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Lavender Breeding for Winter Hardiness in a Temperate Climate

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Abstract: *Lavandula angustifolia* is a promising essential oil and ornamental crop whose distribution in the temperate zone and northern regions is limited by its low winter hardiness. Analyzing the causes of low winter hardiness will facilitate the selection of the most winter-hardy hybrids. The study goal is to evaluate the climatic conditions and winter hardiness of narrow-leaved lavender and to determine critical conditions for the successful overwintering of plants in the conditions of Moscow. The studies were conducted in the laboratory of cultivated plants of MBG RAS from 2015 to 2022. The research objects were 72 lavender hybrids. The assessment of hybrids' winter hardiness was carried out after complete snow melt. Average daily temperature, snow cover height, and precipitation were considered daily. Data statistical processing was carried out using Microsoft Excel and PAST 4.5 software. Optimal lavender overwintering conditions were formed in 2018 and the greatest plant damage was observed in 2017. The research years were grouped by winter hardiness structured into clusters, which allowed us to identify common features in climatic conditions and to identify critical periods of the winter period leading to a decrease in winter hardiness. Temperature fluctuations in winter, frequent temperature transitions over the 0 °C mark, high levels of snow cover and the formation of ice deposits led to severe damage to some lavender hybrids. Severe frosts in the absence of snow cover can lead to the death of lavender plants in the temperate zone. Lavender hybrids were grouped by winter hardiness into two clusters and 11 subclusters. A group of hybrids with consistently high resistance has been selected throughout the years of the study; these hybrids are the most promising for further hybridization.

Keywords: *Lavandula angustifolia*; hybrids; climatic conditions; desiccation; winter hardiness

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1. Introduction

Lavender is a plant of the Lamiaceae family cultivated as an essential oil, ornamental and medicinal plant [1]. The *Lavandula* genus includes more than 45 species. The genus representatives' growing region is the Mediterranean Sea, southern Europe, North and East Africa, the Middle East, and southwest Asia and southeast India [2,3]. Representatives of four lavender species are most often used in the industry—*Lavandula angustifolia* Mill., *Lavandula stoechas* L., *Lavandula latifolia* Medik., and *Lavandula x intermedia* Emeric ex Loisel. The last one is a hybrid between *L. latifolia* and *L. angustifolia* [4–6].

The main purpose of lavender cultivation in the world is to obtain essential oil, which is included in a wide range of products [7–9]. This is possible mainly in countries with

a high sum of active temperatures and a warm, dry climate. The leading countries for lavender production are Bulgaria and France, followed by Russia, Ukraine, Moldova, Romania and others [10].

Among *Lavandula* species, the most important and most winter-hardy is the *Lavandula angustifolia*, which makes it increasingly important to move the cultivation area northward.

Lavender essential oils contain more than 100 components, including linalyl acetate (30–55%), linalool (20–35%), tannins (5–10%), and caryophyllene (8%) as well as other sesquiterpenoids, perillyl alcohols, esters, oxides, ketones, cineole, camphor, β-ocimene, limonene, caproic acid, and caryophyllene oxide [11]. Lavender essential oils are used as a medicinal agent [12], characterized by a variety of pharmacological properties—anti-inflammatory, antioxidant, antibacterial, antiseptic, antiviral, antidepressant, sedative, immunostimulant [13]. Lavender oil is used in cosmetic products and for insect repellent. Also, lavender oils are used in aromatherapy [14,15]. However, it is known that the accumulation of essential oils is higher at higher temperatures and decreases at lower temperatures [16–18]; therefore, industrial cultivation of lavender for the production of essential oils may not be the main goal in temperate climates.

There is currently a trend towards the development of zero-waste agricultural production technologies, which makes essential oils not the only lavender processing product. Secondary lavender processing products are particularly attractive, and studying these will allow for the best utilization of the crop [19].

Lavender is rich in phenolic compounds, with 8 anthocyanins and 19 flavonols identified in the plants [19]. Lavender leaves are widely used as flavorings for food and beverages and are a source of phenolic components and antioxidants. *Lavandula angustifolia* is a good honey grower and is also used as one of the ingredients for tea blends and ice cream flavoring [20]. Кроме того, лаванда популярна в качестве декоративного растения [21–23]. These uses will be available in regions with temperate and cold climates if plants are obtained that are resistant to the adverse conditions of the winter period—frost-resistant and winter-hardy.

The trends of *Lavandula angustifolia* breeding programs in the world are different depending on the climatic conditions of the growing region. In regions with a warm climate, breeding work is mainly aimed at increasing the content and quality of essential oils [24]. A separate breeding direction is obtaining interspecific hybrids with a complex of valuable traits, including ornamentality, resistance to frost and drought, and content and quality of essential oils [25], but their winter hardiness does not allow growing them in the temperate zone. In Romania, one of the main directions is breeding for drought and salinity tolerance [26].

In temperate regions, low temperatures are the main limiting factor in lavender propagation; therefore, the main breeding direction in these regions is now increasing the winter hardiness and frost resistance of lavender. Even though *Lavandula angustifolia* is one of the most frost-tolerant species, and its ecological optimum is in climates with warm sunny summers but cold winters [21], the region of its industrial use is concentrated in southern Europe, Mediterranean countries, southern Russia and Ukraine [27–29]

In one study, the most resistant varieties of *Lavandula angustifolia* for the conditions of the forest-steppe zone of Ukraine were identified [30]; however, their stability was insufficient for cultivation in the conditions of the Central region of Russia.

Therefore, for the temperate climatic zone, which includes a large part of Russia, наиболее, an important breeding task is to produce, in particular, winter-hardy hybrids. These hybrids should have maximum stability to enable them to be stable for many years since the climatic conditions of the Central region of Russia are very variable in different years. Fluctuations in climatic conditions have become even stronger in recent years due to

the influence of global warming. Climate change-related factors are increasingly affecting plant growth and development worldwide [18].

Among these hardy hybrids, it will be necessary to further select plants with a complex of economically valuable characteristics (ornamentality, content of biologically active agents, not only essential oils).

