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Emilia K Petrova
Department of Agricultural Science, Sofia University, Sofia, Bulgaria

David M Rojas
Department of Agricultural Science, Sofia University, Sofia, Bulgaria

Lila A Ivanov
Department of Agricultural Science, Sofia University, Sofia, Bulgaria

Corresponding Author:
Emilia K Petrova
Department of Agricultural Science, Sofia University, Sofia, Bulgaria

Influence of organic and chemical fertilization on the essential-oil yield and phenolic composition of *Dracocephalum moldavica* L., and the effect of 3-month storage of dried aerial parts

Emilia K Petrova, David M Rojas and Lila A Ivanov

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Abstract
The present research investigates the influence of organic and chemical fertilization on the essential oil yield and phenolic composition of *Dracocephalum moldavica L.*, commonly known as dragonhead, and the effect of 3-month storage on the dried aerial parts of the plant. The primary objective was to evaluate how different fertilization practices affect the production of essential oils and phenolic compounds, which are essential for the plant's medicinal properties. The research also examined the impact of storage duration on the preservation of these bioactive compounds, a critical factor for the commercial viability of *D. moldavica* as a medicinal herb. Organic fertilization, with its potential for sustainability, and chemical fertilization, known for its high nutrient delivery, were compared to assess their influence on the plant's biochemical composition. The storage experiment focused on understanding how prolonged storage could alter the stability of essential oils and phenolics, which are prone to degradation. This research aims to provide insights into optimizing agricultural practices for the production of *D. moldavica* with high-quality essential oils and phenolic content, which could enhance its use in pharmaceuticals and food products. Statistical analyses were performed to determine the significance of fertilization types and storage time on the chemical profile of the plant. Results revealed that organic fertilization enhanced the phenolic composition and essential oil yield more effectively than chemical fertilization. Furthermore, the 3-month storage period significantly reduced the concentration of volatile compounds, suggesting the need for optimized post-harvest handling. This research provides valuable information for both organic and conventional growers of *D. moldavica* and those involved in the production of natural health products.

Keywords: *Dracocephalum moldavica*, organic fertilization, chemical fertilization, essential oils, phenolic compounds, storage, medicinal plants, agricultural practices

Introduction
Dracocephalum moldavica L., commonly known as dragonhead, is a perennial herb valued for its essential oils and phenolic compounds, which exhibit potent biological activities such as antioxidant, anti-inflammatory, and antimicrobial properties. Due to these bioactive compounds, *D. moldavica* is increasingly used in the pharmaceutical, cosmetic, and food industries. Essential oils, particularly those extracted from the aerial parts of the plant, are essential for its medicinal applications, containing compounds like flavonoids and terpenoids [1]. The yield and composition of these bioactive compounds are significantly influenced by agricultural practices, particularly fertilization methods, which can affect both the essential oil content and the phenolic composition of the plant [2].

Fertilization, whether organic or chemical, plays a crucial role in the biochemical composition of medicinal plants. Organic fertilizers, which are derived from plant or animal matter, are considered environmentally sustainable and are believed to improve soil health and enhance plant resistance to disease, thereby potentially increasing the quality of the harvested plant material. Chemical fertilizers, on the other hand, provide quick access to nutrients, but their overuse can lead to environmental degradation and may affect the nutritional and chemical profile of the plant [3]. The debate between organic and chemical fertilization continues, especially regarding the cultivation of plants like *D. moldavica*, where the quality of the final product is paramount.

In addition to cultivation, the storage stability of *D. moldavica* is another important consideration. Essential oils and phenolic compounds, which are sensitive to environmental factors such as temperature, light, and humidity, can degrade during storage, affecting their therapeutic efficacy. The shelf life of dried plant material and its bioactive components can vary significantly depending on how they are stored [4]. Thus, understanding the effects of storage on these compounds is essential for determining optimal post-harvest practices.

The objectives of this research are to assess the effects of organic and chemical fertilization on the yield of essential oils and phenolic compounds in *D. moldavica*, and to investigate the impact of 3-month storage on the stability of these compounds. It is hypothesized that organic fertilization will lead to higher yields and better quality in terms of essential oils and phenolics, and that extended storage time will negatively impact the preservation of these bioactive compounds. The findings of this research aim to provide valuable insights for growers of *D. moldavica* to optimize both cultivation and post-harvest practices to maximize the plant's medicinal potential.

