



Research article

Ameliorating Lime-Induced Stress in *Arctotis × hybrida* through Peat Moss and Perlite Amendments: Growth, Physiology, and Multivariate Analysis

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ABSTRACT

This study evaluates how organic and inorganic soil amendments can reduce the negative effects of high pH and low nutrient levels in calcareous soils. The research focuses on improving the growth and quality of *Arctotis × hybrida*. A randomized complete block design (RCBD) with three replications was used under both indoor and outdoor conditions. Six substrate treatments were tested: 100% calcareous soil (Control, T1), and various mixtures of calcareous soil with either peat moss (25% and 50%; T2, T3) or perlite (25%, 50%, and a mixture; T4, T5, T6). Statistical analysis, including Principal Component Analysis (PCA), showed that the first two components explained 87.4% of the total variance. Peat moss treatments performed significantly better than both the control and perlite-based media. We found a strong negative correlation between soil CaCO₃ levels and plant performance ($r = -0.65$ to -0.82), while growth markers showed strong positive relationships with each other ($r > 0.80$). Adding peat moss significantly increased leaf area (40.2–48.1%), leaf dry weight (17.8–34.8%), and root dry weight (66.1–165.3%) compared to the control. Additionally, flowering traits improved by up to 47.6%. In contrast, perlite amendments showed only minor benefits. Overall, indoor cultivation produced much better results across all physiological parameters than outdoor environments.

1. Introduction

The African Daisy (*Arctotis × hybrida*) is a significant ornamental plant, valued worldwide for its bright flowers and attractive silvery-gray leaves (Dole & Wilkins, 2005). Its ability to bloom for long periods and tolerate different weather conditions makes it a top choice for landscaping and pot gardening in Mediterranean climates (Khalil *et al.*, 2023). In the horticulture industry, the quality of these plants is measured by their growth rate, leaf health, and flowering intensity, all of which are traits highly influenced by the growing medium (El-Menaie *et al.*, 2008).

However, growers in the Kurdistan Region and many arid areas face a major challenge: calcareous soils. These soils are characterized by a high concentration of calcium carbonate (CaCO₃), which leads to a high alkaline pH, often between 7.5 and 8.5 (Brady & Weil, 2017). This alkalinity creates a hostile



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environment for many ornamental species, as it limits the availability of essential nutrients. Plants often struggle to absorb phosphorus, iron, manganese, and zinc because they turn into solid, unusable forms in high-pH conditions (Marschner, 2012). For *Arctotis*, this can result in small, stunted plants and yellowing leaves, a condition known as lime-induced chlorosis (Osman, 2013).

To overcome these soil limitations, soil amendments are commonly used. Peat moss is one of the most effective organic materials for this purpose. It is known for its high ability to hold water, storing nutrients through a high cation exchange capacity, and its natural acidity, which helps in lowering the pH of alkaline soils (Raviv & Lieth, 2008). Adding peat moss to calcareous soil increases organic matter, improves soil structure, and promotes beneficial microbial activity (Hawash 2025). On the other hand, perlite is an inorganic amendment used to improve physical soil properties. It is highly porous, providing excellent aeration and drainage, which prevents root rot and ensures that roots have enough oxygen (Landis & Morgan, 2015). While perlite is effective in improving soil structure, its success in mitigating the chemical stress of calcareous soils has shown mixed results in past research, as it does not provide nutrients or change the soil pH significantly (Gruda, 2019).

Despite the widespread use of these materials, there is limited research on the specific response of *Arctotis × hybrida* to various mixtures of peat moss and perlite when grown in the highly calcareous soils of the Ranya region. This study aims to evaluate the efficiency of these organic and inorganic amendments in improving the vegetative growth and flowering quality of *Arctotis*, providing sustainable solutions for local nursery production.

2. Materials and Methods

2.1. Plant Material and Growth Conditions

The study was conducted at the experimental nursery of the College of Agricultural Engineering Sciences, University of Raparin, Ranya, Kurdistan Region of Iraq. The experiment took place in Qaladiza city, which is situated approximately 120 kilometers north of Sulaimaniyah city in the Kurdistan region of Iraq. The specific coordinates of the location are 36° 10' 19" N latitude, 45° 8' 17" E longitude, and an altitude of 576 meters above sea level (masl).



Fig(1) qaladziah location

Terminal stem cuttings of *Arctotis × hybrida* were collected, each with a length of 8 cm. These cuttings were planted in clay pots with a diameter of 20 cm, containing the designated substrate treatments.

