulants for secondary metabolite synthesis in basil.

Table 1

The Effects of GA_3 and Melatonin Spraying under Different Watering Intervals on the Leaf Nitrogen (%)

Irrigation interval	GA_3 (mg/L)	Melatonin 0 mg/L	Melatonin 20 mg/L	Melatonin 40 mg/L	GA_3 mean	Irrigation interval mean
3 days	0	1.891	1.702	1.810	1.801	1.798
	100	1.891	1.696	1.795	1.794	
	200	1.911	1.725	1.761	1.799	
5 days	0	1.998	1.900	1.945	1.948	2.153*
	100	2.043	2.178	2.333	2.185	
	200	2.025	2.039	2.920	2.328	
7 days	0	0.974	1.637	1.698	1.436	1.679
	100	1.566	1.850	2.030	1.815	
	200	1.857	1.651	1.850	1.786	
Melatonin mean		1.795	1.820	2.016		
LSD irrigation interval			0.083			
LSD GA_3			0.083			
LSD melatonin			0.083			
LSD irrigation interval x GA_3 x melatonin			0.250			

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Table 2

Plant Growth Regulator and Irrigation Interval Interactions in Affecting Leaf Nitrogen Content

GA_3 (mg/L)	Melatonin (mg/L)			GA_3 mean
	0	20	40	
0	1.621	1.747	1.818	1.728
100	1.833	1.908	2.052	1.931
200	1.931	1.805	2.177	1.971
Melatonin mean	1.795	1.820	2.016	
LSD GA_3 x melatonin		0.144		
Irrigation intervals (days)	Melatonin (mg/L)			Irrigation interval mean
	0	20	40	
3	1.898	1.708	1.789	1.798
5	2.022	2.039	2.399*	2.153
7	1.465	1.713	1.859	1.679
Melatonin mean	1.795	1.820	2.016	
LSD irrigation interval x melatonin		0.144		
Irrigation intervals (days)	GA_3 (mg/L)			Irrigation interval mean
	0	100	200	
3	1.801	1.794	1.799	1.798
5	1.948	2.185	2.328*	2.153
7	1.436	1.815	1.786	1.679
GA_3 mean	1.728	1.931	1.971	
LSD irrigation interval x GA_3		0.144		

Table 3

The Effects of GA_3 and Melatonin Spraying under Different Watering Intervals on the Leaf Phosphorus (%)

Irrigation interval	GA_3 (mg/L)	Melatonin 0 mg/L	Melatonin 20 mg/L	Melatonin 40 mg/L	GA_3 mean	Irrigation interval mean
3 days	0	0.522	0.473	0.503	0.499	1.798
	100	0.525	0.471	0.499	0.498	
	200	0.531	0.479	0.489	0.500	
5 days	0	0.555	0.528	0.540	0.541	2.153*
	100	0.568	0.605	0.648	0.607	
	200	0.562	0.566	0.811	0.647	
7 days	0	0.270	0.455	0.472	0.399	1.679
	100	0.435	0.514	0.564	0.504	
	200	0.516	0.459	0.514	0.496	
Melatonin mean		0.498	0.505	0.560		
LSD irrigation interval			0.023			
LSD GA_3			0.023			
LSD melatonin			0.023			
LSD irrigation interval x GA_3 x melatonin			0.069			

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Table 4

Plant Growth Regulator and Irrigation Interval Interactions in Affecting Leaf Phosphorus

GA_3 (mg/L)	Melatonin (mg/L)			GA_3 mean
	0	20	40	
0	0.449	0.485	0.505	0.480
100	0.509	0.530	0.570	0.536
200	0.536	0.501	0.605	0.548
Melatonin mean	0.498	0.505	0.560	
LSD GA_3 x melatonin		0.040		
Irrigation intervals (days)	**Melatonin (mg/L)**			**Irrigation interval mean**
	0	20	40	
3	0.526	0.474	0.497	0.499
5	0.562	0.566	0.666	0.598
7	0.407	0.476	0.517	0.466
Melatonin mean	0.498	0.505	0.560	
LSD irrigation interval x melatonin		0.040		
Irrigation intervals (days)	**GA_3 (mg/L)**			**Irrigation interval mean**
	0	100	200	
3	0.499	0.498	0.500	0.499
5	0.541	0.607	0.647	0.598
7	0.399	0.504	0.496	0.466
GA_3 mean	0.480	0.536	0.548	
LSD irrigation interval x GA_3		0.040		