The purpose of this work is to assess the climatic conditions and winter hardiness of *Lavandula angustifolia* and to determine the critical conditions for successful overwintering of plants in the conditions of Moscow, Russia.

2. Materials and Methods

2.1. Plant Materials

The studies were conducted during 2015–2022 in the laboratory of cultivated plants of the N.V. Tsitsin Main Botanical Garden of the Russian Academy of Sciences (Moscow, Russia). The geographic coordinates of the plant collection location are [55.84360134560778 N; 37.6201296230011 E].

The objects of the study were 72 second-generation seedlings of lavender narrow-leaved from free pollination (Figure 1), parental forms of which were produced as a result of seed exchange between botanical gardens in the 1980s.



Figure 1. Lavender field.

The plantation grows only narrow-leaved lavender plants, so the origin of seedlings as a result of interspecific hybridization is excluded.

Each hybrid represents five plants produced by the rooting of semi-timbered cuttings. The age of plants in 2014 (when the experiment started) was 5 years.

The plants are planted in rows; the distance between rows is 80 cm, and the distance between plants in a row is 60 cm. One of the lavender cultivation problems is weed control [19]; to reduce the number of weeds, we used mulching agro-fabric (manufactured NPK "PROTECT" Pereslavl-Zalesskiy, Russia) in our cultivation technology, which is permeable to water and air but prevents weeds growth and development. During the growing season, feeding three times with complex mineral fertilizers was carried out—in spring, fertilizers with high nitrogen content were applied, and in autumn, phosphorus–potassium fertilizers were applied. Formative pruning (removal of peduncles and shortening of shoots) was carried out at the end of the vegetation period (September–early October); damaged, broken and frozen shoots were also removed in spring after snow melt.

2.2. Plants Winter Hardiness Assessment

Winter hardiness was assessed according to a 6-point system: 0 points—the plant died, 1 point—the plant froze to the soil level, 2 points—perennial shoots were damaged, 3 points—biennial and annual shoots were damaged, 4 points—annual shoots were damaged, 5 points—the plant survived the winter without damage. Winter hardiness tests were performed after the complete snow melt in April-May, before spring pruning. Figure 2 shows the growing plants for better visibility.

2.3. Climatic Conditions Analysis

During the winter period, the average daily temperature, snow cover height, and precipitation were considered. Climatic data were provided by the meteorological observatory named after V.A. Mikhelson by RSAU-MAA named after K.A. Timiryazev (Russia, Moscow) (license for activities in the field of hydrometeorology and related fields No. L039-00117-77/00654436). The main climatic data were obtained according to the methodology created Tudriy and Ismagilov [31].

2.4. Statistical Analysis

The volume of the necessary sample was determined according to the previously developed methodology [32]. Sample statistical analysis (basic statistics) [33] was used to assess the reliability of the obtained results, and cluster analysis was used to group objects. Cluster analysis was carried out according to the comprehensive scores of principal component evaluation using Ward's method. Analysis of the results and their visualization were performed using Microsoft Excel, Microsoft Visio, PAST 4.5 software.



(**a**) (**b**)

(**c**) (**d**)

(**e**) (**f**)

Figure 2. Post-winter damage assessment methodology of regrowing plants. Litera (**a**)—5 points, (**b**)—4 points, (**c**)—3 points, (**d**)—2 points, (**e**)—1 points, (**f**)—0 points.

3. Results

3.1. Analysis of Lavender Hybrids' Winter Hardiness in Research Years

The winter hardiness of narrow-leaved lavender seedlings varied significantly among the years of the study (Table 1 and Figure 3). The worst indicators in the sample, on average, were observed in 2017—all plants were damaged to different degrees after overwintering;

the mode and median were 2 points, and the average overwintering score for the sample was 1.9 points. Also, the first plant dropouts were noted.

Table 1. Statistical parameters of lavender hybrids for winter hardiness.

Year	Mediana	Mode	Average Point	Overwintered Plants, %
2015	4	4	3.5	100
2016	4	4	3.4	100
2017	2	2	1.9	97.2
2018	5	5	4.5	98.6
2019	4	5	3.9	97.1
2020	4	4	3.6	91.0
2021	4	5	4.2	95.1
2022	3	4	3.3	98.3

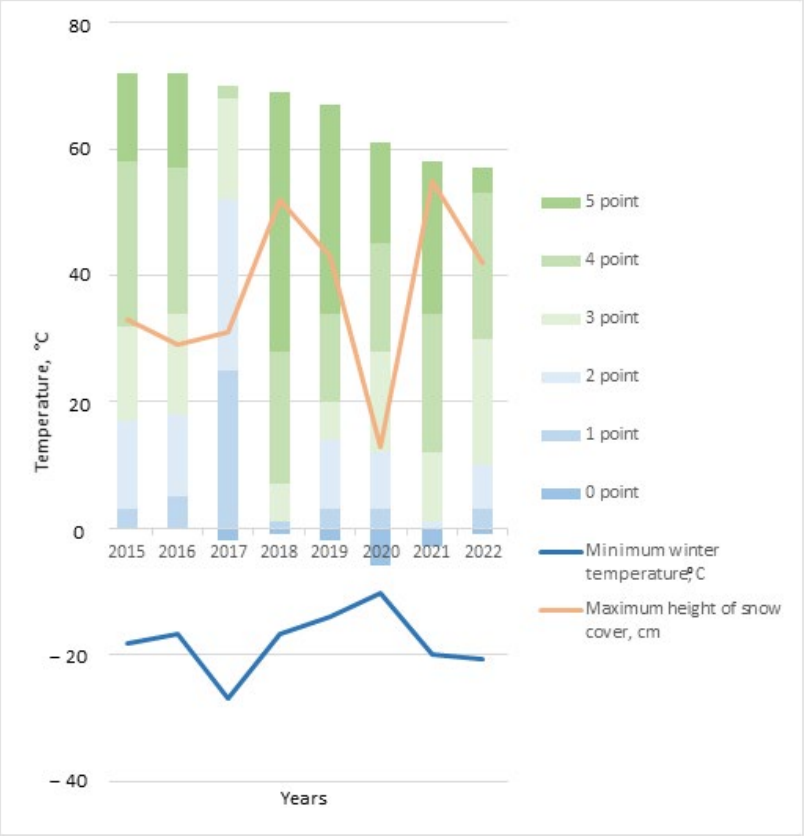


Figure 3. Structure of winter hardiness of *Lavandula angustifolia* hybrids in absolute numbers.

