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Tolerance of hazelnuts towards unfavorable environmental factors

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We performed a comprehensive analysis of the bioecological characteristics of growing *Corylus* spp., among them number of native, introduced, and newly created by us hazelnut varieties in the conditions of the Forest-Steppe Zone of Ukraine. The majority of Ukrainian breeding varieties (in particular, "Dar Pavlenka", "Shedevr", "Dohidny", "Lozivskyi Bulavovydnyi") demonsrated strong tolerance towards the air temperature ocillations during the vegetation period. We separated thd varieties of hazelnuts, which were frost-resistant during the entire cold period within the year. Comprehensive evaluation of their winter- and frost-resistance confirmed their sufficient adaptability to the conditions of the studied horticultural area. The newly created hazelnut varieties "Sofiyevskiy 1" and "Sofiyevskiy 15" turned out to be the best concerning their winter hardiness potential. We also found that, with a water deficit, the content of total water in the leaves of hazelnut varieties "Sofiyivsky 15", "Ukraina-50", and "Trapezund" was 56.9–57.8% in August. The least amount of total water was registered in "Cherkeskyi-2" leaves (54.2 %). We established, that the minimum moisture deficit was typical for the varieties "Ukraina-50" and "Trapezund" and made 5.1 and 6.4% to the raw mass of leaves in the hottest period of studies, while for the varieties "Sofiyivsky 15" and "Cherkeskyi-2", these values exceeded 9.0 and 12.5%. Thus, the analysis of the water regime of the leaves of the studied varieties of hazelnut in terms of total water content, water deficit, relative turgorescence, intensity of loss and the percentage of moisture recovery indicated a high level of drought adaptation in "Ukraine-50" and "Trapezund" hazelnut varieties. We suggested that the deterioration of the light regime negatively affected the growth processes of all the studied varieties of hazelnut. In the conditions of insufficient illumination, the hazelnut plants did not die but significantly retarded in size and number of lateral shoots and leaves as compared with plants grew in a well-lit plot. As a result of the research, we created a number of new varieties of hazelnuts, namely "Sofiyivsky 1" and "Sofiyivsky 15". These carieties combined enhanced tolerance to the abiotic factors with high productivity and fruit quality. We also applied for registration of "Sofiyivsky 1" and "Sofiyivsky 15" in the Ukrainian Institute for Plant Variety Examination for State Scientific and Technical Expertise in Ukraine.

Key words: Agro-climatic conditions; Forest-steppe zone; Ukraine; Variety; Drought tolerance; Total water content; Leaves water regime; Winter and frost resistance

Introduction

The genus *Corylus* L. (hazel) belongs to the family Betulaceae S. F. Gray, subfamily Coryloideae (Takhtajan, 2009). In due time, some authors, by morphological features, distinguished genera of the subfamily Coryloideae into the separate family Corylaceae Mirb. with four genera and 50 species (Hutchinson, 1967; Mosyakin & Fedoronchuk, 1999). We previously supported such a system in relation to the placement of the genus Corylus in higher taxa too. However, after the publication of a thorough monograph (Reveal & Chase, 2011), dedicated to the ordering of botanical names and synonyms of orders and families of Magnoliidae, in which scientists from Cornell University (USA) and the Royal Botanic Gardens, Kew (United Kingdom) give the name Corylaceae as one of the unadmitted synonyms Betulaceae, we agreed with these nomenclatural innovations (Kosenko, 2015).

The current area of the genus *Corylus* covers North America (approximately from 20th to 50th parallel north), almost the whole Europe, except its northeastern part (60th parallel north), Asia Minor, Iran, Afghanistan, the Himalayas, and southeastern part of East Asia. In addition, hazel is found on Taiwan, where its local species *C. formosana* Hayata grows currently. However, modern botanists consider the status of the name *C. formosana* rather questionable (*Corylus formosana*…, 2018; Kosenko et al., 2008).

The hazel (*Corylus* spp.) also known as filbert, was domesticated in Turkey (Anatolia) more than 2 thousand years ago. Now, the hazelnut culture in this country has received great development, hazelnut production area is 705 thousand hectares, and the welfare of almost 250 thousand Turkish families is based on its cultivation (İslam, 2018). In addition, the production, processing, and export of hazelnuts provide about 8 million employments (Kosenko et al., 2017). Turkey has been the world market leader of hazelnuts for over 600 years (Ciemniewska-Żytkiewicz et al., 2015).