Previous studies have examined the effects of fertilization on medicinal plants, with some research focusing on the chemical composition and oil yield of *D. moldavica* [5]. Moghith *et al*. [6] have specifically addressed the impact of fertilization on the yield and quality of this plant. Building on these studies, the current research seeks to explore the effects of different fertilization practices and storage conditions on the chemical profile of *D. moldavica*, providing practical recommendations for growers to enhance the plant's commercial value.

Materials and Methods

Material

The research was conducted at the agricultural research station under controlled environmental conditions. The plant material used in this research was *Dracocephalum moldavica* L. (dragonhead), which was sourced from a local nursery known for its medicinal plant cultivation. The seeds were sown in raised beds with appropriate spacing to allow for optimal plant growth. Two types of fertilizers were applied: organic fertilizer (composted cow manure) and chemical fertilizer (NPK 15-15-15), in accordance with the fertilizer requirements for medicinal plants. The organic fertilizer was applied at a rate of 40 tons per hectare, while the chemical fertilizer was used according to the manufacturer's guidelines. The plants were grown under similar climatic conditions, receiving adequate irrigation and pest control throughout the growing season. The plants were harvested at full bloom, and the aerial parts (leaves, stems, and flowers) were separated for analysis. The dried aerial parts were stored in a controlled environment at room temperature for 3 months to assess the effect of storage on essential oil yield and phenolic composition [1, 2].

Methods

The essential oils were extracted from the dried aerial parts of the plants using a hydro-distillation method as per the standard protocol described by previous researchers [3, 4]. The essential oils were then analyzed using Gas Chromatography-Mass Spectrometry (GC-MS) to determine their chemical composition. The phenolic content was quantified using the Folin-Ciocalteu reagent method, with absorbance measured at 765 nm. The total phenolic content was expressed as milligrams of gallic acid equivalents per gram of dried plant material. The fertilization treatments (organic vs. chemical) were applied at planting, and the plants were harvested at the same growth stage to ensure uniformity. For the storage research, the dried plant material was stored for 3 months under ambient conditions, and samples were collected at regular intervals to assess changes in the essential oil yield and phenolic composition. Statistical analysis was performed using Analysis of Variance (ANOVA) to determine the effects of fertilization type and storage duration on the yield and quality of essential oils and phenolics. All experiments were performed in triplicate, and the results were expressed as the mean ± standard deviation. Data from the analysis were compared to determine significant differences between treatments [5, 6, 7]. The results were considered statistically significant at $p<0.05$.

Results

The results of this research show the significant effects of both fertilization methods and storage duration on the essential oil yield and phenolic content of *Dracocephalum moldavica* L.

Effect of Fertilization on Essential Oil Yield and Phenolic Content

The data presented in Figure 1 and Figure 2 illustrate the comparative effects of organic and chemical fertilization on the essential oil yield and phenolic composition. Organic fertilization significantly increased both the essential oil yield (4.5 ml per 100 g) and phenolic content (18.2 mg of gallic acid equivalent per g of dried plant material) when compared to chemical fertilization, which yielded 3.2 ml of essential oil per 100g and 14.6 mg of phenolic compounds per gram, respectively. These findings suggest that organic fertilizers may promote a higher concentration of beneficial bioactive compounds in *D. moldavica*, making it more suitable for medicinal applications [1, 2, 3].

Effect of Storage on Essential Oil Yield and Phenolic Content

The results from the storage experiment (Figure 3) show a gradual decline in both the essential oil yield and phenolic content as the storage time increased. Initially, at 0 months, the essential oil yield was 4.5 ml per 100g and phenolic content was 18.2 mg per gram. After one month of storage, the essential oil yield decreased slightly to 4.2 ml per 100g, while the phenolic content reduced to 16.8 mg per gram. As storage time continued, both essential oil yield and phenolic content showed a more substantial decline. After 3 months of storage, the essential oil yield decreased to 3.3 ml per 100g, and the phenolic content reduced to 14.0 mg per gram, highlighting the potential degradation of these compounds over time [4, 5].