According to the set of statistical parameters of winter hardiness, the optimal year for overwintering was 2018; the mode and median were 5 points, and the average winter hardiness score for the sample was 4.5. This was the maximum average score for the whole time of observations, and only one seedling died.

The winter hardiness in 2019–2021 was quite leveled, but in 2020, the maximum death of plants during the observation period (6 pcs.) was noted. In general, more than 90% of plants came out of winter alive with different degrees of damage during the 8 years of the study.

3.2. Climatic Conditions Analysis

It was assumed that winter hardiness may be influenced by the following climatic features of the year: minimum winter temperature, sum of active temperatures, maximum snow cover height, and precipitation amount for the year (Table 2).

Table 2. Mean annual climatic parameters in the research years.

Year	Minimum Winter Temperature, °C	The Sum of Active Temperatures Is Above 10 °C	Maximum Snow Cover Height, cm	Precipitation Amount for the Year, mm
2015 [1b]	−18.3	2911	33	717
2016 [1b]	−16.8	2877	29	881
2017 [3]	−27.0	2555	31	870
2018 [1a]	−16.7	3355	52	652
2019 [1a]	−13.9	3093	43	556
2020 [2a]	−10.3	2966	13	901
2021 [2b]	−20.0	2897	55	817
2022 [2b]	−20.6	3065	42	648

[1a, 1b] years included in the first cluster, [2a, 2b] years included in the second cluster, [3] year included in the third cluster—are presented in Figure 3.

The lowest winter minimum temperatures were observed in 2017, 2021, and 2022 and the highest in 2019 and 2020.

In a more detailed analysis of the temperature regime, the minimum and average ten-day temperatures from December 1 to March 30 for 2014–2022 were determined (minimum temperatures are marked in Table 3 in red font, near-zero temperatures in green font).

Table 3. Minimum and average ten-day temperatures for the winter period. Minimum temperatures are marked in red font, near-zero temperatures in green font.

Month	Ten-Day Period	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021	2021–2022
Minimum temperature, °C									
December	1	−12	−1	−14	−4	−15	−5	−13	−14
	2	−3	−10	−19	0	−16	−2	−11	−14
	3	−17	−10	−4	−4	−10	−4	−11	−21
January	1	−20	−20	−30	−4	−14	−3	−9	−8
	2	−12	−20	−12	−9	−11	−6	−20	−17
	3	−18	−19	−23	−10	−20	−7	−9	−8
February	1	−14	−5	−23	−13	−5	−15	−17	−8
	2	−12	−8	−11	−10	−10	−4	−18	−3
	3	−2	−8	−7	−18	−12	−5	−17	−3
March	1	−5	−8	−2	−13	−12	−3	−16	−9
	2	−4	−9	−5	−13	−11	−9	−11	−4
	3	−10	−10	−6	−6	−3	−6	−2	−4
Average temperature, °C									
December	1	−7.2	0.7	−8.9	−1.4	−5.9	−1.1	−8.2	−5.3
	2	−0.5	−3.5	−10.8	1.8	−8.1	0.0	−5.6	−4.1
	3	−9.5	−0.6	−2.0	−0.7	−9.1	−1.0	−5.9	−12.8
January	1	−10.2	−16.6	−19.0	0.0	−8.5	−1.4	−2.8	−5.3
	2	−2.8	−13.7	−6.3	−6.9	−7.3	−1.2	−13.4	−5.8
	3	−9.3	−9.4	−10.0	−6.0	−12.3	−2.8	−0.8	−5.1
February	1	−7.5	−1.8	−14.1	−5.5	−3.3	−6.1	−10.4	−2.8
	2	−6.0	−3.3	−4.9	−6.4	−3.6	−0.9	−13.3	0.1
	3	−0.5	−3.8	−3.9	−14.4	−5.4	−1.5	−5.8	−0.1
March	1	−0.7	−1.2	0.4	−8.8	−6.2	2.3	−5.0	−2.9
	2	−2.0	−4.0	−1.1	−5.4	−2.3	−0.4	−1.7	0.0
	3	−2.8	−4.2	−1.8	−1.5	−0.5	−2.2	2.2	1.4

The minimum winter temperature was most often observed in January, but in some years, it was observed in late December (2022) and early February (2017). In some years, winter temperatures never dropped below −15–18 °C (2018 and 2020).

The ten-day average temperatures became close to critical for lavender starting in January, while December, February and March generally had average temperatures ranging from 0 to −5 °C, which is not a problem for lavender plants.

The temperatures in the winter months mainly range from 0 to minus 10–12 °C, but in recent years, due to global warming, there have been sharp temperature changes and days with extremely low temperatures, which can be clearly seen when analyzing the daily temperature using basic statistics and box-plot visualization (Figure 4). In winter 2017, there were 4 days with extreme temperature variations, and in 2022, there were three days.