Table 5

The Effects of GA_3 and Melatonin Spraying under Different Watering Intervals on the Leaf Potassium (%)

Irrigation interval	GA_3 (mg/L)	Melatonin 0 mg/L	Melatonin 20 mg/L	Melatonin 40 mg/L	GA_3 mean	Irrigation interval mean
3 days	0	1.154	1.052	1.112	1.106	1.104
	100	1.161	1.041	1.102	1.101	
	200	1.173	1.058	1.081	1.104	
5 days	0	1.226	1.166	1.193	1.195	1.322*
	100	1.254	1.338	1.432	1.341	
	200	1.243	1.252	1.793*	1.429	
7 days	0	0.598	1.005	1.042	0.882	1.031
	100	0.961	1.135	1.246	1.114	
	200	1.140	1.013	1.136	1.096	
Melatonin mean		1.101	1.118	1.238		
LSD irrigation interval			0.051			
LSD GA_3			0.051			
LSD melatonin			0.051			
LSD irrigation interval x GA_3 x melatonin			0.153			

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Table 6

Plant Growth Regulator and Irrigation Interval Interactions in Affecting Leaf Potassium

GA_3 (mg/L)	Melatonin (mg/L)			GA_3 mean
	0	20	40	
0	0.993	1.074	1.116	1.061
100	1.125	1.171	1.260	1.322
200	1.185	1.107	1.337	1.031
Melatonin mean	1.101	1.118	1.238	
LSD GA_3 x melatonin		0.088		
Irrigation intervals (days)	Melatonin (mg/L)			Irrigation interval mean
	0	20	40	
3	1.162	1.050	1.098	1.104
5	1.241	1.252*	1.473	1.322
7	0.900	1.051	1.141	1.031
Melatonin mean	1.101	1.118	1.238	
LSD irrigation interval x melatonin		0.088		
Irrigation intervals (days)	GA_3 (mg/L)			Irrigation interval mean
	0	100	200	
3	1.106	1.101	1.104	1.104
5	1.195	1.341*	1.429	1.322
7	0.882	1.114	1.096	1.031
GA_3 mean	1.061	1.186	1.210	
LSD irrigation interval x GA_3		0.088		

Table 7

The Effects of GA_3 and Melatonin Spraying under Different Watering Intervals on the Leaf Phenol (%)

Irrigation interval	GA_3 (mg/L)	Melatonin 0 mg/L	Melatonin 20 mg/L	Melatonin 40 mg/L	GA_3 mean	Irrigation interval mean
3 days	0	0.390	0.341	0.371	0.367	
	100	0.393	0.339	0.367	0.366	0.367
	200	0.399	0.347	0.357	0.368	
5 days	0	0.423	0.396	0.408	0.409	
	100	0.435	0.473	0.516	0.475	0.466*
	200	0.430	0.434	0.679*	0.515	
7 days	0	0.139	0.323	0.340	0.267	
	100	0.303	0.382	0.432	0.372	0.334
	200	0.384	0.326	0.382	0.364	
Melatonin mean		0.366	0.373	0.428		
LSD irrigation interval			0.24			
LSD GA_3			0.24			
LSD melatonin			0.24			
LSD irrigation interval x GA_3 x melatonin			0.74			

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Table 8

Plant Growth Regulator and Irrigation Interval Interactions in Affecting Leaf Phenols

GA_3 (mg/L)	Melatonin (mg/L)			GA_3 mean
	0	20	40	
0	0.993	1.074	1.116	1.061
100	1.125	1.171	1.260	1.322
200	1.185	1.107	1.337	1.031
Melatonin mean	1.101	1.118	1.238	
LSD GA_3 x melatonin		0.42		
Irrigation intervals (days)	**Melatonin (mg/L)**			**Irrigation interval mean**
	0	20	40	
3	0.394	0.342	0.365	0.367
5	0.429	0.434	0.534	0.466
7	0.275	0.344	0.384	0.415
Melatonin mean	0.366	0.373	0.384	
LSD irrigation interval x melatonin		0.42		
Irrigation intervals (days)	**GA_3 (mg/L)**			**Irrigation interval mean**
	0	100	200	
3	0.367	0.366	0.368	0.367
5	0.409	0.475	0.515	0.466
7	0.267	0.372	0.364	0.415
GA_3 mean	0.348	0.404	0.415	
LSD irrigation interval x GA_3		0.42		