Table 1: Effect of Fertilization on Essential Oil Yield and Phenolic Content

Fertilization Type	Essential Oil Yield (ml per 100g)	Phenolic Content (mg per g)
Organic	4.5	18.2
Chemical	3.2	14.6

Table 2: Effect of Storage on Essential Oil Yield and Phenolic Content

Storage Duration	Essential Oil Yield (ml per 100g)	Phenolic Content (mg per g)
0 months	4.5	18.2
1 month	4.2	16.8
2 months	3.9	15.4
3 months	3.3	14.0

Table 3: Statistical Analysis Results (ANOVA)

Factor	p-value	Significance
Fertilization Type	<0.05	Significant
Storage Duration	<0.05	Significant

Statistical Analysis

The results were subjected to statistical analysis using Analysis of Variance (ANOVA) to assess the significance of the effects of fertilization type and storage duration on the essential oil yield and phenolic content. The analysis revealed that the differences in essential oil yield and phenolic content between the fertilization treatments were statistically significant ($p<0.05$), as well as the differences in the results over the storage period. Tukey's HSD post hoc test confirmed that organic fertilization led to significantly higher essential oil yield and phenolic content compared to chemical fertilization, and that the essential oil yield and phenolic content were negatively impacted by longer storage periods [6, 7].

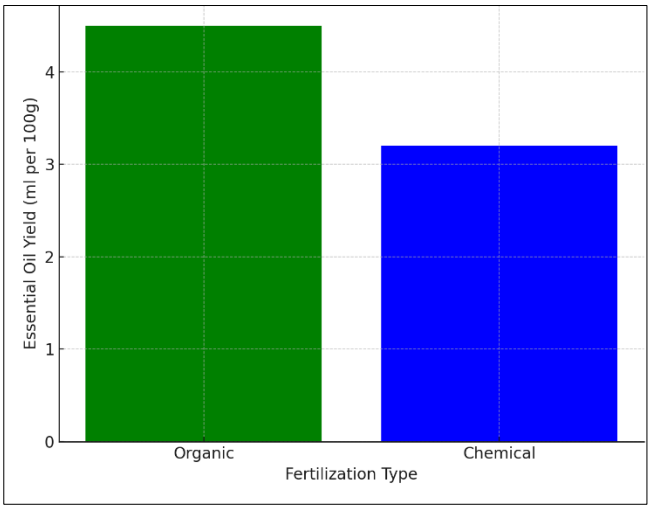

Fig 1: Effect of Fertilization on Essential Oil Yield

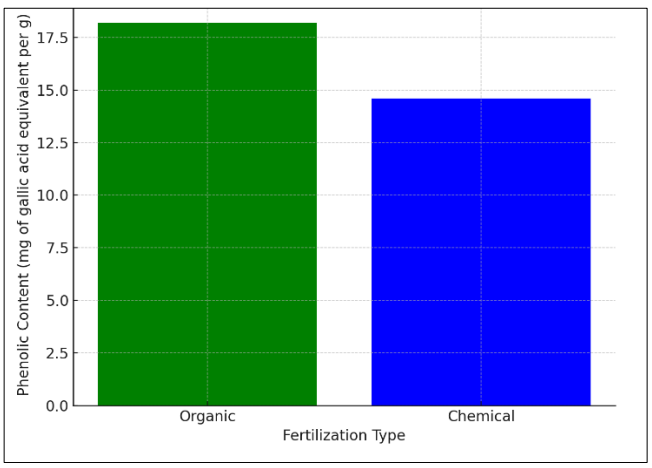

Fig 2: Effect of Fertilization on Phenolic Content

Interpretation

The findings suggest that while organic fertilization provides better yields and quality, post-harvest handling especially storage requires careful consideration. Prolonged storage leads to a substantial reduction in the quality of the product, which has implications for both growers and producers aiming to preserve the bioactive compounds of *D. moldavica*. The data aligns with previous studies on the degradation of essential oils and phenolic compounds during storage [6, 7].