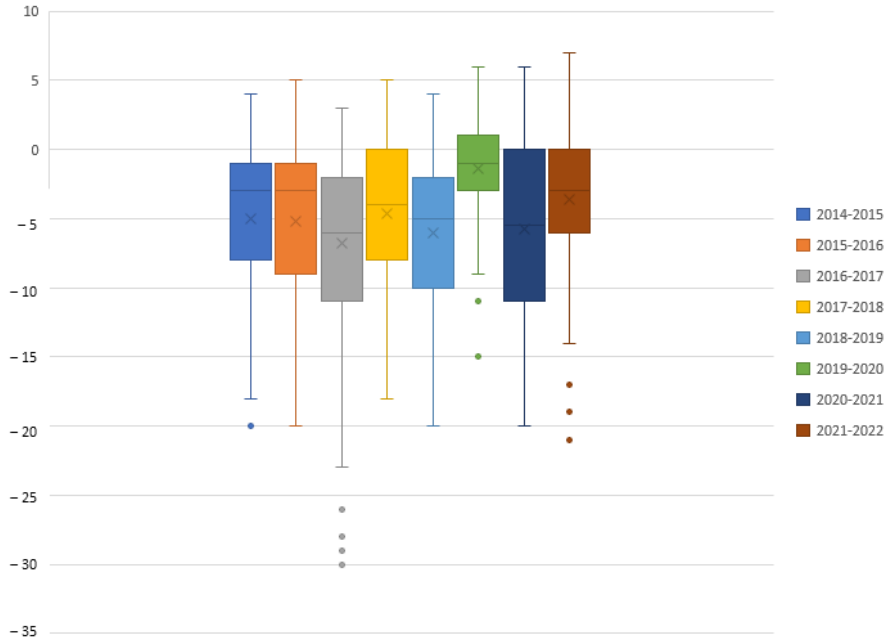


Figure 4. Box-plot of average daily temperatures for winter months.

Through a detailed analysis of climatic conditions in winter for the research years, possible critical points causing damage to plants in winter were determined based on winter hardiness indicators (Figure 5).

The following critical points were identified (shown in Figure 5):

(1) Absence of snow cover and temperature decrease below zero (blue vertical arrows);
(2) Sufficient snow cover and increase in temperatures to positive values (red vertical arrows);
(3) Formation of a dense layer of snow with prolonged preservation of positive temperatures and subsequent decrease in temperatures to negative values (red double-sided horizontal arrow).

Visualizing the values of temperature and snow cover height, differences between years became visible. The winter of 2014–2015 was characterized by a snow-free period followed by a sharp cold snap, numerous temperature increases to positive values, and two periods with the formation of a dense ice crust. In the winter of 2015–2016, there was only one episode of sharp (temperature difference from +6° to −18 °C) cold weather in the absence of snow and a thaw at the end of January, which led to the formation of ice crust. In the winter of 2016–2017, we did not observe sharp fluctuations with complete absence of snow, but three episodes with temperature increase to zero and formation of frost were observed. The first half of winter 2017–2018 was characterized by almost complete

absence of snow and temperature fluctuations around zero, in mid-January temperatures dropped to −10 °C in the absence of snow, and in early February heavy snowfalls were observed; despite a one-time temperature increase to zero, the formation of snow crust was not observed. Conditions in the winter months of 2018–2019 were characterized by stable snow cover and temperature, with one critical point in early December with a short-term temperature increase to zero, which did not lead to the formation of ice, as well as temperature fluctuations near zero in February, leading to the formation and melting of snow crust. Winter conditions in 2019–2020 resembled climatic conditions in the regions of traditional cultivation of narrow-leaved lavender in all parameters—practically no snow cover and temperature fluctuations around zero, with a single cold snap to −5 °C in the absence of snow and to −10 °C in the presence of 10 cm of light cover. In the winter of 2020–2021, three critical points characterized by zero temperature in the presence of snow cover were observed, one of which was accompanied by the formation of ice crust; however, the height of snow under the crust was significantly higher than normal. In 2021–2022, the snow cover height was also higher than normal, and three thaws were noted during the winter period, two of which led to the formation of ice crust; however, in the first case, the ice crust was thin for a short time and then broke up.

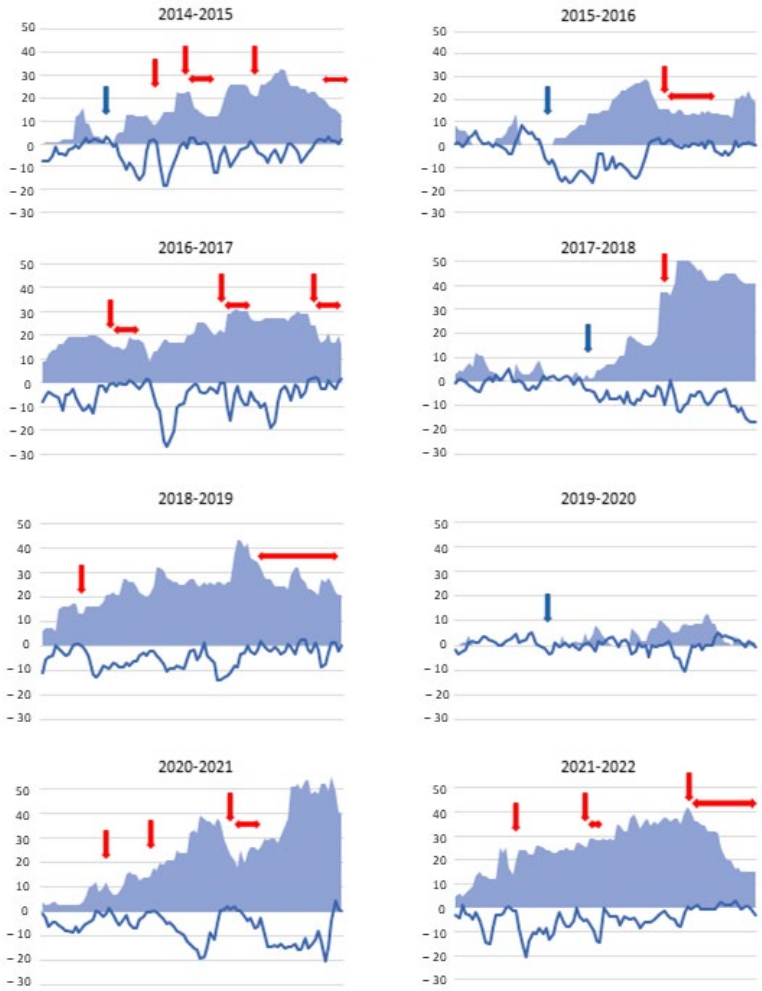


Figure 5. Fluctuations in temperature and snow cover height during the study period from early December to late February: (a) 2014–2015; (b) 2015–2016; (c) 2016–2017; (d) 2017–2018; (e) 2018–2019; (f) 2019–2020; (g) 2020–2021; (h) 2021–2022. The blue line shows the variation in minimum daily mean temperature, and the filled box shows the snow cover height. The blue vertical arrow is a Type 1 critical point, the red vertical arrow is a Type 2 critical point, and the red horizontal arrow is a Type 3 critical point.

