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THE IMPACT OF PEDOCLIMATIC CONDITIONS ON THE PRODUCTION OF ESSENTIAL OIL AND LAVENDER HYDROLATE

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Abstract

Lavender is a particularly valuable plant, having multiple uses and economic benefits (oil production, derived products, tourism), medicinal (aromatherapy, therapeutic properties) and gastronomic. Its cultivation combines economic and ecological benefits, contributing to the creation of sustainable agricultural practices. The present study refers to the amount of lavender essential oil and hydrolate, that can be extracted depending on the year of cultivation and the specific pedoclimatic conditions of three cultivation areas: Deta (Timiş County), Mailat and Vinga (Arad County). The climatic conditions of the analyzed period had a positive impact on the amount of volatile oil and lavender hydrolate. The amount of lavender oil, ranged from 10.7 liters/hectare at Deta and 13 liters/hectare at Vinga, in the second year and between 31 liters/hectare at Deta and 35 liters/hectare at Mailat, in the third year. Regarding the amount of lavender hydrolate, was between 111 liters/hectare in Deta and 129 liters/hectare in Vinga, in the second year and between 310 liters/hectare in Deta and 392 liters/hectare in Mailat, in the third year.

Key words: *essential oil, hydrolate, Lavandula sp., sustainable agriculture.*

INTRODUCTION

Lavender (*Lavandula* sp.) is an aromatic shrub native to the Mediterranean region, used in many fields due to its high content of essential oils. It is especially appreciated in the cosmetics and pharmaceutical industries, but also in food and landscaping (Mac & Harris, 2002; Kara & Baydar, 2013; Giray, 2018).

Of the 39 species belonging to the genus *Lavandula*, only 17 have been studied in detail for the chemical composition of volatile oils. *Lavandula angustifolia* is recognized as the most valuable species for essential oil production due to its chemical composition and extensive applicability in the pharmaceutical, medical, and cosmetic fields (Yukes & Balick, 2010; Salehiá et al., 2018; Pokajewicz et al., 2021; Butta et al., 2024).

Chemically, lavender oil contains mainly linalool (20-45%) and linalyl acetate (25-47%), compounds responsible for its characteristic aroma and therapeutic benefits. In addition to these, other compounds are also present in lower concentrations, such as eucalyptol (≤2.5%) and camphor (≤1.2%), the latter being associated with lower oil quality (Ceaușescu, 1988; Lis-Balchin, 2002; Wells et al., 2018; Tăbărașu et al., 2023).

Lavender essential oil is mainly used for cosmetic and therapeutic purposes, being recognized for its antiseptic, soothing and sedative effects, especially in the treatment of insomnia and stress (Sönmez et al., 2018; Zhu et al., 2018). According to the standards of the European Pharmacopoeia, the use of oil obtained by distillation of dried flowers (13 ml/kg) and that extracted from the upper stems is allowed in the pharmaceutical industry (Mykhailenko et al., 2022).

The quality and chemical composition of lavender oil are influenced by several factors, including the species and variety used, environmental conditions, cultivation technology, and distillation methods. For example, steam distillation favors a higher concentration of alpha-terpineol, linalool, and linalyl acetate, compounds that contribute to its therapeutic and commercial properties (Parkash & Singh, 2013). From a taxonomic point of view, the genus groups 39 species, classified in three subgenera (*Lavandula, Fabricia, Sabaudia*) and eight sections (*Lavandula, Dentatae, Stoechas, Pterostoechas, Subnudae*, *Chaetostachys, Hasikenses and Sabaudia*). The number of taxa is much higher (up to 90), if we also consider taxa, subspecies and hybrids (Pokajewicz et al, 2023; Haban et al., 2023). Botanically, lavender species marketed for essential oil are part of the section *Lavandula* and include *Lavandula angustifolia*, *Lavandula latifolia* and *Lavandula x intermedia*. In contrast, species belonging to the section *Stoechas* and *Pterostaechas* are mostly used for ornamental purposes (Yukes & Balick, 2010; Salehi et al., 2018; Batiha et al., 2023).

The components of lavender essential oil are grouped into two main categories: terpene hydrocarbons (monoterpenes, sesquiterpenes, diterpenes) and oxygenated compounds derived from them (alcohols, aldehydes, esters, ketones, phenols and oxides). Of the monoterpenes, the most valuable are linalool and linalyl acetate, which contribute to the characteristic aroma and superior quality of the essential oil (Urwin, 2009; Rus et al., 2016; Bialon et al., 2019; Batiha et al., 2023). Other minority compounds include cineole, borneol, β-pinene, terpineol, and camphor, the latter of which is considered a factor in quality reduction (Baser, 1993; Bialon et al., 2019; Masyita et al., 2022; Beicu et al., 2022).

