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REVIEW ARTICLE

A comprehensive review of physiological and phytochemical adaptations in German chamomile (*Matricaria chamomilla* L.) in response to abiotic stress and factors

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Abstract

In the face of contemporary climate change, crops are grappling with stress, leading to reduced production. Understanding the plant's response to environmental stressors is crucial for enhancing its adaptability and optimizing the production of bioactive compounds with therapeutic and industrial significance. *Matricaria chamomilla* L., commonly known as chamomile, has a rich history of use in traditional medicine owing to its numerous medical benefits. The phytochemistry and physiology of chamomile can be strongly influenced by abiotic factors such as temperature, water availability, salinity, light exposure and nutritional imbalances. These stressors may lead to reduced growth, altered secondary metabolite composition and compromised medicinal properties. The review provides a thorough description of how chamomile responds to abiotic stresses, including heat, salt, salinity and drought. Gaining insights into the effects of abiotic stressors on chamomile is essential for refining cultivation techniques and enhancing the overall quality of herbal products derived from chamomile. Drawing on a compilation of previous research, this review addresses diverse facets that capture the attention of both farmers and researchers. Furthermore, insights gained from this exploration are pivotal for enhancing the quality of chamomile-based herbal products in the face of changing environmental conditions.

Keywords

drought; salinity; chamomile; phytochemistry; abiotic stress

Introduction

In the current era of climate change, agricultural ecosystems face unprecedented challenges, including the detrimental effects of abiotic stresses on crop plants. Abiotic stresses, such as temperature fluctuations, salinity, heat, cold and drought, have profound impacts on the metabolic processes and growth of plants, leading to reduced agricultural productivity. Among the diverse array of crops, *M. chamomilla* L., commonly known as chamomile, stands out for its historical significance and extensive use in traditional medicine. Chamomile has gained recognition for its therapeutic properties, contributing to its widespread use in various herbal remedies and pharmaceutical applications. India exports chamomile flowers to the United States, Australia and the United Kingdom as per Volza's India Export Statistics. It ranks as the world's third-largest exporter of chamomile flowers.