3.3. Relationship Between Winter Hardiness and Winter Climatic Conditions

For further identification of climatic features affecting the winter hardiness of lavender hybrids, the years of the study were grouped according to the complex winter hardiness score (Figure 6). At an association distance of 19 Euclidean distances, 2017 was separated into a separate cluster, and at a distance of 17 Euclidean distances, the remaining years were divided into two clusters; the first was included in subgroup 1—2015 and 2016 and in subgroup 2—2018 and 2019, and the second cluster was included in 2020–2022, with 2021 and 2022 being close to each other in terms of complex winter hardiness, and 2020 differing from them to some extent.

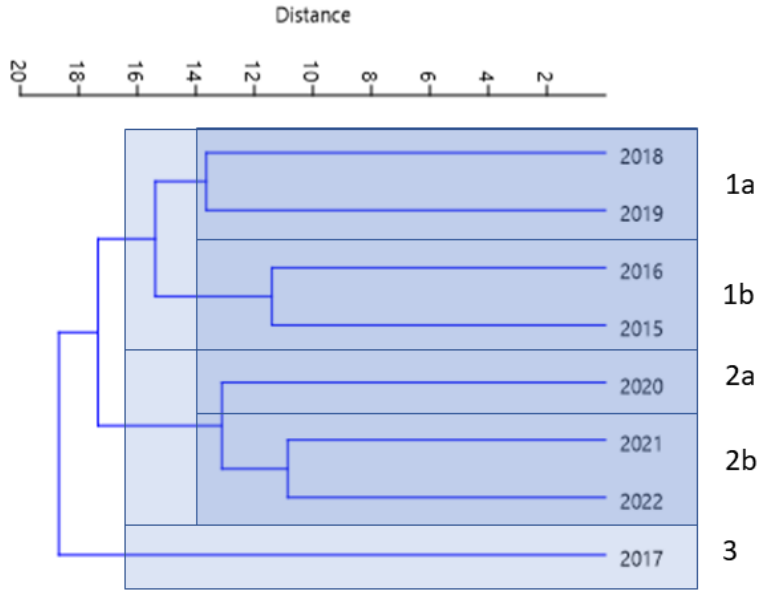


Figure 6. Grouping of research years based on the structure of winter hardiness of lavender hybrids. Numbers indicate clusters, and literals indicate subclusters.

Based on the data on winter hardiness obtained over 8 years of research, we grouped the seedlings. The grouping was carried out for all hybrids, except for those that completely fell out during the years of research (Figure 7).

The sample was divided into 2 large clusters (groups), including 11 smaller ones. The most interesting in this case is the separation of the second- and third-order clusters. The first and second subclusters of the third order, combined into a second-order cluster, united objects with relatively low winter hardiness in all years of research, except 2018, and the average winter hardiness for them was 3.2 points. The third, fourth, fifth and sixth subclusters were characterized by high winter hardiness, averaging 3.9–4.1 points in all years, except 2017, when all plants in the study showed low winter hardiness. This group of plants showed high winter hardiness compared to the others regardless of the conditions that year. The seventh and eighth subclusters included plants with average winter hardiness that reacted quite strongly to the climatic conditions of the year—in more favorable years their winter hardiness was high, while in years with a complex of unfavorable conditions it sharply decreased. Finally, the ninth, tenth and eleventh subclusters united objects characterized by a rather low average (2.5–3.4 points) and, at the same time, unstable winter hardiness.

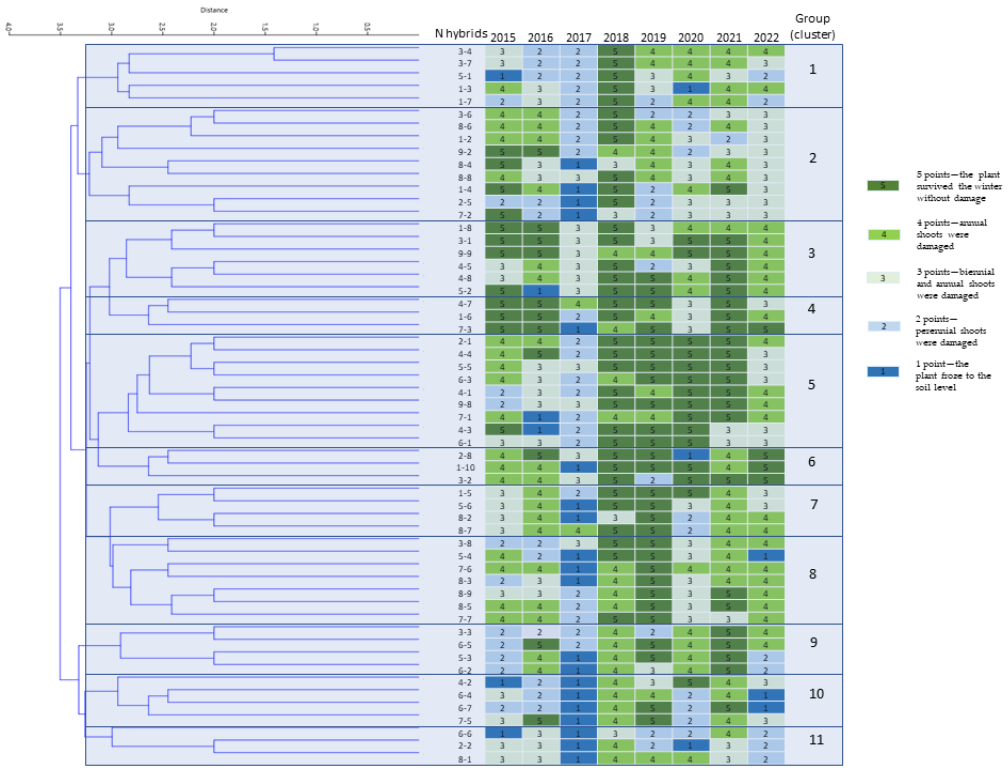


Figure 7. Lavender seedlings grouped by winter hardiness.