To ensure uniform vegetative establishment and prevent early energy depletion, a 20-day debudding period was implemented, during which all emerging flower buds were manually removed.

2.2. Experimental Design and Treatments

The study was carried out during March till May of 2024. Two independent experiments were conducted simultaneously under indoor and outdoor conditions. The experiment followed a Randomized Complete Block Design (RCBD) with three replications. Each experimental unit (replication) consisted of three individual pots (one plant/ pot), totaling 54 plants for the each study. The individual pot containing one plant was considered the experimental unit. Plant in both experiment were irrigated regularly based on plant water requirement to maintain soil moisture near field capacity. To ensure optimal nutrient availability, a balanced water-soluble fertilizer (NPK 19-19-19) was applied uniformly to all pots at a concentration of 1 g/L. fertilization was perormed twice weekly during the active plant growth period, Six substrate treatments were evaluated which mixed strictly on a volume-to-volume(v/v):

- T1: 100% Calcareous soil (Control) (v/v)
- T2: 75% Calcareous soil + 25% Peat moss. (v/v)
- T3: 50% Calcareous soil + 50% Peat moss. (v/v)
- T4: 75% Calcareous soil + 25% Perlite. (v/v)
- T5: 50% Calcareous soil + 50% Perlite. (v/v)
- T6: 50% Calcareous soil + 25% Peat moss + 25% Perlite. (v/v)

2.3. Measurements and Data Collection Vegetative growth parameters

The measurements data Collection Including plant height, leaf area, and dry weight, were recorded at the end of the growing season. Total chlorophyll content was determined using the method described by Zibilske (2021). For nutrient analysis, nitrogen (N) was determined by the micro-Kjeldahl method, while phosphorus (P) and potassium (K) were analyzed following the protocols of Chapman and Pratt (1961) and Evenhuis and Dewaard (1980).

Table 1. Physical and chemical properties of the growing media used in the experiment.

Measured Properties	Amount	Units
Electrical Conductivity	0.2	dsm ⁻¹
EC 1:1		
pH 1:1	7.14	----
Available N	21.0	
Available P	8.21	mg kg ⁻¹ soil
Available K	76.51	
Soil Organic Matter	4.01	gm kg ⁻¹
Calcium Carbonate CaCO ₃	278.2	
Dissolved Ca ⁺²	3.51	
Dissolved Mg ⁺²	2.19	
Dissolved Na ⁺	1.12	meq lit ⁻¹
Dissolved Bicarbonate Hco ₃	0.82	
Dissolved Cl	2.91	
Dissolved K	0.33	

Texture Class		Silt Loam
	Sand	% 37.2
Soil Particles	Clay	% 10.8
	Silt	% 52.0

2.4. Data Collection and Measurements Data were collected across three main categories to provide a comprehensive evaluation

- **Growth and Flowering Traits:** Parameters included plant diameter (PD), tiller number (TN), leaf count (LN), leaf area (LA), and leaf dry weight (LDW). Root development was assessed via root volume (RV) and root dry weight (RDW). Reproductive traits were evaluated by measuring inflorescence diameter (ID), stem length (PL), flower count (IN), flower dry weight (IDW), and flowering duration (FD).
- **Physiological and Nutrient Analysis:** Total chlorophyll content was measured in SPAD units using a portable chlorophyll meter, following the methodology described by Zibilske (2021). For mineral analysis, leaves were oven-dried and processed to determine the concentrations of Nitrogen (N), Phosphorus (P), and Potassium (K) as percentages (%), while Copper (Cu), Manganese (Mn), and Zinc (Zn) were recorded in ppm, according to Chapman and Pratt (1961) and Evenhuis and Dewaard (1980).
- **Soil Properties:** Post-experiment soil analysis was conducted to determine the residual levels of nitrogen (N), phosphorus (P), potassium (K), zinc (Zn), iron (Fe), and total calcium carbonate content (CaCO_3).

2.5. Statistical Analysis

The data were subjected to Analysis of Variance (ANOVA). Mean separations were performed using the Least Significant Difference Test (LSD) at a significance level of $P \leq 0.05$. To explore the interrelationships between growth, physiology, and mineral nutrition, Principal Component Analysis (PCA) and Pearson correlation coefficients were calculated using XLSTAT and PAST software suites (Kadir & Salih, 2023).