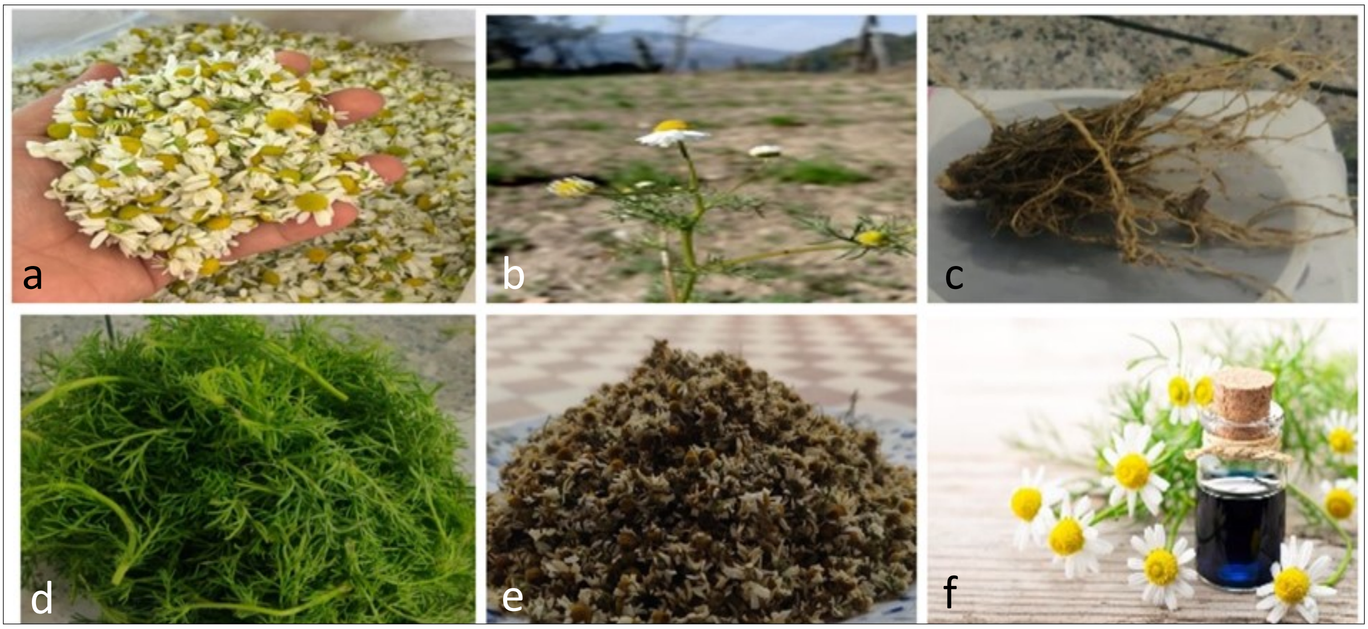


Fig.1 (**a**) Flower, (**b**) Flower head, (**c**) Roots, (**d**) Leaves, (**e**) Dry flower, and (**f**) Essential oil of *M. chamomila* (46).

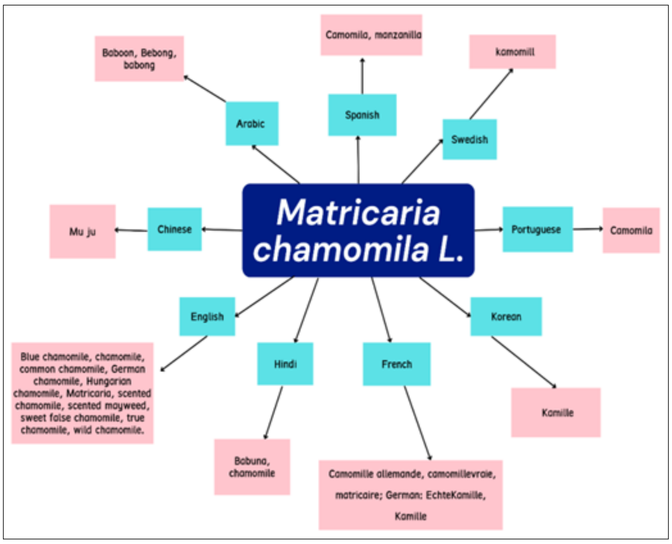


Fig. 2 . Vernacular names of Chamomile (45).

Fig. 3. Accepted species of genus *M.* and their distribution (46).

Currently, chamomile flowers are being exported from India to several nations by M/S Ranbaxy Laboratories Limited, M/S German Remedies, Budwhite Teas Private Limited and A.G. Organica, among other businesses (1). The intricate relationship between abiotic stressors and the resulting physiological and phytochemical changes in chamomile presents a compelling avenue for exploration. According to various authors, environmental conditions have a significant impact on the output of aromatic and medicinal plants as well as the quantity and quality of essential oils. The specific set of environmental conditions to which the plant is exposed during its growing phase is determined by the time of planting, which is a particularly climacteric factor. The chamomile plant's ontogeny affects environmental control and several additional elements, including light intensity, day length, temperature, irrigation, plant growth regulators, tissue culture, diseases and harvest management are known to affect the yield and makeup of chamomile essential oils (2).

This comprehensive review aims to investigate the multifaceted responses of *M. chamomilla* L. to abiotic stresses, providing a nuanced understanding of how these stressors influence the plant's physiology and phytochemistry. Recognizing the impact of abiotic stresses on chamomile is not only crucial for the optimization of cultivation practices but also holds the key to improving the quality of chamomile-based herbal products. By synthesizing existing knowledge and insights from previous research, this review endeavours to shed light on the complexities of abiotic stress-induced alterations in chamomile, offering a valuable resource for researchers, practitioners and stakeholders involved in the cultivation and utilization of this botanical gem.