In addition to the essential oil, another valuable by-product is lavender water, obtained as a by-product in the distillation process. It has antifungal and antibacterial properties, being used especially in the cosmetic industry, in the formulation of face and body lotions (Kunicka et al., 2015; Imbrea et al., 2016; Bălășoiu et al., 2024).

MATERIALS AND METHODS

The research was carried out on three lavender plantations from different localities in the Banat area, namely Deta (Timiș County), Vinga and Mailat (Arad County). The objective of the research is the behavior of a variety of *Lavandula angustifolia* in the crop in terms of the level of lavender volatile oil and lavender water productions, obtained in different years. The year 2023 represents the first year of study and is the 2nd year after planting, and the year 2024 represents the 2nd year of study, namely the 3rd year after planting. Harvesting was done starting with the second year after planting to allow the development of the root system of the plant, therefore it was not distilled in order to obtain lavender oil and water.

To determine the amount of lavender/plant flowers (inflorescence), 25 individuals from each location were sampled and only the tips of the stem were cut 3-5 cm below the inflorescence. The quantity of flowers/individual was weighed, the number of cuttings per hectare was taken into account and the average quantity resulting from the determinations on the 25 individuals was multiplied by the number of cuttings/hectare. Knowing the quantity of flowers per hectare for each site, three distillations were carried out for each site for a sample of 10 kg of fresh flowers and the extraction yield for each 10 kg of flowers was calculated. To determine the amount of lavender oil and water per hectare, the amount of oil and water obtained using the formula was mathematically calculated:

Oil production $(ha) = \frac{\text{U10}}{10} x\ Fha,$

where: U10 is the average amount of oil obtained from 10 kg of flowers and Fha is the amount of flowers per hectare.

The same formula was used to determine the amount of lavender water per hectare:

Lavender water production $(ha) = \frac{\text{U10}}{10} x\ Fha,$

where: U10 is the average amount of lavender water obtained from 10 kg of flowers and Fha is the amount of flowers per hectare.

RESULTS AND DISCUSSIONS

The synthesis of the results obtained according to the crop year and the quantitative variations of the oil per hectare are presented in Table 1. From the analysis of the data, it can be seen that, in the crop year 2023 (A1), the production of essential oil was 12.08 l/ha, and in 2024 (A2), this value increased to 33.33 l/ha, representing an increase of 270% compared to the previous year. The positive difference of 21.27 l/ha exceeds the DI 0.1% (20.51), which means that this increase is very statistically significant. This increase is explained by the fact that lavender being a perennial crop, in the first years, the yield is lower, but reaches an optimal peak starting with the 3rd or 4th year of cultivation (Lis-Balchin, 2002).

Table 1. Amount of oil/ha by crop year

Year of culture	Oil/ha (l)	%	Difference (l)	Significance
A1 - 2023	12.06	100		
A2 - 2024	33.33	276	21.27	***
DL 5% = 2.79; DL 1% = 6.44; DL 0.1% = 20.51				

Table 2 shows the results regarding the amount of oil/ha depending on the cultivation location. The data is organized across three different locations: Deta, Vinga, and Mailat. From the analysis of the results, we can observed, that the amount of oil depending on the location, had values of 20.85 l/ha at Deta, 23.1 l/ha at Vinga, which represents an increase of 10% compared to Deta and 23.75 l/ha at Mailat, which represents an increase of 14% compared to Deta (considered a control).

Analyzing the results obtained, we can say that there is a variability of the oil content depending on the cultivation location. The highest values of oil are in Mailat (23.75 l/ha), and the lowest in Deta (20.85 l/ha). These results suggest that location significantly influences oil accumulation, which may have implications for agriculture and plant nutrition.

Table 2. Amount of oil/ha depending on the cultivation location

Locality	Oil/ha (l)	%	Difference (l)	Significance
b1 - Deta	20.85	100		
b2 - Vinga	23.50	113	2.65	Ns
b3 - Mailat	23.75	114	2.9	Ns
Dl 5% = 3.42; Dl 1%=7.89; Dl 0.1% = 25.11				

TEST DUNCAN - factor B, DL5% = 3.42

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Date originale                      Date sorate
 Mean    1 =    20.85  A    Mean    3 =    23.75  A
 Mean    2 =    23.50  A    Mean    2 =    23.50  A
 Mean    3 =    23.75  A    Mean    1 =    20.85  A
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Mean 1 – b1 – Deta
Mean 2 – b2 – Vinga
Mean 3 – b3 – Mailat

Although there is an apparent increase in oil production/ha in Mailat and Vinga compared to Deta, these differences are not statistically significant.