3. Results and Discussion

3.1. Vegetative Growth Characteristics

The experimental results (Tables 2 and 3) indicate that *Arctotis* plants grown in the untreated calcareous soil (Control, T1) exhibited the poorest growth performance in both indoor and outdoor environments. This significant growth suppression is attributed to the inherently harsh physical and chemical properties of the native calcareous soil used in this study.

Our baseline analysis revealed a high alkaline pH of 7.14 and an extremely high calcium carbonate (CaCO_3) content of 27.82% (278.2g kg^{-1}). These extreme levels of CaCO_3 , combined with a low cation exchange capacity (CEC) and poor water-holding capacity (15.77%), created a high-stress environment for the plants. The high alkalinity prevents essential nutrients from dissolving, making them "locked" and unavailable for root uptake (Marschner, 2012). Furthermore, the limited water retention capacity likely subjected the plants to drought stress, which was exacerbated by excess calcium interfering with the uptake of other vital minerals through antagonistic effects (Brady & Weil, 2017). These findings are consistent with recent research on various ornamental species, which confirms that untreated calcareous soils lead to severe physiological disorders, nutrient deficiencies—particularly lime-induced chlorosis—and stunted vegetative development (El-Sharawy, 2019; Bader,

2022 & Al-Zobaie, 2024). The poor performance of the control group in this study clearly demonstrates that soil amendments, particularly organic ones like peat moss, are indispensable for mitigating the negative impacts of soil alkalinity and making these substrates suitable for *Arctotis* production (Kadir & Salih, 2023).

Table 2. Effect of growing media on plant diameter (PD), tiller number (TN), and leaf number (LN) of *Arctotis* under indoor and outdoor conditions.

Treatment	Indoor			Outdoor		
	PD (cm)	TN	LN	PD (cm)	TN	LN
T1	62.25	129.51c	1280.66ab	49.34c	87.82d	660.01c
T2	64.05	147.84a	1247.33ab	58.54ab	157.82a	1178.00a
T3	64.56	143.51ab	1425.32a	61.77a	149.15ab	950.00ab
T4	64.13	135.64bc	1340.16ab	53.37bc	127.52c	847.83bc
T5	67.02	123.01c	1096.83b	57.90ab	110.32d	920.33ab
T6	63.82	139.66ab	1183.82ab	58.91ab	141.01bc	1026.30a
LSD (0.05)	NS	12.45	215.32	6.82	18.76	198.45

Means followed by the same letter within a column are not significantly different at $P \leq 0.05$ according to LSD test. NS = not significant. n=3

3.2. Impact of Peat Moss Amendments on Vegetative Growth

The addition of peat moss at 25% (T2) and 50% (T3) significantly enhanced all growth parameters compared to the control. Under indoor conditions, T3 (50% peat moss) was the most effective, increasing leaf area by 48.1% and leaf dry weight by 34.8% over the control (T1). Similarly, T2 (25% peat moss) increased tiller number by 14.2% and leaf area by 40.2%.

These improvements are attributed to peat moss's ability to lower soil pH and increase the Cation Exchange Capacity (CEC), which unlocks essential nutrients for root uptake (Raviv & Lieth, 2008). Furthermore, the high porosity and water-holding capacity of peat moss create an ideal rhizosphere, mitigating the drought stress typical of calcareous soils (Zibilske, 2021). These results align with Kadir and Salih (2023), who found that organic amendments are crucial for optimizing the growth of Asteraceae species in the Kurdistan Region's alkaline environments.

Table 3. Effect of growing media on leaf area (LA) and leaf dry weight (LDW) of *Arctotis* under indoor and outdoor conditions

Treatment	Indoor		Outdoor	
	LA (cm ²)	LDW (g)	LA (cm ²)	LDW (g)
T1	5212.38c	54.72c	2543.07d	31.28d
T2	7307.66ab	64.49ab	4822.72a	43.53ab
T3	7720.92a	73.75a	4318.70ab	44.65a
T4	5329.99c	59.20bc	3519.83c	34.53cd

T5	6401.84b	56.13c	4243.57ab	35.75c
T6	6975.06ab	60.90b	4958.41a	41.13b
LSD (0.05)	892.45	7.82	654.32	5.43

Means followed by the same letter within a column are not significantly different at $P \leq 0.05$ according to LSD test, $n=3$