From the Black Sea coast of Turkey, hazelnut culture quickly spread throughout Europe and in the second half of the 19th century- in the USA and Canada (Enescu et al., 2016). Our long-term studies have shown that the natural conditions of all the agro-climatic regions of Ukraine are quite satisfactory in meeting the needs of hazelnuts in temperature conditions and the duration of the photoperiod (Kosenko, 2015; Kosenko et al., 2008, 2016, 2017, 2019; Kulbida et al., 2013). In addition, hazelnut as a cultivated nut-bearing plant is distinguished by sufficient plasticity, which made it possible to grow it in more northern horticultural zones. At the same time, the active promotion of the hazelnut varieties further northward requires greater winter- and frost-resistance of this crop. In the conditions of Ukraine, the cold season of the year is characterized by a instable temperature regime (Kulbida et al., 2013; Makhno, 2014). Hazelnut as a subtropical culture is characterized by a very short period of organic dormancy, especially with respect to male inflorescences. Wintering conditions characterized by frequent thaws with subsequent frosts provoke hazelnut plants to an early exit from dormancy with a significant loss of frost resistance (Kosenko et al., 2008). Therefore, the suitability of hazelnut varieties for industrial cultivation in a certain horticultural zone of Ukraine requires the most accurate evaluation of the potential of their winter and frost resistance. Improvement of winter hardiness, and especially resistance to frosts, is an important line of selection also for regions with more favorable wintering conditions (Gökirmak et al., 2009).

In addition to the dependence of hazelnut varieties on the temperature factor and the level of water supply, other abiotic environmental factors play an important role in their vital activity processes. Including such a physical factor as the level of illumination, since the main process that affects the formation of the entire biological mass of the fruit tree, including the economically useful part of the crop, is photosynthesis (Alasalvar et al., 2006). For its optimal passage, a regular supply of solar energy is needed (Amaral et al., 2005).

Methods

The study of the adaptive properties of representatives of the *Corylus* spp. collection, as well as a number of native, introduced and newly created by us hazelnut varieties, was carried out stepwise based on long-term phenological data using quantitative analysis methods and empirical information. The frost and drought resistance of the hazelnut plant material was additionally investigated under laboratory conditions. Frost resistance and winter hardiness of the studied hazelnut varieties were evaluated during 2015-2016 on plants grown in the collection garden of the National Dendrological Park "Sofiyivka" of the National Academy of Science of Ukraine, according to generally accepted methods and recommendations (Kondratenko & Bublyk, 1996; Tkachyk, 2014). An 8-point scale of frosting (Sokolov, 1957) rated the actual (field) winter-hardiness. Evaluation of potential frost resistance was performed by laboratory method of direct freezing in thermostatic chamber by microscopic analysis of the tissue damage pattern by the method of N. A. Solov'eva (Соловьёва, 1967) as modified by V. V. Grokholsky and M. O. Bublyk (Bublyk et al., 2013) on tissue browning intensity. Therefore, in the winter periods of 2014–2015 and 2015–2016, freezing of one-year growths, anthers and buds was carried out at temperatures of –25, –30, and –35°C. In the control variants, one-year growths, anthers and buds of plants of the “Lozivskyi Sharovydnyi” variety were frozen.

The actual drought tolerance was evaluated in two ways: on a 6-point scale (Pyatnitsky, 1961) and on a 9-point scale of drought tolerance by V. M. Mezhenskyj (Mezhenskyj, 2007). For the study of drought, tolerance also used a laboratory-field method (Kushnirenko et al., 1975. We studied the water content of tissues, water deficit of leaves, water-retention capacity (weight method).

In the process of studying the effect of lighting on the growth of hazelnut seedlings, two variants of experience were laid, for each of which 1000 seeds of the model variety “Dar Pavlenka” were taken. In the experiment, the nuts were sown in optimal time with the appropriate preparation — in the first decade of September with a husk according to the following scheme: the first variant was a plot with 100% illumination ($50.3 \cdot 10^3$ Lux); the second variant — a plot with poor illumination ($5.1 \cdot 10^3$ Lux). The period from sowing to the appearance of the first shoots in both variants was about 210 days. The light intensity on dimly lit areas and on the open plot was tested on clear sunny days of the second ten-day period of July with the MS 6610 Lux Meter.

For a statistical analysis of the experimental data obtained, the *t*-test was used (Fisher, 2006). The calculations of the least significant difference (LSD) were performed using Microsoft Excel (Millar, 2001).

Results

The meteorological conditions during May-September 2015, when the average monthly air temperature exceeded the average long-term indicators by 1.0°C-4.1°C, were unfavorable for the formation of winter hardiness. Such a thermal anomaly caused a delay in the end of the cambium activity and the process of full differentiation of the wood cells, the achievement of an appropriate degree of lignification of the shoots and the termination of the autumn vegetation.