The highest value 23.75 was obtained in the Mailat location - class A, and the lowest 20.85, in the Deta location - class A. Between the values obtained at each location, there are no statistically assured differences, they are part of the same homogeneity class - class A.

The differences observed between the locations could be caused by natural variations or external factors, but they are not large enough to be considered statistically relevant. We can also state that although there is variation between locations, it is not large enough to justify major changes in cultivation technologies

The percentage contribution of different factors (crop year, location and error), to the variation in the probable oil yield/ha is shown in Figure 1.

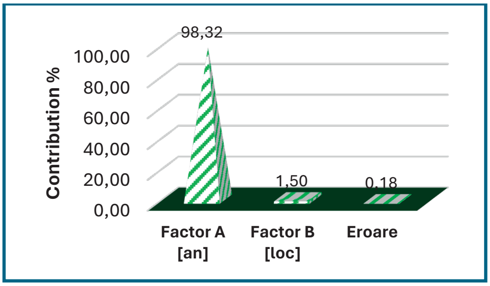

Figure 1. Contribution of factors A [crop year], B [crop locality] to lavender oil content

Factor A (crop year) contributes the most with 98.32%, this suggests that the age of the lavender crop plays a dominant role in determining the yield.

The B factor (location) has a minor contribution of 1.50%, the influence of location indicates that although location may have some effect, it is not the main determinant of yield variation.

The error variation is negligible at 0.18%, the unexplained variation (random errors or experimental uncertainties), is extremely low. This implies that the study design is robust and the results are very reliable.

The results of the cluster analysis of lavender oil content by crop year and location are shown in Figure 2.

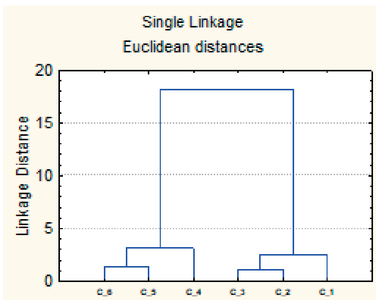

Figure 2. Cluster analysis of lavender oil content by crop year and location

This dendrogram suggests that the dataset contains well-defined groups, and the Single Linkage method produces a "chain" effect in

which closer objects are grouped quickly, but large groups are joined at large distances. This can be useful if the goal is to discover elongated structures in the data.
Analyzing the growing areas, the results presented in the dendrogram indicate similar plant growth conditions (C_1 and C_2 are very close, suggesting that they could be two varieties related or having similar agronomic characteristics). The results of the impact of the lavender crop year on the amount of hydrolate/ha are presented in Table 3. From the analysis of the data, a significant difference can be observed between 2023 and 2024 in terms of the amount of hydrolate obtained per hectare.
If in 2023, the hydrolate production/ha was 123 l, considered the reference base (100%), in 2024, the production increased considerably to 361 l/ha, which represents an increase of 238 l/ha compared to the previous year, distinctly statistically significant difference. These results prove that lavender being a perennial crop, the amount of hydrolate increases as it advances in vegetation.

Table 3. Quantity of hydrolate/ha by crop year

Year of culture	Hydrolate/ ha (l)	%	Difference (l)	Significance
A1 - 2023	123	100		
A2 - 2024	361	293	238	**
DL 5% = 85.45; DL 1%= 197.09; DL 0.1% = 627.31				

With reference to the influence of location on hydrolate production (Table 4), the results show that these significant variations between the three analyzed locations: Deta, Vinga and Mailat.

Table 4. Amount of hydrolate/ha depending on the cultivation location

Locality	Hydrolate/ha (l)	%	Difference (l)	Significance
b1 - Deta	211	100		
b2 - Vinga	255	121	44	Ns
b3 - Mailat	260	123	49	Ns
DL 5% = 104.65; DL 1%=241.38; DL 0.1% = 768.29				

The lowest amount of hydrolate/ha was recorded in the experimental field from Deta, 211 l/ha, followed by Vinga with a production of 255 l/ha, which means a difference of 44 l/ha compared to Deta and Mailat with the highest production, 260 l/ha, an increase of 49 l/ha compared to Deta. Even if there are differences between locations, these differences are insignificant.