3.3. Mechanisms of Soil Improvement: Peat Moss vs. Perlite

By enriching organic matter, peat moss transformed the growth-limiting calcareous medium into a fertile rhizosphere, consistent with findings by Zibilske (2021) and Ahmad and Mahmoud (2022). Conversely, perlite (T4 and T5) showed limited impact. While perlite improves aeration, it lacks the buffering capacity and nutrient-holding ability of organic matter (Li & Chen, 2020). In highly alkaline soils, the primary constraints are chemical rather than physical; thus, perlite's inability to alter pH or CaCO_3 levels limited its efficacy. Furthermore, its rapid drainage may have exacerbated water stress in this environment, aligning with Landis and Morgan (2015). The moderate performance of the tripartite mixture (T6) further suggests that perlite may interfere with the water-retention benefits of peat moss in high-lime soils.

3.4. Flowering Characteristics and Quality

Flowering patterns mirrored vegetative growth, with the control group (T1) exhibiting the poorest performance (Table 4). High CaCO_3 levels and nutrient deficiencies not only stunted growth but also reduced flower count, diameter, and duration. This confirms that *Arctotis* reproduction is highly sensitive to "lime-induced stress," a physiological constraint also noted in other Asteraceae species (Hassan & Al-Zobaie, 2024). The significant enhancement of flowering in T3 and T2 highlights the role of organic amendments in supporting nutrient uptake during the blooming stage. (Khalil et al., 2023; Kadir & Salih, 2023).

Table 4. Influence of increased media on the flowering of *Arctotis* in an indoor and outdoor environment. ID = inflorescence diameter; PL = pedicel length; IN =inflorescence number; IDW=infloscape dry weight;FD=flowering period.

Treatment	Indoor					Outdoor				
	ID (cm)	PL (cm)	IN	IDW (g)	FD (days)	ID (cm)	PL (cm)	IN	IDW (g)	FD (days)
T1	3.65d	10.81c	79.83cd	0.294bc	12.33c	3.65c	8.63d	81.12c	0.243c	12.01d
T2	3.85ab	12.01ab	117.84a	0.311ab	12.95ab	3.81ab	10.22ab	127.31a	0.276ab	13.70ab
T3	3.98a	12.99a	113.82ab	0.318a	13.11a	3.67bc	10.77a	118.14ab	0.283a	13.95a
T4	3.86ab	10.60c	99.50bc	0.293bc	12.76b	3.86a	9.95bc	97.62c	0.247bc	13.53ab
T5	3.77bc	11.81b	89.02cd	0.281c	12.53bc	3.82ab	9.70bc	97.20c	0.246bc	13.73ab
T6	3.79bc	11.76b	112.60ab	0.323a	12.86ab	3.77ab	9.98bc	128.89a	0.286a	13.88a
LSD (0.05)	0.12	0.65	15.43	0.024	0.42	0.14	0.58	18.65	0.028	0.52

Means followed by the same letter within a column are not significantly different at $P \leq 0.05$ according to LSD test, $n=3$

3.5. Comparative Analysis of Flowering Traits

Peat moss amendments (T2 and T3) significantly enhanced all reproductive parameters. Indoors, T2 and T3 produced 47.6% and 42.6% more flowers, respectively, with flower diameters increasing by up to 9.0% and pedicel length by 20.2% compared to the control (T1). These improvements are directly linked to the optimized rhizosphere; by buffering the alkaline pH and increasing nutrient bioavailability, peat moss enhanced nutrient availability and uptake required for prolific flowering. These findings align with Khalil et al. (2023) and (Adeleye *et al* 2010), who emphasized that organic-rich substrates improve floral quality and longevity in ornamental species. Conversely, perlite (T4 and T5) showed negligible effects on flowering, likely due to its low water-holding capacity during the moisture-critical blooming stage, as suggested by Landis and Morgan (2015).

3.6. Root System Development and Architecture

The root system exhibited significant increase in response to soil amendment. Peat moss treatments achieved substantial gains in both volume and biomass (Table 5). Under indoor conditions, T3 (50% peat moss) attained a root volume of 475.65 cm³ and a dry weight of 141.14 g, representing extraordinary increases of 101.1% and 165.3%, respectively, over the control (T1). These results demonstrate peat moss's efficacy in ameliorating the physical constraints of calcareous soils. By enhancing porosity and aeration, peat moss facilitates deeper root penetration and expansive architecture (Raviv & Lieth, 2008). Furthermore, the sustained moisture availability in peat-amended media ensures a stable environment for root elongation and nutrient acquisition, consistent with the root-zone studies of Zibilske (2021) and Kadir and Salih (2023).