Impact of abiotic factors on Physiology and Phytochemistry of chamomile

Effect of Day Length and Irradiance

A study indicates that the flowering and essential oil content of chamomile plants are influenced by exposure to different day durations (3). Longer day lengths lead to increase dry weight of flower heads compared to vegetative growth, with continuous light resulting in the highest flower head yield. The study found that maximum oil content occurs early in the growth cycle, particularly at 18 h of daylight, followed by 14 and 24 h. Overall, oil content tends to rise with daily irradiation time. The peak production of essential oil per plant is observed at 18 h of daylight, followed by 14 and 24 h. Prolonged daily light exposure, however, leads to a decline in vegetative growth, flower head production and essential oil quality. According to a study, secondary metabolite production in chamomile is also influenced by irradiance, impacting the synthesis of primary metabolites (4). A study specifically focuses on how chamomile's essential oil production varies with irradiance (3). The study recorded an essential oil accumulation of 0.88 % (with 8.4 % chamazulene) at an irradiation of 9.5 x 104 erg $m^2 sec^{-1}$. Lowering the irradiance by two-thirds resulted in a reduced essential oil accumulation of 0.40 %, with approximately half the chamazulene content. Furthermore, periodogram studies have been employed to identify diurnal regularities in the concentration of α- -bisabolol and other sesquiterpenes in chamomile flowers. However, these studies did not reveal a diurnal pattern in the overall oil content (5). Concentrations of enin-dicycloether, bisabolol and chamazulene were found to increase in the mornings and evenings (6). Research may focus on understanding how chamomile responds to changes in natural day length and light conditions associated with climate change. Strategies for adapting chamomile cultivation to evolving environmental conditions could be explored to maintain or enhance phytochemical content.

Effect of Air Temperature and Thermoperiodicity

Exposing chamomile plants to high temperatures (25 °C) throughout a 24 h cycle resulted in the maximum number of flower heads per individual plant, albeit with smaller-sized flower heads. The relationship between the percentage of essential oil and temperature conditions indicates a positive correlation with oil secretion. Specifically, higher temperatures during the 24 h cycle and lower night temperatures such as a constant air temperature of 25 °C with a night temperature of 15 °C, were found to most favor oil formation in chamomile flower heads. Among the different night temperature treatments, the 15 °C treatment yielded the highest proportion of chamazulene, followed by 20 °C and 25 °C night temperatures, in that sequence. While night time temperature variations did not show a noticeable impact on the rate of vegetative development, specialization in the early stages of growth, or the rate of decline, the influence of air temperature on the growth of the vegetative parts of chamomile plants follows a hyperbolic and diminishing trend (2). With the increasing use of controlled environments, such as greenhouses and indoor farms, future research may explore the precise control of air temperature and thermoperiodicity to optimize chamomile cultivation.

Effect of Temperature and Irrigation

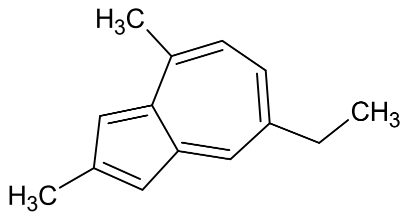
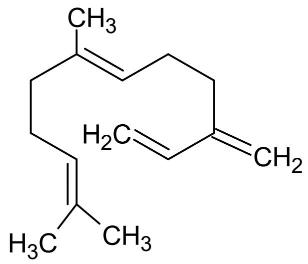
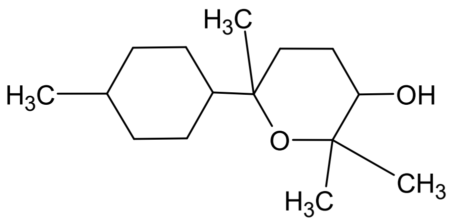
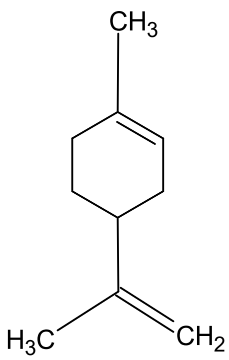
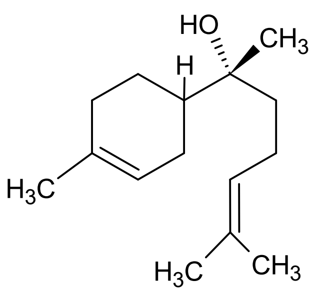
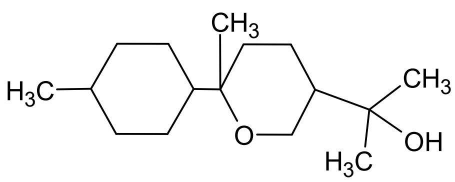
Assessing the impact of temperature on chamomile presents challenges due to the natural variability in temperature across different locations, elevations, seasons and even within a single day. Consequently, many studies have been conducted in controlled environments. Despite facing diverse and harsh natural conditions, chamomile essential oil quantities remained consistent both quantitatively and qualitatively (7). In a phytotron, chamomile plants exhibited significant essential oil production under conditions of either a constant temperature of 25 °C or a nightly temperature of 15 °C, with the highest amount of chamazulene observed at 15 °C (2). Chamomile's vegetative stage can be sustained in cold climates with short days. In a controlled growth environment with a 12 h day duration and a temperature of 12 °C, chamomile plants can be kept alive for vegetative propagation for up to a year. Following this stage, they transition to developing blossom buds (8). A study highlight that due to chamomile's short and shallow roots, it requires frequent watering to maintain optimal moisture levels, as it cannot extract moisture from the lower layers of damp soil (1). During the blooming phase, irrigation proves beneficial for increasing flower yield, prompting a second flush of blooms and delaying seed germination. It was notes that watering during the rosette stage significantly enhances output, with the crop requiring more frequent irrigation on alkaline soils (9). The crop needs to be irrigated more regularly on alkaline soils; during the crop cycle, 6-8 irrigations are needed (10). Researchers may investigate the resilience of chamomile varieties to temperature extremes and develop strategies to mitigate the potential negative effects on plant growth and phytochemical production.