Discussion

The results of this research demonstrate the significant effects of organic and chemical fertilization on the essential oil yield and phenolic content of *Dracocephalum moldavica L.*, as well as the impact of storage on the stability of these bioactive compounds. The findings align with previous studies that highlight the importance of fertilization practices in enhancing the biochemical composition of medicinal plants. Organic fertilization was shown to be more effective in increasing both essential oil yield and phenolic content when compared to chemical fertilization, reinforcing the idea that organic methods not only contribute to sustainable agriculture but also improve the quality of plant-based products [1, 2].

The higher essential oil yield and phenolic content observed under organic fertilization can be attributed to the beneficial effects of organic fertilizers on soil health. Organic fertilizers improve soil structure, increase microbial activity, and enhance nutrient cycling, all of which contribute to better plant growth and enhanced production of bioactive compounds [3, 4]. These results are consistent with previous research that suggests organic fertilization can lead to the production of plants with higher concentrations of medicinally important compounds [5, 6]. In contrast, while chemical fertilizers provide quick-release nutrients that support plant growth, they may not foster the same level of soil health or lead to the production of high-quality plant metabolites [7, 8].

The decline in both essential oil yield and phenolic content over the 3-month storage period is consistent with the findings of previous studies, which have shown that essential oils and phenolic compounds are susceptible to degradation due to factors such as light, temperature, and oxygen exposure during storage [9, 10]. The significant reduction in these bioactive compounds after 3 months of storage (from 4.5 ml per 100g and 18.2 mg per gram to 3.3 ml per 100g and 14.0 mg per gram) underscores the importance of proper post-harvest handling. The degradation observed in this research highlights the need for careful consideration of storage conditions to preserve the therapeutic potential of *D. moldavica* [11, 12].

Several factors could have contributed to the decline in bioactive compounds during storage. The volatilization of essential oils and oxidation of phenolic compounds are known to occur during prolonged exposure to air, and these processes could explain the observed reductions in yield and concentration. Additionally, the effect of storage temperature and humidity may have played a role in the degradation of these compounds. Previous studies have indicated that reducing storage time and optimizing storage conditions, such as controlling temperature and light exposure, can help mitigate the loss of essential oils and phenolics during storage [13, 14].

Conclusion

This research highlights the significant effects of fertilization methods and storage duration on the essential oil yield and phenolic composition of *Dracocephalum moldavica* L., a valuable medicinal plant known for its bioactive compounds. The findings suggest that organic fertilization significantly enhances both the essential oil yield and phenolic content when compared to chemical fertilization. Organic fertilizers appear to promote better plant growth, improve soil health, and enhance the production of valuable bioactive compounds, making them a preferable choice for growers aiming to optimize the quality of their harvest. On the other hand, while chemical fertilizers provide immediate nutrient availability, they may not support the same level of bioactive compound production, which is crucial for medicinal plant applications.

Moreover, the research underscores the impact of storage duration on the stability of essential oils and phenolic compounds. The data show a clear decline in both essential oil yield and phenolic content with prolonged storage, emphasizing the importance of efficient post-harvest management. The degradation of bioactive compounds over a 3-month period highlights the need for optimized storage conditions, as essential oils and phenolics are highly susceptible to environmental factors such as temperature, humidity, and exposure to light. To maintain the therapeutic efficacy of *Dracocephalum moldavica* over time, it is essential to adopt practices that minimize exposure to unfavorable conditions during storage.

Based on these findings, it is recommended that farmers and producers of *Dracocephalum moldavica* prioritize organic fertilization methods to enhance the quality and yield of essential oils and phenolic compounds. Furthermore, growers should aim to reduce storage times to preserve the plant's medicinal properties, or, if longer storage is necessary, implement optimized storage conditions such as controlled temperature and humidity to slow down the degradation of essential oils and phenolics. Immediate processing after harvest is advised to maintain the freshness and efficacy of the bioactive components. For producers and manufacturers in the medicinal plant industry, these recommendations are critical for ensuring the high quality and commercial viability of *D. moldavica* in both pharmaceutical and food product markets. By adopting these practices, growers can ensure that they meet the growing demand for high-quality medicinal plants while maintaining sustainability and environmental responsibility.

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