Table 5. Effect of growing media on root volume (RV) and root dry weight (RDW) of *Arctotis* under indoor and outdoor conditions.

Treatment	Indoor		Outdoor	
	RV (cm ³)	RDW (g)	RV (cm ³)	RDW (g)
T1	236.50c	53.21c	190.65b	47.77bc
T2	288.16bc	88.37b	285.82a	50.44bc
T3	475.65a	141.14a	272.33a	74.17a
T4	292.34bc	83.07bc	221.01ab	67.32ab
T5	326.65ab	62.17c	261.50a	40.84c
T6	316.82b	82.15bc	219.15ab	55.27bc
LSD (0.05)	72.81	24.26	75.07	22.76

Means followed by the same letter within a column are not significantly different at $P \leq 0.05$ according to LSD test, n=3

3.7. Physiological Responses: Chlorophyll and Nutrition

The physiological vigor of *Arctotis* was significantly compromised in the untreated calcareous soil (T1). This is supported by Marschner (2012), who explains that chlorophyll synthesis depends heavily on the bioavailability of nitrogen and magnesium, both of which are unavailable in high-pH environments.

On the other hand, the highest chlorophyll concentrations were found in the peat moss treatments. According to Zibilske (2021), organic matter facilitates soil acidification, which directly supports the enzymatic pathways for chlorophyll production. Furthermore, Kadir and Salih (2023) demonstrated that such amendments are essential for overcoming lime-induced stress in the Kurdistan Region.

Regarding mineral nutrition, Li and Chen (2020) noted that while perlite improves aeration, it fails to address chemical nutrient fixation. This confirms our results where perlite-treated plants remained weak, similar to the findings of Landis and Morgan (2015) regarding the limited moisture retention of inorganic substrates.

Table 6. Effect of growing media on chlorophyll content (Chl) and leaf macronutrient concentrations (N, P, K) of *Arctotis* under indoor and outdoor conditions.

Treatment	Indoor				Outdoor			
	Chl (SPAD)	N (%)	P (%)	K (%)	Chl (SPAD)	N (%)	P (%)	K (%)
T1	51.13c	2.289f	0.240d	1.661f	45.01e	2.671f	0.211f	1.861f
T2	57.37a	2.779a	0.430a	2.561a	55.42a	3.261b	0.321a	2.631b
T3	57.12a	2.560b	0.351b	2.521b	53.30ab	3.340a	0.291b	2.891a
T4	54.93b	2.311e	0.261c	2.311d	51.95bc	3.151d	0.260d	2.131d
T5	56.95a	2.490c	0.261c	1.991e	52.71b	2.721e	0.241e	1.921e
T6	50.21c	2.401d	0.350b	2.341c	50.21cd	3.201c	0.281c	2.408c
LSD	3.17	0.008	0.006	0.010	2.24	0.006	0.005	0.008

Means followed by the same letter within a column are not significantly different at $P \leq 0.05$ according to LSD test, $n=3$

3.8. Leaf Mineral Composition and Nutrient Dynamics

The mineral concentrations in *Arctotis* leaves mirrored the growth and physiological patterns previously discussed (Tables 6 and 7). Plants in the untreated calcareous soil (T1) exhibited the lowest levels of macronutrients (N, P, K) and micronutrients (Cu, Mn, Zn). Marschner (2012) explains that this deficiency is a direct consequence of the chemical barriers imposed by high alkalinity and extreme CaCO_3 levels, which reduce nutrients available in the soil and prevent their solubility in the soil solution (Abd El-Kader *et al.*, 2010)

In contrast, the application of 25% and 50% peat moss resulted in the highest nutrient accumulation in the leaf tissues. These improvements occurred because peat moss fundamentally altered the chemical properties of the substrate. As noted by Raviv and Lieth (2008), organic amendments improve the Cation Exchange Capacity (CEC) and provide buffering against high pH. This dual mechanism, as highlighted by Zibilske (2021), prevents nutrient leaching while simultaneously "unlocking" fixed minerals for easier root uptake. Consequently, our findings support the conclusions of Kadir and Salih (2023), confirming that peat moss effectively remediates the nutritional imbalances of native calcareous soils, ensuring a steady supply of minerals for healthy plant development.

Table 7. Effect of growing media on leaf micronutrient concentrations (Cu, Mn, Zn) of *Arctotis* under indoor and outdoor conditions.