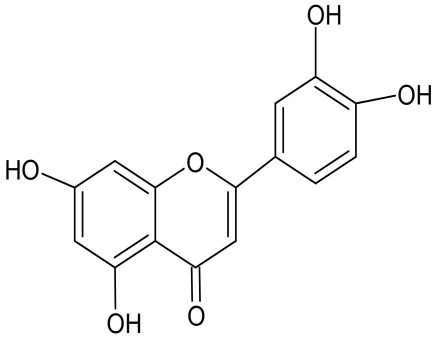
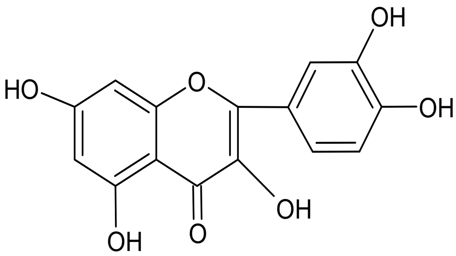
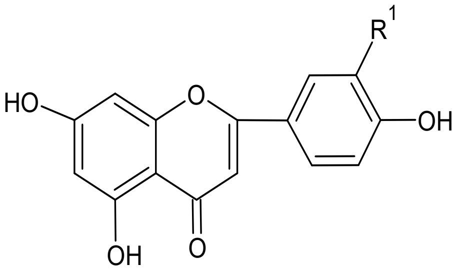
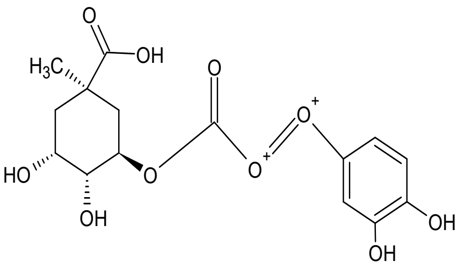
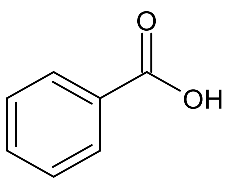
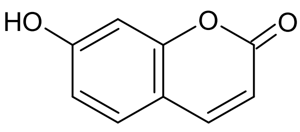
Effect of Abiotic Stresses on Physiology and Phytochemistry of chamomile

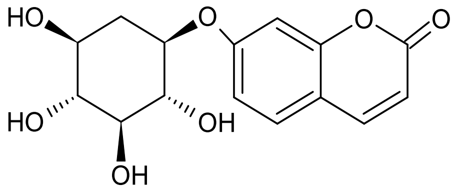
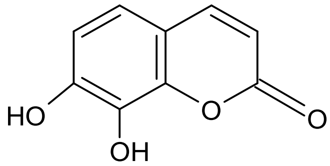
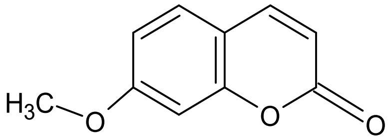
Drought Stress