4. Discussion

Based on the analysis of climatic conditions and the degree of damage to lavender plants in different years of research, the years with the greatest damage to plants were identified. We noted the greatest degree of damage to lavender plants in 2017, which was characterized by the lowest temperatures, the lowest amount of active temperatures, (Table 2), strong temperature fluctuations (Figure 4, Table 3) and a high level of snow cover. Similar average conditions were observed in 2021 and 2022, characterized by significantly higher winter hardiness of plants. It is possible that plants' winter hardiness in 2017 was influenced by the conditions of the previous year of 2016, which was characterized by a low sum of active temperatures, resulting in insufficient shoot maturation.

In temperate climates, lavender behaves as a chamaephyte, a perennial evergreen semi-shrubby plant with perennial buds located on single-trunked shoots above the soil surface [19,34]. Young plants are most sensitive to adverse weather conditions as their resistance increases with their age [22]; also, young tissues are more susceptible to spring damage [35]. The risk of damage exists for plants buds in forced dormancy during warming in winter or in early spring [36].

Usually, low temperatures have been recognized as a major factor limiting the geographical distribution of plants [16,37], as cold stress leads to morphological changes, such as a decrease in biomass and leaf surface area [38]. However, in the case of lavender, as our data show, the effect of a complex of climatic factors should be considered.

Plant winter hardiness is a complex parameter, which depends on many factors both in the external environment and in the state and plant genotype. Winter hardiness includes resistance to low negative temperatures of the above-ground part and root system, as well as resistance to uprooting, soaking, and fungal diseases, which can progress in conditions of high humidity and positive temperature under the snow crust. There are many ways woody plants adapt to lower temperatures—nutrient outflow before the dormant period, biochemical acclimatization, and phenology peculiarities [39,40].

A comparative analysis of temperature and snow cover fluctuations revealed critical climatic conditions that are most likely to cause severe damage to plants (Figure 5). Critical conditions determining the winter hardiness of *Lavandula angustifolia* hybrids are as follows: lack of snow cover with temperature decreases below 0 °C; sufficient snow cover and temperature increase to positive values; and snow crust formation with prolonged preservation of positive temperatures and consequent temperature decrease to negative values.

The combination of such critical climatic conditions led to the greatest damage to plants in the winter of 2017. However, most of the plants, despite severe damage, remained alive (Table 1)

The highest plant death rate was recorded in 2020, which was characterized by relatively high temperatures and light snow cover.

Thus, according to the influence of climatic conditions on lavender plants in winter, it can be concluded that with strong temperature fluctuations, especially with frequent passage through 0 °C, high snow cover and the formation of vegetation, severe damage to plants is observed, but this does not lead to their death; also, with low negative temperatures and the absence of snow cover, the death of plants is seen.

Such climatic conditions in the temperate zone are repeated regularly and have recently been exacerbated by climate change due to global warming [18]. Hybrids that have shown severe or even moderate damage in such climatic conditions should not be used in further breeding work. As our research has shown, lavender hybrids vary quite significantly in the degree of damage, which allowed us to identify individual samples that are consistently more resistant to adverse climatic conditions in winter.

Plant biological characteristics play an important role, as the results of the research show significant differences between seedlings in terms of winter hardiness in the dynamics over the years of the study (Figure 7). As a result of cluster analysis of the long-term winter hardiness of seedlings, we identified groups of plants that consistently had the highest resistance to unfavorable conditions: cluster 3 (Figure 7), hybrids 1-8, 3-1, 9-9, 4-5, 4-8 and 5-2. These hybrids, even in the most unfavorable year of 2017, had the least damage at the end of winter compared to the rest. It is recommended to use these hybrids in further breeding work as sources of the complex trait "winter hardiness", since studies have shown that winter-hardy genotypes from the most northern regions (northern border of the cultivation area) transmit this trait to offspring better [41]. Also, hybrids with stable winter hardiness, which does not depend on a set of winter factors, are more important in breeding work due to global climate change, which creates additional risks in plant cultivation [42].

In the future, understanding which biological characteristics of plants are related to high winter hardiness will enable us to select seedlings at the earliest development stages, as happens in the directed selection of more-studied crops.

Some studies show that aromatic plants' essential oils components are involved in some mechanisms that protect against biotic and abiotic factors [19,43], and growing conditions affect the composition of lavender essential oils, which requires additional study in temperate climates [9]. Also morphological and anatomical features are considered as important indicators for cold tolerance studies [44].

5. Conclusions

Temperature fluctuations in winter, frequent temperature transitions over the 0 °C mark, high levels of snow cover and the formation of ice deposits lead to severe damage to some lavender hybrids. Severe frosts in the absence of snow cover can lead to the death of lavender plants in the temperate zone. Information about the reaction of lavender hybrids to various unfavorable winter conditions will make it possible to plan breeding

work in other regions, as well as plan the industrial cultivation of the most winter-hardy hybrids. The lavender hybrids obtained on the basis of free pollination in our collection vary significantly in the degree of stability and damage during the winter period during the years of research. Hybrids that are moderately or severely damaged are eliminated from breeding work. As a result of our research, we have identified groups of the most winter-hardy hybrids, as well as hybrids showing stable winter hardiness regardless of unfavorable winter conditions. These hybrids will be used for further breeding work.

The next stage of our work, studying the winter hardiness of narrow-leaved lavender and breeding to increase winter hardiness, will be to analyze the relationship between morphological, anatomical and phenological parameters of hybrids from clusters selected by us and their winter hardiness.