Treatment	Indoor	Outdoor
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	Cu (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)
T1	5.86b	41.21d	24.90c	5.43b	33.11d	41.50d
T2	7.22ab	66.61c	52.61a	8.06a	82.20a	72.61ab
T3	9.92a	120.69a	51.21a	8.81a	89.00a	82.61a
T4	7.06ab	63.21c	48.81ab	6.08b	45.31c	67.61bc
T5	6.16b	43.00d	44.91b	7.01ab	51.69c	63.80c
T6	7.62ab	89.21b	49.91ab	7.12ab	62.51b	76.91ab
LSD (0.05)	3.19	9.37	5.88	2.27	8.29	11.07

Means followed by the same letter within a column are not significantly different at $P \leq 0.05$ according to LSD test, $n=3$

3.9. Multivariate Statistical Analysis: Principal Component Analysis (PCA)

To elucidate the complex interactions between substrate compositions and environmental conditions, a Principal Component Analysis (PCA) was performed based on the original data. The biplot analysis revealed that the first two principal components (PC1 and PC2) accounted for 87.4% of the total variance (Figure 2), providing a robust statistical framework for interpreting the data.

The PCA biplot revealed that the first two principle components

The "Growth and Nutritional Capacity" Factor (PC1): Explaining 73.2% of the variance, PC1 exhibited strong positive loadings for leaf parameters (LA, LDW), root development (RV, RDW), and available soil nutrients (SP, SK, SFe). As noted by Kadir and Salih (2023), the high correlation between these traits underscores the fundamental role of nutrient availability in driving vegetative and below-ground biomass in *Arctotis*. The "Reproductive Efficiency" Factor (PC2): Accounting for 14.2% of the variance, PC2 was primarily influenced by soil potassium (SK) and flowering metrics. This reflects the specific physiological demand for potassium during the blooming phase, a relationship previously highlighted by Marschner (2012).

Grouping and Correlations:

Peat Moss Superiority: Indoor treatments enriched with peat moss (T2I, T3I, and T6I) clustered in the upper right quadrant, indicating a strong positive correlation with optimal growth and nutritional status. T3I (50% peat moss) emerged as the superior treatment. According to Zibilske (2021), such clustering confirms the efficacy of organic matter in creating a stabilized rhizosphere that promotes holistic plant health. Environmental and Chemical Inhibitors: Conversely, all outdoor treatments and the untreated controls (T1I, T1O) were restricted to the lower left quadrant. This segregation highlights the inhibitory effects of raw calcareous soil and adverse outdoor abiotic factors. Notably, soil calcium carbonate CaCO_3 showed a strong negative correlation with growth parameters, statistically validating the conclusion of Hassan and Al-Zobaie (2024) that high CaCO_3 is the primary chemical constraint in these substrates.

The analysis identifies leaf area (LA) and leaf number (LN) as the most sensitive indicators of plant success. The synergy between controlled indoor environments and organic amendments (peat moss) is the critical factor for maximizing the vigor and ornamental quality of *Arctotis* in alkaline regions.