As a drought-sensitive plant, chamomile exhibits a range of adaptive mechanisms to cope with reduced water availability. One or more of the factors affecting water interactions is the temperature of the leaf and canopy, as well as transpiration rate and conductance of stomatal cells. Although stomatal conductance is most negatively impacted, exposure to drought stress disturbs all these characteristics in plants (11). Drought stress influences various physiological and biochemical processes in plants, leading to reduced growth and crop yield. In response to drought, plants undergo several morpho-anatomical, physiological and biochemical changes that are consistent with that environment. The highest yields of proline, total soluble sugars (TSS) and essential oils were seen under extreme stress; however, the severe drought greatly reduced the yields of dried flowers and leaves that contained protein. During a severe drought, exogenously given spraying treatments dramatically enhanced the amount of proline in the leaves (12). Drought stress reduced plant height, flower production, shoot weight and apigenin concentration but had little to no impact on oil composition or content (13). The findings of the assessment of the impacts of drought stress on growth indices revealed that the plant was able to maintain its capacity for biomass output. The results of the growth study and the phytochemical properties of this plant revealed that chamomile may be recommended as a drought-resistant medicinal plant with acceptable performance, despite a loss in agronomical attributes. According to a study the use of vermicompost increased nutrient %, especially when plants were subjected to moderate to severe drought stress conditions (14). Drought stress decreased the nutrient percentages in the shoots. The outcomes of this investigation also show a substantial relationship between irrigation treatments and vermicompost rates on leaf chlorophyll content. Comparing the combined treatments revealed that chamomile plants that received 5 and 10 t/ha of vermicompost had considerably higher leaf chlorophyll contents than the control treat

Table 1. Chemical class, chemical constituents, its structure, relative mass, biological activity, percentage in essential oil of *M. chamomila*

Chemical Class/ Compound Groups	Chemical constituents	Structure	Relative Mass	Biological Activity	Percentage	References
Terpenoid	Chamazulene		184.28	Antiseptic	26.11%	(27)(28)
	Farnesene		204.35	Antifungal	11.64%	(27) (28)
	Bisabolol Oxide A		238.37	Antiphlogistic, Anticancer	33-50.5%	(28) (29)
	limonene		136.23	Anticancer, Antimicrobial, antifungal, AntimalarialandAntitumoral activities	15.25%	(30) (28)
	α -Bisbolol		222.37	Anti -inflammatory, Anti Cancerous	27.36-38.6%	(27) (28)
	α -Bisabolol B		238.37	Anti-microbial	27.5 %	(27) (28)

	Luteolin		286.24	Anti-Bacterial, Anti -thrombic	0.28%	(28) (31)
Flavonoid	Quercetin		302.23	Anti-oxidant, Anti-inflammatory	0.17%	(32) (33) (28)
	Apigenin		269.05	Anti-cancer, anti -inflammatory	0.11%	(34) (35) (36) (28)
Phenolic Acid	Chlorogenic Acid		353.09	Antioxidant activity, antibacterial, hepatoprotective, cardioprotective, anti-inflammatory, antipyretic,	0.110%	(27) (37) (28)
	Benzoic Acid		122.12	Antimicrobial activity	0.041%	(27) (38) (28)
	Umbeliferone		162.14	Antifungal, Anti-inflammatory, Anti-hyperglycaemic, molluscicidal and Anti-tumor activities.	0.006%	(39) (40) (28)

	Daphnin		340.28	Anti-bacterial	0.014%	(27) (28)
Coumarins	Daphnetin		178.14	Analgesic, anti-pyretic	0.002%	(41) (40) (28)
	Herniarin		176.17	Haemostatic, anthelmintic, antifungal, anti-bacterial anticonvulsant and spasmolytic	0.08%	(42) (43) (44) (28)

ment under regular irrigation and moderate drought stress conditions. According to a study, proline treatment had a substantial impact on all attributes under water stress (15). The foliar spray of 100 mg/L proline improved growth and reduced damage caused by water stress. In general, it would be advised to use 100 mg/L proline to achieve the highest yield of German chamomile under varied water shortage conditions. Understanding these physiological responses to drought stress is crucial for devising strategies to enhance chamomile's drought tolerance, contributing to sustainable cultivation practices and ensuring a stable supply of this valuable plant. Further research is needed to uncover the underlying molecular mechanisms and identify specific genes involved in chamomile's response to drought stress.