Hot summer and high autumn air temperatures also caused the inhibition of the formation of covering tissues on one-year shoots and the lignification of cell membranes of the bark parenchyma, wood, perimedular zone etc. Lignification of tissues prevents damage to the microfibrils of the entire matrix, and strengthens the cell walls, thereby increasing plant resistance to unfavorable environmental conditions, in particular, wintering. Therefore, the delay in lignification of shoots is considered a characteristic indication of deterioration of wood ripening and, consequently, a decrease in winter hardiness (Peng et al., 1996; Sherman & Beckman, 2002). For these reasons, in the autumn of 2015, the plants of the studied varieties of hazelnut entered the phase of autumn-winter dormancy with a delay. However, despite the unfavorable conditions for the formation of winter-hardiness, the total score of the frost damage to hazelnut plants in the natural conditions of wintering 2015–2016 did not exceed 20 points (Table 1). It should be noted that although the plants of the control variety ("Lozivskyi Sharovydnyi") compared to the other varieties were damaged most of all in the experiment, however, the total score of 17.1 obtained by them evidences that the frost resistance of this variety is sufficient for the conditions of Ukraine. The most durable plants were "Dar Pavlenka" with a total frost damage score of 3.7. To the first group of the most winter-hardy varieties in the conditions of natural wintering 2015–2016 in addition to "Dar Pavlenka", "Sofiyivsky 1", "Cherkeskyi-2" and "Futkurami" were included, whose total frost damage score was within 9.4–10.0 points.

Table 1. Frost damages of one-year growths, anthers and buds of hazelnut varieties in natural conditions of wintering 2015–2016 (points)

Variety	Anthers	The total score of damage to the tissues and buds of one-year growth				
		apex of the growth	middle of the growth	bud tissues	node with a bud	total
"Lozivskyi Sharovydnyi" (control variant)	0	6.0	4.7	2.8	6.4	17.1
"Cherkeskyi-2"	0	3.1	2.6	3.0	3.7	9.4
"Dar Pavlenka"	0.3	0.9	1.0	1.2	1.8	3.7
"Futkurami"	0	3.1	2.5	2.3	4.1	9.7
"Halle"	0	3.9	3.9	1.9	4.6	12.4
"Shedevr"	1.3	3.5	2.8	2.3	4.1	10.4
"Sofiyivsky 1"	0	3.1	3.1	1.7	3.8	10.0
"Sofiyivsky 15"	0	4.5	3.1	1.9	5.1	12.7
"Trapezund"	3.0	3.4	4.5	2.8	6.2	14.1
"Ukraina-50"	0	4.1	3.1	1.9	4.7	11.9
LSD_{05}	*	0.1	0.1	0.1	0.2	0.3

* LSD_{05} was not calculated

The degree of frost damage to the bark, wood, core of one-year growths of the variety "Lozivskyi Sharovydnyi" did not exceed two points, and the buds of its one-year shoots froze in the conditions of the natural wintering in the garden by 2.8 points, which corresponds to the average degree of freezing. The degree of frost damage to the buds of the rest varieties ranged from 1.2 ("Dar Pavlenka") to 3.0 ("Cherkeskyii-2") points. Less than 2.0 points were damaged buds of the created by us new varieties "Sofiyivsky 1" (1.7 points) and "Sofiyivsky 15" (1.9 points). Despite the fact that the field method of evaluation winter resistance gives reliable and objective results, its application requires many years of laborious observations.

This is mainly because of the extreme variability of meteorological conditions of frost resistance formation in the months preceding wintering and the conditions of properly wintering in different years, this method is difficult to ensure the necessary reproducibility of results (Kukharska, 2014; Kulbida et al., 2013) whereas the laboratory method of artificially creating low temperatures makes it possible to estimate the potential frost resistance under laboratory conditions. It allows selecting the required temperature regime to evaluate the stability of objects, to simulate the effects of low and variable temperatures inherent in the area under study (Kukharska, 2014). With direct freezing of one-year growths of hazelnut plants of the studied varieties at a temperature of –25°C, the plants of the varieties "Trapezund" and "Lozivskyi Sharovydnyi" suffered the greatest damage. The total score of freezing of tissues and organs of these varieties was 19.7 and 18.8, respectively, which corresponds to a low degree of freezing, which does not pose a significant danger to hazelnut plants to restore their vegetation after wintering and subsequent active growth and development. According to the data of artificial freezing at the temperature of –25°C, the total score of damage to tissues and organs of the experimental variants was within 10.5–19.7, that is, all the plants of the experiment were frost-resistant. In terms of varieties, the studied variants of hazelnut were distributed as follows (in the direction of increasing the freezing effect): 'Trapezund' (total damage score 19.7), 'Lozivskyi Sharovydnyi' (18.8), 'Halle' (16.5), 'Ukraina-50' (15.9), 'Sofiyivsky 15' (15.4), 'Shedevr' (15.1), 'Cherkeskyi-2' and 'Futkurami' (15.0 points each), 'Sofiyivsky 1' (11.3), 'Dar Pavlenka' (10.5).