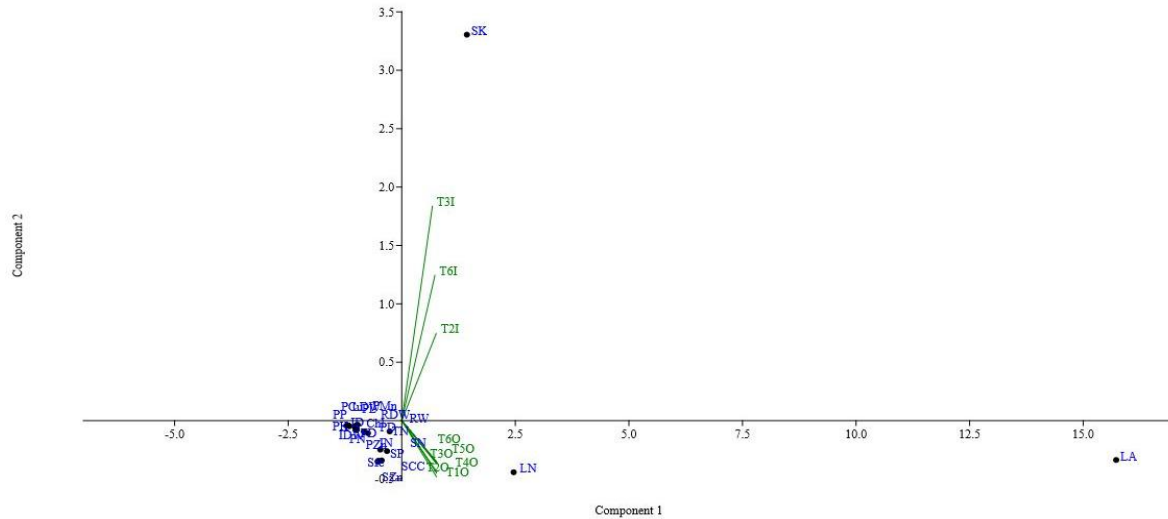


Figure 2. A PCA biplot showing the distribution of growing medium treatments under both indoor (I) and outdoor (O) conditions according to the vegetative growth, flowering, root development and nutritional properties. Codes of treatment: Codes of treatment: T1 = 100% Calcareous soil (Control); T2 = 75% Calcareous soil + 25% Peat moss; T3 = 50% Calcareous soil + 50% Peat moss; T4 = 75% Calcareous soil + 25% Perlite; T5 = 50% Calcareous soil + 50% Perlite; T6 = 50% Calcareous soil + 25% Peat moss + 25% Perlite. Variables abbreviations: PD = plant diameter; TN = tiller number; LN = leaf number; LA = leaf area; LDW = leaf dry weight; ID = inflorescences diameter; PL = pedicel length; IN = number of inflorescences; IDW = inflorescence dry weight; FD = flowering duration; RV = root volume; RDW = root dry weight. Elements within the soil are represented by N (soil nitrogen), P (soil phosphorus), K (soil potassium), Zn (soil zinc), Fe (soil iron), and (CaCO) (soil calcium carbonate).

3.10. Pearson Correlation Analysis

The Pearson correlation matrix (Figure 3) revealed strong and significant relationships among the majority of the measured growth and physiological parameters, providing further evidence of the plant's integrated response to substrate amendments.

Key Relationships:

Vegetative Synergy: A high positive correlation was observed within the vegetative growth traits. For instance, plant diameter (PD) exhibited strong links with tiller number ($r = 0.78$), leaf count ($r = 0.72$), and leaf area ($r = 0.81$). As suggested by Kadir and Salih (2023), these correlations indicate that *Arctotis* maintains a balanced developmental strategy when the chemical constraints of the growing medium are mitigated.

The Root-Shoot Connection: Most significantly, root development parameters (RV and RDW) showed a powerful positive correlation with above-ground biomass and flowering metrics ($r = 0.75$ to 0.89). This confirms that the root system acts as the primary driver of the plant's overall success. According to Raviv and Lieth (2008), a robust root architecture is essential for maximizing nutrient acquisition

and water transport, especially in environments where soil alkalinity typically restricts root expansion (Adeleye et al., 2010)

The correlation data demonstrates that by neutralizing the physical and chemical barriers of calcareous soil through peat moss amendments, a functional "root-to-shoot" synergy was established. Enhanced root systems, facilitated by improved soil porosity and pH, were able to sustain a higher flux of water and nutrients to the leaves and inflorescences. In challenging alkaline soils, this interconnectedness—as emphasized by Zibilske (2021)—is the most critical factor for producing high-quality ornamental plants.

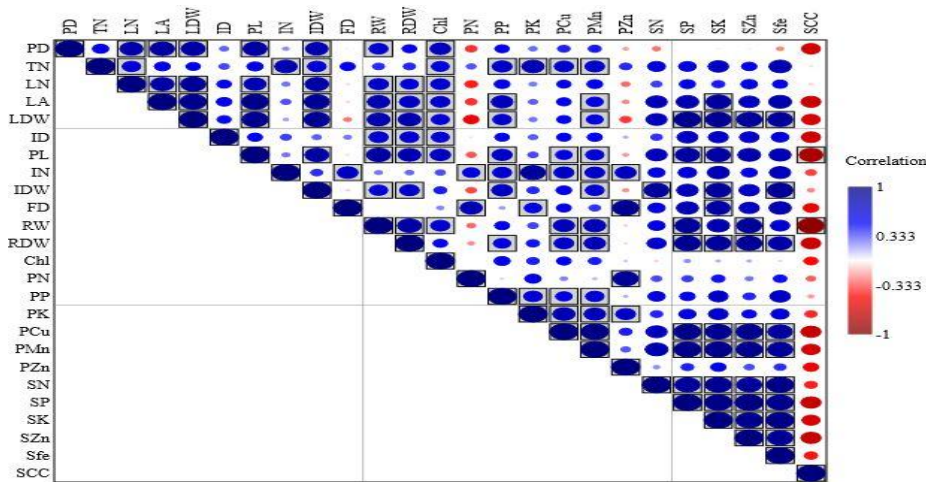


Figure 3. Segment of the Pearson correlation coefficient between all the measured metrics of *Arctotis* grown in different growth media.