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References

1. Blankespoor, J. *Lavender's Medicinal and Aromatherapyuses and Lavender Truffles*; Chestnut School of Herbal Medicine: Weaverville, NC, USA, 2012.
2. Mokhtarzadeh, S.; Hajyzadeh, M.; Ahmad, H.; Khawar, K.M. The problems in acclimatisation of in vitro multiplied plants of *Lavandula angustifolia* Miller under field conditions. *Acta Hortic.* **2013**, *988*, 71–76. [CrossRef]
3. Lis-Balchin, M. Lavender. In *Handbook of Herbs and Spices*; Elsevier: Amsterdam, The Netherlands, 2012; pp. 329–347.
4. Adaszyńska, M.; Swarcewicz, M.; Markowska-Szczupak, A. Comparison of the chemical composition and antimicrobial activity of essential oil obtained from various domestic varieties of narrow-leaved lavender (*Lavandula angustifolia* L.). *Postępy Fitoter.* **2013**, *2*, 90–96.
5. Bejar, E. Adulteration of english lavender (*Lavandula angustifolia*) essential oil. *J. Pharm. Biomed. Anal.* **2020**, *199*, 114050.
6. Détár, E.; Németh, É.Z.; Gosztola, B.; Demján, I.; Pluhár, Z. Effects of variety and growth year on the essential oil properties of lavender (*Lavandula angustifolia* Mill.) and lavandin (*Lavandula x intermedia* Emeric ex Loisel.). *Biochem. Syst. Ecol.* **2020**, *90*, 104020. [CrossRef]
7. Gallotte, P.; Fremondière, G.; Gallois, P.; Bernier, J.-P.B.; Buchwalder, A.; Walton, A.; Piasentin, J.; Fopa-Fomeju, B. Lavandula angustifolia Mill. and *Lavandula* x *Intermedia* Emeric Ex Loisel: Lavender and Lavandin. In *Medicinal, Aromatic and Stimulant Plants*; Novak, J., Blüthner, W.-D., Eds.; Handbook of Plant Breeding; Springer International Publishing: Cham, Switzerland, 2020; pp. 303–311. ISBN 978-3-030-38792-1.
8. Pokajewicz, K.; Białoń, M.; Svydenko, L.; Fedin, R.; Hudz, N. Chemical Composition of the Essential Oil of the New Cultivars of *Lavandula angustifolia* Mill Bred in Ukraine. *Molecules* **2021**, *26*, 5681. [CrossRef]
9. Miastkowska, M.; Kantyka, T.; Bielecka, E.; Kałucka, U.; Kamińska, M.; Kucharska, M.; Kilanowicz, A.; Cudzik, D.; Cudzik, K. Enhanced Biological Activity of a Novel Preparation of *Lavandula angustifolia* Essential Oil. *Molecules* **2021**, *26*, 2458. [CrossRef]
10. Giray, F.H. An Analysis of World Lavender Oil Markets and Lessons for Turkey. *J. Essent. Oil Bear. Plants* **2018**, *21*, 1612–1623. [CrossRef]