Laboratory freezing of one-year growths, anthers and buds of hazelnut plants at a temperature of –30°C showed even more clearly the differences in frost resistance of the studied varieties. Thus, the total damage score of one-year growths of the varieties "Sofiyivsky 1" and "Dar Pavlenka" plants was in the range of 13.9–18.8 points. The plants of the other varieties of experience when freezing in the mode of –30°C were characterized by average degrees of freezing. In the conditions of Ukraine, a decrease in temperature to -35°C is registered extremely rarely (Kulbida et al., 2013). However, the evaluation of the biological capabilities of the studied hazelnut plants with such temperature effects allows us to predict the behavior of promising varieties when growing them outside the Forest-Steppe Zone in more northern regions. The freezing of the tissues and organs of the studied varieties of hazelnut after artificial freezing of –35°C was predominantly medium and weak. The plants of the varieties "Trapezund" and "Futkurami" suffered the greatest damage. The total score of freezing of plants in these variants was 31.0 and 30.5 respectively (Table 2). Most of the variants of the experiment at the freezing temperature of –35°C were characterized by an average degree of the damage. Hazelnut plants "Dar Pavlenka" differed with high frost resistance. The resistance of the "Sofiyivsky 1", "Halle" and "Sofiyivsky 15" varieties was close to the frost resistance of "Dar Pavlenka". According to the meteorological station "Uman" in some years there were periods of drought, especially in the summer of 2007, 2009 and 2012. This was despite the fact that in the Forest-Steppe Zone of Ukraine, drought is not a limiting factor affecting the development of most introduced arborescent plants, and the territory of the National Dendrological Park "Sofiyivka" NAS of Ukraine is situated within the moderate-continental climate area with an average multi-year temperature of +7.4°C. In the same years, the average annual temperature was respectively +10.0, +9.2, and +9.1°C.

Table 2. Frost damages of one-year growths, anthers and buds of hazelnut varieties after artificial freezing at –35°C in 2015–2016 (points).

Variety	Anthers	The total score of damage to the tissues and buds of one-year growth				
		apex of the growth	middle of the growth	bud tissues	node with a bud	total
"Lozivskyi Sharovydnyi" (control variant)	0	9.3	7.6	4.3	11.0	27.9
"Cherkeskyi-2"	0	9.9	7.1	4.1	10.1	27.1
"Dar Pavlenka"	0	5.8	5.7	3.7	7.0	18.5
"Futkurami"	0	10.4	8.2	4.3	11.9	30.5
"Halle"	0	8.2	7.5	3.5	7.9	23.6
"Shedevr"	5.0	9.1	8.4	5.0	11.1	28.6
"Sofiyivsky 1"	0	7.5	6.5	3.0	7.9	21.9
"Sofiyivsky 15"	0	9.5	6.6	3.7	8.8	24.9
"Trapezund"	0	10.9	8.0	4.5	12.1	31.0
"Ukraina-50"	0	10.2	7.9	3.8	9.4	27.5
LSD_{05}	*	0.2	0.1	0.1	0.2	0.4

* LSD_{05} was not calculated

To estimate the potential capability of hazelnut varieties for resistance to dry conditions, studies were conducted on the total water content in the leaves, water deficit, relative turgorescence, water-retention and water-renovating ability of the leaves, which were important in resisting plants to an increase in environmental temperature and in the reaction of plants to moisture deficit. It was found that the maximum difference in drought resistance between varieties was observed in conditions of insufficient humidity (in August) and was practically absent in May, when there was a sufficient amount of moisture in the soil after snow melting. Therefore, the studies of the drought resistance of the taken varieties of hazelnut were carried out three times during the period of vegetation — in the second ten-day periods of June, July and August 2015–2016. As a result of the studies of the water regime of four model varieties of hazelnut, it was found that with water deficit, the total water content in the leaves of the varieties "Sofiyivsky 15", "Ukraina-50", "Trapezund" and "Cherkeskyi-2" was relatively stable and amounted to 54.2–58.9 % (Table 3).

Table 3. The total water content in the leaves of hazelnut varieties in 2015–2016 (%).