Blue circles are used to show positive correlations whereas red circles show negative correlations and the intensity of the circles is used to show the intensity of the relationships. Classification of treatment: T1 = 100% calcareous soil; T2 = 75% calcareous soil + 25 peat moss; T3 = 50% calcareous soil + 50 peat moss; T4 = 75% calcareous soil + 25 perlite; T5 = 50% calcareous soil + 50 perlite; T6: 50% Calcareous soil + 25% Peat moss + 25% Perlite, The variables are abbreviated as follows: PD - plant diameter, TN - tiller number, LN - number of leaves, LA - leaf area, LDW - leaf dry weight, ID - inflorescence diameter, PL - pedicel length, and IN - number of inflorescence. IDW refers to the weight of inflorescence dry. FD is an abbreviation that refers to flowering period; RV refers to root volume; RDW refers to root dry weight. Chl -chlorophyll, plant nitrogen, plant phosphorus, plant potassium. Where Cu, Mn, Zn, N, P, K, Zn, Fe, and CaCo₃ refer to plant copper, plant manganese, plant zinc, soil nitrogen, soil phosphorus, soil potassium, soil zinc, soil iron, and soil calcium carbonate, respectively.

3.11. Biological Interdependence and Nutrient Dynamics

The analysis reveals a high degree of "functional" between the plant's various organs. Flowering success was found to be directly dependent on vegetative vigor; specifically, an increase in tiller number and leaf area led to a significantly higher floral yield ($r = 0.77$ to 0.82). This confirms that a robust vegetative framework serves as the "metabolic fuel" required for reproductive display.

Furthermore, a direct functional link exists between soil nutrient status and plant tissue composition. However, as Hassan and Al-Zobaie (2024) observed, high CaCO_3 levels act as a physiological barrier, obstructing nutrient mobility and root functionality. This is evident in the chlorophyll data, where higher nitrogen levels promoted synthesis, but excessive CaCO_3 induced chlorosis. According to Zibilske (2021), this explains why plants in untreated calcareous soils remain stunted and chlorotic due to the chemical "locking" of essential elements.

3.12. Environmental Comparison: Indoor vs. Outdoor Cultivation

This study demonstrates that protected (indoor) cultivation is superior to outdoor growing for *Arctotis* in the Kurdistan Region. Indoor plants were 15%–35% larger and healthier than their outdoor counterparts. This disparity is attributed to the stable microclimate of the indoor environment, which shields plants from extreme thermal fluctuations, desiccating winds, and high light intensity. For commercial growers in arid and semi-arid regions, Kadir and Salih (2023) emphasize that indoor cultivation is essential to mitigate abiotic stress and ensure high-quality ornamental production (Ball 2004).

4. Conclusion

This research demonstrates that amending calcareous soils with peat moss—specifically at a 25% to 50% ratio—is an effective solution for overcoming the inherent challenges of high-lime substrates. Peat moss significantly enhances vegetative growth, floral quality, root parameters, and mineral nutrition. Multivariate analysis (PCA) confirmed that the interaction between controlled indoor environments and organic amendments achieved optimal plant performance. While peat moss successfully improved nutrient availability, perlite alone proved insufficient in addressing the chemical constraints of the high-pH medium. Overall, the application of 25% to 50% peat moss under indoor conditions represents an efficient method for achieving high-quality plant growth in alkaline regions.

5-Recommendations

Based on the experimental evidence, the following recommended for *Arctotis* production in alkaline substrates:

- Controlled indoor cultivation is recommended over outdoor growing in the Kurdistan Region to avoid extreme thermal fluctuations and desiccating winds.
- Incorporating a 25% to 50% peat moss ratio is recommended to alleviate the inherent challenges of high-lime substrates.
- As suggested by Khalil *et al.* (2023), future research should explore sustainable local organic alternatives to peat moss to further support ornamental growers in the region.

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