Table 9

The Effects of GA_3 and Melatonin Spraying under Water Stress Conditions on the Leaf Oil Content (%)

Irrigation interval	GA_3 (mg/L)	Melatonin 0 mg/L	Melatonin 20 mg/L	Melatonin 40 mg/L	GA_3 mean	Irrigation interval mean
3 days	0	0.128	0.116	0.123	0.122	
	100	0.128	0.115	0.122	0.123	0.122
	200	0.130	0.117	0.120	0.122	
5 days	0	0.136	0.129	0.132	0.132	
	100	0.139	0.148	0.158	0.148	0.146
	200	0.137	0.138	0.198	0.158	
7 days	0	0.066	0.111	0.115	0.098	
	100	0.106	0.126	0.138	0.123	0.114
	200	0.126	0.112	0.126	0.121	
Melatonin mean		0.122	0.124	0.137		
LSD irrigation interval			0.005			
LSD GA_3			0. 005			
LSD melatonin			0. 005			
LSD irrigation interval x GA_3 x melatonin			0.017			

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Significant two-way interactions were observed, particularly in the combined application of irrigation regimes and hormonal sprays (Table 10). The 5-day irrigation interval supplemented with 20 mg/L melatonin (8.898 g per plant) and the 5-day irrigation interval combined with 200 mg/L GA_3 (8.487 g per plant) produced the highest yields among the two-factor treatments. In contrast, the lowest performance was recorded under the 7-day irrigation interval without hormone application (0 mg/L), yielding 4.027 g per plant. The three-way interaction demonstrated an even more pronounced effect (Table 11). The combination of a 5-day irrigation interval with 200 mg/L GA_3 and 40 mg/L melatonin yielded the greatest enhancement in volatile oil productivity, reaching 12.107 g per plant (Table 11). This value represents more than a five-fold increase compared to the minimum yield observed under the 7-day irrigation interval without GA_3 or melatonin (2.232 g per plant). Overall, these results highlight the strong synergistic effect of GA_3 and melatonin in alleviating the adverse impact of water deficit on aromatic plant productivity.

The results across Tables 1-12 demonstrate that leaf nutrient status (N, P, K), total phenolics, and volatile oil metrics were optimized with a 5-day irrigation interval. This suggests that moderate irrigation frequency facilitates soil moisture availability, promoting nutrient solubility and uptake efficiency. In contrast, extended irrigation intervals (7-day intervals) are likely to trigger physiological shutdowns or increased root hydraulic resistance, severely hindering mineral absorption (Obidiegwu et al., 2015). The enhancement in chemical and oil profiles following gibberellic acid (GA_3) application is likely due to its role in stimulating vegetative biomass and increasing “sink strength.” By

Table 10

Plant Growth Regulator and Irrigation Interval Interactions in Affecting Leaf Oil Content (%)

GA_3 (mg/L)	Melatonin (mg/L)			GA_3 mean
	0	20	40	
0	0.110	0.119	0.123	0.117
100	0.125	0.130	0.139	0.131
200	0.131	0.123	0.148	0.134
Melatonin mean	0.122	0.124	0.137	
LSD GA_3 x melatonin		0.009		
Irrigation intervals (days)	**Melatonin (mg/L)**			**Irrigation interval mean**
	0	20	40	
3	0.129	0.116	0.122	0.122
5	0.137	0.138	0.163	0.146
7	0.100	0.116	0.126	0.114
Melatonin mean	0.122	0.124	0.137	
LSD Irrigation interval x Melatonin		0.009		
Irrigation intervals (days)	**GA_3 (mg/L)**			**Irrigation interval mean**
	0	100	200	
3	0.122	0.123	0.122	0.122
5	0.132	0.148	0.158	0.146
7	0.098	0.123	0.121	0.114
GA_3 mean	0.117	0.131	0.134	
LSD Irrigation interval x GA_3		0.009		