Salinity Stress

Salinity stress presents a significant challenge to the physiological health of *M. chamomilla* L. The adaptable chamomile plant faces disruptions in vital physiological processes when exposed to elevated soil salinity, particularly in arid and semi-arid regions where 25 % of irrigated agriculture is adversely affected. The plant's capacity to withstand salt stress plays a crucial role in determining the distribution and yield of crops. The presence of excessive soluble salts in the soil leads to ionic imbalances, specific ion toxicity and osmotic stress. Higher salt concentrations activate genes responsible for stress mitigation, enhancing the plant's adaptability to challenging conditions. Solute concentration buildup facilitates excessive mineral absorption, cell wall modification and the incorporation of transporters, aiding in the transport of salts back to the mesophyll. This intricate process contributes to maintaining potassium homeostasis and induces positive stress responses (16). It was observed that heightened salinity led to a reduction in the number of branches, flowers, peduncle length and head diameter in chamomile plants (17). Additionally, increased salinity significantly decreased the fresh and dry flower weight and essential oil content. This reduction in essential oil quantity was contrary to the findings of studies suggesting a significant impact of increasing sodium ions on oil content and composition (18, 19). The research involved applying irrigation water with varying salt levels at the shooting stage, revealing that elevated salt levels led to diminished branches, flowers, longer flower stalks and larger flower heads. There was a notable decline in the fresh weight, dry weight and essential oil content of flowers with increasing salt levels. The study identified a critical threshold for sodium chloride content in agricultural soils, determining that most soils can support chamomile growth if the level remains below 84 mmol. Salinity-induced reductions in leaf net photosynthesis resulted in decreased total carbon fixation in plant leaves, limiting carbon availability for growth and flower primordial initiation under salinity stress, ultimately causing a reduction in essential oil production. Qualitative and quantitative analyses of essential oils under saline conditions indicated a potential compromise in the significance of oil as a vital component of chamomile. Previous studies suggesting a significant impact of increasing sodium ions on oil content and composition were acknowledged (18, 19). Apigenin changes, as a flavonoid, were seen as a phytochemical response to the biotic and abiotic environment (20). These physiological responses to salinity stress are crucial for developing strategies to enhance chamomile's salt tolerance, facilitating its cultivation in regions affected by soil salinization. Further research is needed to unravel the molecular mechanisms underlying chamomile's response to salinity stress and identify potential targets for breeding salt-tolerant chamomile varieties.

Soil Drought

Chamomile, known for its sensitivity to water availability, employs various adaptive mechanisms to confront soil drought. Despite being recognized for its drought tolerance, German chamomile faces the challenge of soil drought, particularly in Europe, due to climate change. Previous investigations on diploid and tetraploid German chamomile genotypes highlighted distinct responses to dehydration. A specific study delved into the reactions of chamomile plants, encompassing the wild type and strain C6/2, subjected to soil drought and subsequent 7-day rehydration. Parameters such as shoot and leaf growth, vegetative growth, water and protein contents, ascorbate peroxidase activity and gas exchange were scrutinized. In the wild-type plants, water content exhibited marginal changes during the stress phase, normalizing after rehydration. Gas exchange reduction was temporary and despite a decrease in leaf surface area, new leaves emerged. In contrast, C6/2 plants displayed drier leaves, with a prolonged decrease in water content leading to a 20-40 % reduction in gas exchange during the recovery stage. Both experiment phases witnessed a significant reduction in long branch growth and leaf formation in the C6/2 genotype. The sequence of changes in wild-type plants suggested improved metabolism due to proper water content and gas exchange during recovery, although drought induced an increase in ascorbate peroxidase activity in the leaves of both genotypes. Protein content exhibited fluctuations, with a modest increase in wild-type leaves and a 1/4 reduction in C6/2 leaves. Wild-type plants demonstrated more resilient responses to desiccation and rewatering compared to C6/2 plants. (21). Understanding these physiological responses is essential for devising strategies to enhance chamomile's drought tolerance, such as optimizing irrigation practices, selecting drought-tolerant cultivars and exploring molecular breeding approaches.