TEST DUNCAN - factor B, DL5% = 104.6

Date originale			Date sorate			
Mean	1 =	210.5 A	Mean	3 =	260.0 A	Mean 1 - b1 - Deta
Mean	2 =	254.5 A	Mean	2 =	254.5 A	Mean 2 - b2 - Vinga
Mean	3 =	260.0 A	Mean	1 =	210.5 A	Mean 3 - b3 - Mailat

The highest value, 260 liters, was obtained in the Mailat location - class A, and the lowest 210.5 liters, in the conventional Deta location - class A. Between the values obtained at each location there are no statistically assured differences, they are part of the same homogeneity class - class A.

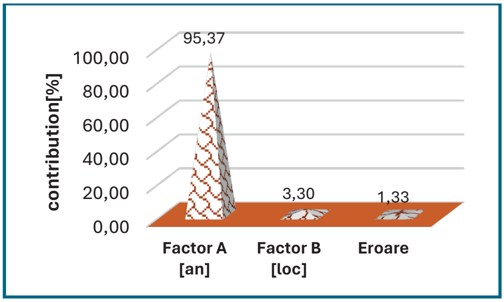

Figure 3. Contribution of factors A [crop year], B [crop locality] to lavender hydrolate content

Analyzing the results obtained, it can be seen that Factor A (year of cultivation) has the greatest influence (95.37%), which means that the differences between locations were not significant or have a much lower impact on the parameter studied, and the Experimental Error (1.33%) is very small, which suggests a high precision of the experiment and a good reproducibility of the results (Figure 3).
The results of the cluster analysis for lavender hydrolate content by crop year and location are shown in Figure 4.
Analyzing the data, it is observed that there are two large groups, united at a very large distance (~160-180), indicating major differences between them.
The clusters C_5 and C_4 are the closest, suggesting a high similarity in hydrolate content between these two samples. Another smaller group is formed between C_3 and C_2, and C_1 is more isolated and different from the others
In conclusion, we can also say from this analysis that in terms of hydrolate content, the age of the plants has a greater influence than the location.

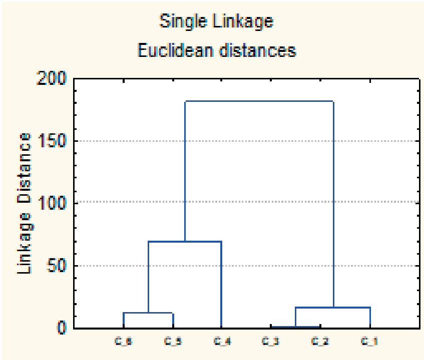

Figure 4. Cluster analysis of lavender hydrolate content by crop year and location

The correlation between the amount of flowers and lavender oil is shown in Figure 5.

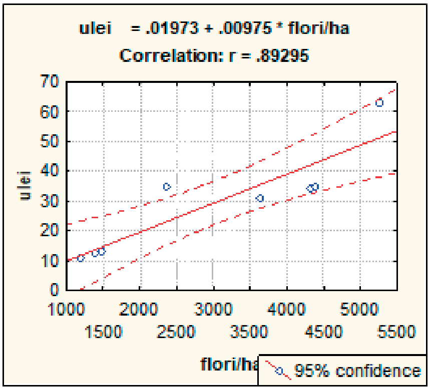

Figure 5. Correlation between the amount of flowers and lavender oil

The linear regression equation indicates that there is a positive linear relationship between the number of flowers per hectare and the amount of oil obtained. In other words, as the density of the flowers increases, so does the amount of oil extracted. According to the correlation coefficient (R=0.89295), the correlation between flowers and oil is very strong, because r is close to 1. This means that the variables are closely related: an increase in the number of flowers per hectare causes a significant increase in the amount of oil. The regression model suggests that, on average, for each increase of 1000 flowers/ha, the amount of oil increases by about 9.75 units. This is valuable information for optimizing the production of lavender essential oil.

The correlation between the amount of flowers and lavender hydrolate shown in Figure 6, indicates that there is a positive linear relationship between the number of flowers per hectare and the amount of hydrolate obtained.

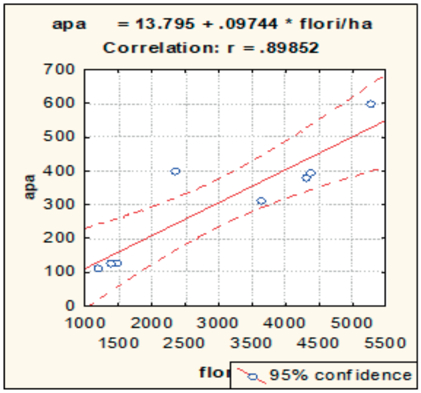

Figure 6. Correlation between the amount of flowers and lavender hydrolate

The linear regression equation indicates that there is a positive linear relationship between the number of flowers per hectare and the amount of hydrolate obtained. More precisely, each growth with 1000 flowers/ha determines an average growth of about 97.44 hydrolate units.