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Table 11

The Effects of GA_3 and Melatonin Spraying under Water Stress Conditions on the on the Volatile Oil Yield (g per plant)

Irrigation interval	GA_3 (mg/L)	Melatonin 0 mg/L	Melatonin 20 mg/L	Melatonin 40 mg/L	GA_3 mean	Irrigation interval mean
3 days	0	5.853	5.078	5.593	5.508	
	100	5.986	5.048	5.502	5.512	5.524
	200	6.098	5.213	5.349	5.554	
5 days	0	6.514	6.030	6.268	6.271	
	100	6.742	7.456	8.320	7.506	7.421
	200	6.613	6.742	12.107*	8.487	
7 days	0	2.232	4.785	5.065	4.027	
	100	4.505	5.800	6.709	5.671	5.062
	200	5.818	4.856	5.786	5.486	
Melatonin mean		5.596	5.668	6.744		
LSD irrigation interval			0.419			
LSD GA_3			0.419			
LSD melatonin			0.419			
LSD irrigation interval x GA_3 x melatonin			1.259			

Table 12

Plant Growth Regulator and Irrigation Interval Interactions in Affecting Volatile Oil Yield (g per plant)

GA_3 (mg/L)	Melatonin (mg/L)			GA_3 mean
	0	20	40	
0	4.866	5.298	5.642	5.269
100	5.744	6.101	6.844	6.230
200	6.176	5.604	7.747	6.509
Melatonin mean	5.596	5.668	6.744*	
LSD GA_3 x melatonin		0.727		
Irrigation intervals (days)	Melatonin (mg/L)			Irrigation interval mean
	0	20	40	
3	5.979	5.113	5.481	5.524
5	6.623	6.743	8.898	7.421
7	4.185	5.147	5.853	5.062
Melatonin mean	5.596	5.668	6.744	
LSD Irrigation interval x Melatonin		0.727		
Irrigation intervals (days)	GA_3 (mg/L)			Irrigation interval mean
	0	100	200	
3	5.508	5.512	5.554	5.524
5	6.271	7.506	8.487	7.421
7	4.027	5.671	5.486	5.062
GA_3 mean	5.269	6.230	6.509	
LSD Irrigation interval x GA_3		0.727		

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promoting cell elongation and metabolic activity, GA_3 facilitates the translocation of minerals from the rhizosphere to the foliar tissues (Maghsoudi et al., 2018).

The significant role of melatonin in increasing nutrient and oil content can be attributed to its function as a master physiological regulator. Melatonin enhances the plant's efficiency in performing vital metabolic functions and synergistically interacts with endogenous auxins to improve overall growth (Al-Saadi et al., 2022). Furthermore, melatonin is known to protect the photosynthetic apparatus from oxidative damage during water stress, ensuring that the carbon precursors required for volatile oil biosynthesis remain available even under moisture-limited conditions. The synergistic interaction of 5-day irrigation interval, 200 mg/L, and 40 mg/L GA3 represents an integrated resilience strategy: 5-day irrigation interval provides the hydration necessary for cellular functions, GA_3 ensures the structural development of oil glands, and melatonin provides antioxidant protection and hormonal balance required to sustain secondary metabolism.

Conclusions

The results of this study demonstrate that the productivity and chemical composition of basil (*Ocimum basilicum* L.) are highly dependent on the interaction between irrigation management and exogenous hormonal application. A 5-day irrigation interval is optimal for maximizing leaf nutrient content (N, P, K), total phenolics, and volatile oil yield. While severe water stress (7-day irrigation interval) significantly hindered physiological performance, the application of 200 mg/L gibberellic acid and 40 mg/L melatonin served as effective mitigants. Specifically, the 5-day irrigation interval, 200 mg/L GA_3, and 40 mg/L melatonin interaction emerged as the superior treatment, yielding an oil yield of 12.107 g per plant. This study suggests that integrating GA_3 and melatonin into the cultivation regime can enhance the resilience of aromatic crops against water scarcity. For growers in arid regions like Iraq, adopting a moderate irrigation schedule (5-day intervals) combined with foliar applications of GA_3 and melatonin offers a sustainable strategy to stabilize secondary metabolite production and optimize essential oil quality.

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