11. Ciesielska, K.; Ciesielski, W.; Girek, T.; Kołoczek, H.; Oszczęda, Z.; Tomasik, P. Reaction of *Lavandula angustifolia* Mill. to Water Treated with Low-Temperature, Low-Pressure Glow Plasma of Low Frequency. *Water* **2020**, *12*, 3168. [CrossRef]
12. Lis-Balchin, M.; Hart, S. Studies on the mode of action of the essential oil of Lavender (*Lavandula angustifolia* P. Miller). *Phytother. Res.* **1999**, *13*, 540–542. [CrossRef]
13. Dezici, S. Promising anticancer activity of lavender (*Lavandula angustifolia* Mill.) essential oil through induction of both apoptosis and necrosis. *Ann. Phytomed.* **2018**, *7*, 38–45.
14. Cavanagh, H.M.A.; Wilkinson, J. Biological activities of lavender essential oil. *Phytother. Res.* **2002**, *16*, 301–308. [CrossRef] [PubMed]
15. Kasper, S.; Gastpar, M.; Müller, W.E.; Volz, H.P.; Möller, H.J.; Dienel, A.; Schläfke, S. Silexan, an orally administered Lavandula oil preparation, is effective in the treatment of 'subsyndromal' anxiety disorder: A randomized, double-blind, placebo controlled trial. *Int. Clin. Psychopharm.* **2010**, *25*, 277–287. [CrossRef]
16. Rastogi, S.; Shah, S.; Kumar, R.; Vashisth, D.; Akhtar, M.Q.; Kumar, A.; Dwivedi, U.N.; Shasany, A.K. Ocimum metabolomics in response to abiotic stresses: Cold, flood, drought and salinity. *PLoS ONE* **2019**, *14*, e0210903. [CrossRef] [PubMed]
17. Manukyan, A. Effects of PAR and UV-B radiation on herbal yield, bioactive compounds and their antioxidant capacity of some medicinal plants under controlled environmental conditions. *Photochem. Photobiol.* **2013**, *89*, 406–414. [CrossRef] [PubMed]
18. Mansinhos, I.; Gonçalves, S.; Romano, A. How climate change-related abiotic factors affect the production of industrial valuable compounds in Lamiaceae plant species: A review. *Front. Plant Sci.* **2024**, *15*, 1370810. [CrossRef] [PubMed]
19. Crișan, I.; Ona, A.; Vârban, D.; Muntean, L.; Vârban, R.; Stoie, A.; Mihăiescu, T.; Morea, A. Current Trends for Lavender (*Lavandula angustifolia* Mill.) Crops and Products with Emphasis on Essential Oil Quality. *Plants* **2023**, *12*, 357. [CrossRef]
20. Bagget, N. *The Art of Cooking with Lavender*; Kitchenslane Productions: Columbia, MD, USA, 2016.
21. Lis-Balchin, M. *Lavender: The Genus Lavandula*; CRC Press: Boca Raton, FL, USA, 2003.
22. Mason, J. *Growing and Knowing Lavender*; ACS Distance Education: Nerang, QLD, Australia, 2014; ISBN 978-0-9925878-0-2.
23. Demasi, S.; Caser, M.; Lonati, M.; Gaino, W.; Scariot, V. Ornamental traits of *Lavandula angustifolia* Mill. are affected by geographical origin and cultivation substrate composition. *Acta Hortic.* **2021**, *1331*, 49–56. [CrossRef]
24. Urwin, N. Lavender Breeding for Commercial Yield. *Comb. Proc. Int. Plant Propagator Soc.* **2008**, *58*, 78–84.
25. Van Oost, E.; Leus, L.; De Rybel, B.; Van Laere, K. Determination of Genetic Distance, Genome Size and Chromosome Numbers to Support Breeding in Ornamental Lavandula Species. *Agronomy* **2021**, *11*, 2173. [CrossRef]
26. Szekely-Varga, Z.; González-Orenga, S.; Cantor, M.; Jucan, D.; Boscaiu, M.; Vicente, O. Effects of Drought and Salinity on Two Commercial Varieties of *Lavandula angustifolia* Mill. *Plants* **2020**, *9*, 637. [CrossRef]
27. Kremenchuk, P.I.; Kitaev, O.I. Estimation of lavender (*Lavandula angustifolia*) frost resistance. *Plant Var. Stud. Prot.* **2013**, *13*, 155–161. [CrossRef]
28. Zheljazkov, V.; Astatkie, T.; Hristov, A. Lavender and hyssop productivity, oil content, and bioactivity as a function of harvest time and drying. *Ind. Crop. Prod.* **2012**, *36*, 222–228. [CrossRef]
29. Stanev, S.; Zagorcheva, T.; Atanassov, I. Lavender cultivation in Bulgaria—21st century developments, breeding challenges and opportunities. *Bulg. J. Agric. Sci.* **2016**, *22*, 584–590.
30. Verlet, N. The world herbs and essential oils economy-analysis of a medium term development. *Acta Hortic.* **1992**, *306*, 474–481. [CrossRef]
31. Tudrij, V.D.; Ismagilov, N.V. *Metody i Sredstva Gidrometeorologicheskih Izmerenij*; Kazanskij Universitet: Kazan', Russia, 2011; p. 296. (In Russian)
32. Isachkin, A.V.; Kryuchkova, V.A. Algoritmy opredeleniya dostatochnyh ob"emov vyborok (na primere sadovyh rastenij). *Byulleten' Gl. Bot. Sada Bul. MBS RAS* **2020**, *4*, 68–78. (In Russian)
33. Isachkin, A.V. *Osnovy Nauchnyh Issledovanij v Sadovodstve: Uchebnik Dlya Bakalavrov i Magistrov po Napravleniyu «Sadovodstvo»*; Isachkin, A.V., Kryuchkova, V.A., Eds.; Izdatel'stvo "Lan": Moskva, Russisa, 2019; (In Russian). ISBN 978-5-8114-5019-0.
34. Colțun, M. Step-by-Step Creation of a Lavender Plantation. *J. Bot.* **2016**, *8*, 76–80.
35. Kovaleski, A.P. Woody species do not differ in dormancy progression: Differences in time to budbreak due to forcing and cold hardiness. *Proc. Natl. Acad. Sci. USA* **2022**, *119*, e2112250119. [CrossRef]
36. Nole, A.; Rita, A.; Ferrara, A.M.S.; Borghetti, M. Effects of a large-scale late spring frost on a beech (*Fagus sylvatica* L.) dominated Mediterranean mountain forest derived from the spatio-temporal variations of NDVI. *Ann. For. Sci.* **2018**, *75*, 83. [CrossRef]
37. Niu, R.; Zhao, X.; Wang, C.; Wang, F. Physiochemical Responses and Ecological Adaptations of Peach to Low-Temperature Stress: Assessing the Cold Resistance of Local Peach Varieties from Gansu, China. *Plants* **2023**, *12*, 4183. [CrossRef]
38. Lianopoulou, V.; Bosabalidis, A.M.; Patakas, A.; Lazari, D.; Panteris, E. Effects of chilling stress on leaf morphology, anatomy, ultrastructure, gas exchange, and essential oils in the seasonally dimorphic plant *Teucrium polium* (Lamiaceae). *Acta Physiol. Plant* **2014**, *36*, 2271–2281. [CrossRef]
39. Vitasse, Y.; Lenz, A.; Körner, C. The interaction between freezing tolerance and phenology in temperate deciduous trees. *Front. Plant Sci.* **2014**, *5*, 541. [CrossRef] [PubMed]

40. Guo, X.; Khare, S.; Silvestro, R.; Huang, J.; Sylvain, J.D.; Delagrange, S.; Rossi, S. Minimum spring temperatures at the provenance origin drive leaf phenology in sugar maple populations. *Tree Physiol.* **2020**, *40*, 1639–1647. [CrossRef] [PubMed]
41. Butnor, J.R.; Wilson, C.P.; Bakır, M.; D'Amato, A.W.; Flower, C.E.; Hansen, C.F.; Keller, S.R.; Knight, K.S.; Murakami, P.F. Cold Tolerance Assay Reveals Evidence of Climate Adaptation Among American Elm (*Ulmus americana* L.) Genotypes. *Forests* **2024**, *15*, 1843. [CrossRef]
42. Li, X.; Liu, Y.; Yang, S.; Wang, J.; Xia, H.; Liu, X.; Chen, Q. Invisible Frost Stress on Introduced Dalbergia odorifera: A Bioassay on Foliar Parameters in Seedlings from Six Provenances. *Sustainability* **2023**, *15*, 14097. [CrossRef]
43. Demasi, S.; Caser, M.; Lonati, M.; Cioni, P.L.; Pistelli, L.; Najar, B.; Scariot, V. Latitude and Altitude Influence Secondary Metabolite Production in Peripheral Alpine Populations of the Mediterranean Species *Lavandula angustifolia* Mill. *Front. Plant Sci.* **2018**, *9*, 1–12. [CrossRef]
44. Wisniewski, M.; Fuller, M.; Glenn, D.; Gusta, L.; Duman, J.; Griffith, M. Extrinsic ice nucleation in plants: What are the factors and can they be manipulated. In *Plant Cold Hardiness: Gene Regulation and Genetic Engineering*; Kluwer Academic/Plenum Publishing: New York, NY, USA, 2002.

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