Figure 7 shows the results of the correlation between the amount of herba and lavender oil.

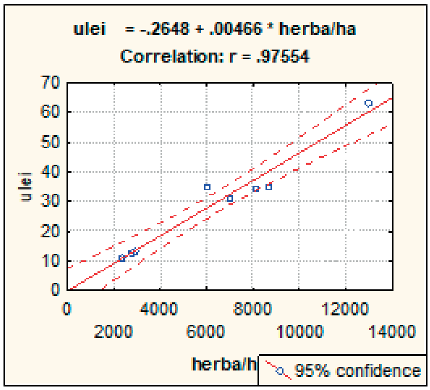

Figure 7. Correlation between the amount of herb and lavender oil

The linear regression equation indicates a positive linear relationship between the amount of herba per hectare and the amount of lavender oil obtained.

For every 1000 kg of grass/ha, the amount of oil increases by an average of 4.66 units.

The correlation coefficient (r=0.97554) is very close to 1, which means that the variations in the amount of grass/ha almost entirely explain the variation in the amount of oil obtained.

Correlation between the amount of herb and lavender hydrolate (Figure 8). The linear regression equation indicates a positive linear relationship between the amount of grass harvested per hectare and the amount of lavender hydrolate obtained. Each 1000 kg of grass/ha causes an average growth of 45.8 units of hydrolate. The correlation is very strong, suggesting that more harvested grass leads to a significant increase in the amount of hydrolate.

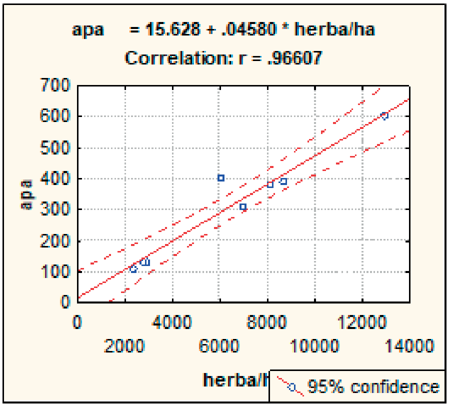

Figure 8. Correlation between the amount of herb and lavender hydrolate

Correlation between the amount of oil and lavender hydrolate (Figure 9).

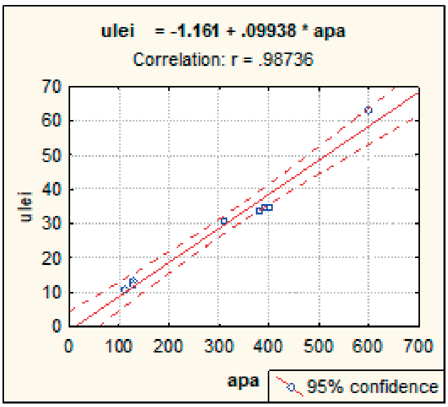

Figure 9. Correlation between the amount of oil and lavender hydrolate

The linear regression equation indicates a positive linear relationship between the amount of hydrolate (lavender water) and the amount of oil obtained.

Every 100 units of hydrolate results in an average increase of 9,938 units of oil.

The correlation coefficient value (r=0.98736) indicates the existence of an extremely strong correlation between the amount of hydrolate and lavender oil.

The 95% confidence interval indicates that the reliability of the model is very high, which means that this relationship can be used to optimize the distillation process.

CONCLUSIONS

The production of lavender oil and hydrolate varies depending on the year of cultivation, in the first two years after planting, lavender has a lower yield of essential oil and hydrolate, as the plants are still developing. From the 3rd year of cultivation, the plants reach maturity and the production of flowers and grass increases significantly, also influencing the production of oil and hydrolate.

The cluster analysis confirms that the year of cultivation is the main influencing factor on the oil content and the lavender hydrolate content, and the location plays a secondary role.

There is also a strong positive relationship between the number of lavender flowers per hectare, the amount of herba/ha and the amount of oil and hydrolate obtained.

Farmers and producers of lavender oil and hydrolate can use this model to estimate hydrolate production based on the amount of flowers and grass harvested per hectare.

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