Heat Stress

Chamomile, known for its sensitivity to temperature fluctuations, employs diverse adaptive mechanisms to cope with elevated temperatures. In a study conducted in northern Egypt and east of Cairo, it was observed that spraying gibberellins or melatonin during mid-October and November improved growth parameters and maintained oil quality in chamomile plants (22). Under optimal conditions, the Bodegold cultivar demonstrated superior growth, with the tallest plants at 64.41 cm, a larger average capital diameter of 8.94 mm and the highest 1000 grain weight of 0.056 g. However, under heat stress, the Bodegold cultivar experienced a reduction in height, capital diameter and 1000 grain weight by 2.08 mm, 0.035 g and an undetermined amount respectively. The Bona cultivar, despite having the lowest 1000 grain weight under heat stress, exhibited resilience by producing the highest fresh flower weight at 260.42 g/m^2. Salicylic acid concentration influenced fresh flower weight, reaching the highest at 287.97 g/m^2 at a concentration of 1 mg L^{-1} under normal conditions and the lowest at 83.09 g/m^2 at 25 mg L^{-1} under heat stress. In terms of dried flower production, the Bona cultivar consistently excelled with 65.63 g/m^2 and 51.08 g/m^2 under normal and heat stress conditions respectively. Total chlorophyll concentration decreased significantly under heat stress, dropping to 5.59 g/g_dw from 34.90 g/g_dw under normal conditions. The Bona cultivar exhibited the highest leaf-free proline content at 71.56 mol/g dw under heat stress, while essential oil content varied, with the Bona cultivar displaying the highest and lowest values at 1.23 % (w/w) and 0.74 % (w/w) under normal and heat stress conditions respectively (23). These findings suggest that salicylic acid and other plant growth regulators can enhance chamomile, a moderately heat-resistant medicinal plant and increase both the quality and quantity of essential oil content under typical abiotic stress conditions.

Discussion

The review explores the multifaceted responses of *M. chamomilla* L. commonly known as chamomile, to abiotic stresses, emphasizing the significance of understanding these responses for optimizing cultivation practices and improving the quality of herbal products derived from chamomile. The plant's physiology and phytochemistry are influenced by various stressors, including temperature, water availability, salinity, light exposure and nutritional imbalances. The impact of abiotic stress on chamomile is detailed through specific examples, such as the effects of day length, irradiance, air temperature, thermoperiodicity, temperature and irrigation on its growth and essential oil production. The review delves into the responses to drought stress, salinity stress and heat stress, providing insights into adaptive mechanisms and potential strategies for enhancing chamomile's resilience. The comprehensive examination of the intricate relationship between environmental stressors and chamomile's physiological and phytochemical changes serves as a valuable resource for researchers, practitioners and stakeholders involved in chamomile cultivation and utilization. The discussion highlights the need for further research on stress-responsive genes, molecular pathways and stress mitigation techniques to support sustainable cultivation in challenging environments. The essential oil percentage increased initially as the temperature dropped from 25 °C to 10 °C, but then decreased with further cold stress. Additionally, it suggests that cold stress during the flowering stage had a more pronounced effect on the shoot organs of German chamomile compared to the root organs. The mention of high genetic diversity among the 5 German chamomile genotypes studied implies that there is potential for improving cold tolerance through selective breeding or other genetic interventions (24). According to this information, drought stress had significant effects on physiological traits, essential oil yield and essential oil components. Specifically, under severe drought stress conditions, there was an increase in the essential oil components. However, despite this increase in components, the essential oil yield decreased. This suggests that while the concentration or composition of essential oil components may be influenced by drought stress, the overall yield of essential oil is negatively affected (25). A study revealing that subjecting chamomile to medium drought stress, with irrigation set at 70 % of field capacity (FC), led to a dual effect of improved growth and heightened oil productivity. The research highlighted an intriguing correlation between moderate drought conditions and enhanced oil production in chamomile plants. Furthermore, the investigation observed an increase in the levels of proline, soluble carbohydrates and malondialdehyde (MDA) – indicative of stress responses – under drought conditions (26). Notably, the maximum accumulation of these stress-related compounds occurred when the chamomile plants experienced severe drought stress. These findings suggest a nuanced relationship between drought stress levels, physiological responses and essential oil productivity in chamomile, with moderate stress potentially triggering beneficial outcomes while severe stress prompts more pronounced biochemical reactions.

Conclusion

Understanding the abiotic stress-induced changes in the physiology and phytochemistry of *M. chamomilla* L. is essential for developing strategies to enhance its resilience and productivity. Future research should focus on identifying stress-responsive genes and molecular pathways to facilitate the breeding of stress-tolerant chamomile varieties. Additionally, the exploration of stress mitigation techniques, such as agronomic practices and exogenous applications of stress-alleviating substances can contribute to sustainable chamomile cultivation in challenging environments.

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Authors' contributions

Subhdara and KDJ collected the literature, prepared the original draft and wrote the manuscript. DP drew the map and structures. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

Ethical issues: None.

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