Variety	Month		
	June	July	August
"Cherkeskyi-2'	55.3	54.8	54.2
'Sofiyivsky 15'	58.9	58.2	57.8
'Trapezund'	57.6	57.2	56.9
'Ukraina-50'	58.4	57.7	57.2
LSD_{05}	4.6	5.2	4.1

At the same time, the relative turgorescence of the leaves of "Ukraina-50" was 87.6–88.6%, while in the other studied varieties it was within 92.4–95.5% (Table 4).

Table 4. The relative turgorescence of the leaves of hazelnut varieties in 2015–2016 (%).

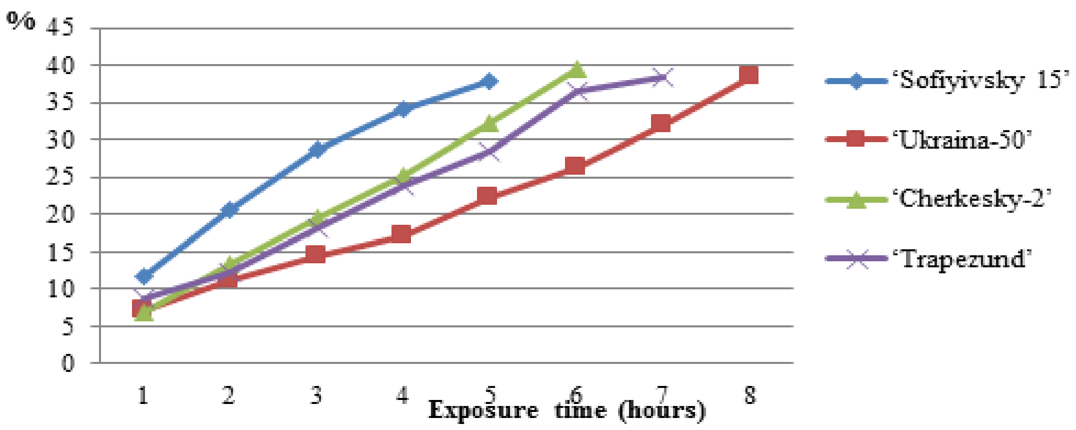
Variety	Month		
	June	July	August
"Cherkeskyi-2"	94.8	95.7	95.5
"Sofiyivsky 15"	92.4	93.2	93.8
"Trapezund"	93.2	94.1	93.4
"Ukraina-50"	88.3	87.6	88.7
LSD 05	6.2	7.5	4.9

The minimum moisture deficit was characteristic for the leaves of the varieties "Ukraine-50" and "Trapezund", and in the hot months it was 5.1% and 6.4% of the raw mass of the leaves, whereas for the varieties "Sofiyivsky 15" and "Cherkeskyii-2" these values were 9.0 and 12.5% respectively (Table 5). In the selection of forms and varieties for breeding and industrial plantings, genotypes selected according to a preliminary estimation of water-retention capacity are of special interest. Water-retention capacity is the ability of a plant to retain the bound water that remains after dehydration and the loss of free water from cells. The water-retention capacity of various plant organs shows their adaptability to unfavorable environmental conditions. The more time it takes to dehydrate the leaves to the level of 30–35% of moisture from the initial mass of these leaves, the more deeply bound water they contain. This indicates the potential ability to endure deep wilting, and the ability to restore turgor of the leaves after such wilting indicates the possibility to renovate physiological processes in the leaf tissues without significant changes.

Table 5. The water deficit of the leaves of hazelnut varieties in 2015–2016 (%).

Variety	Month		
	June	July	August
"Cherkeskyi-2"	9.9	10.3	12.5
"Sofiyivsky 15"	6.2	6.5	9.0
"Trapezund"	3.8	4.4	6.4
"Ukraina-50"	2.8	3.0	5.1
LSD 05	1.6	1.3	0.8

The evaluation of water-retention capacity during wilting revealed differences in this indicator for different varieties of hazelnuts. The process of wilting under laboratory conditions lasted the longest for the drought-resistant variety "Ukraina-50" (eight hours), for the other varieties the duration of leaf dehydration to the level of 30–35% moisture from their initial weight was 5–7 hours (Fig. 1). After 2 hours of dehydration, the loss of water from the leaves of "Ukraina-50" was only 11.1%, while for the variety "Sofiyivsky 15" this figure reached 20.7%. Thus, the leaves of the variety "Sofiyivsky 15" lost the water the fastest, the loss of 38 % of moisture occurred after five hours of wilting already. The leaves of the varieties "Cherkeskyi-2" and "Trapezund" lost more moisture more slowly: 39.6% in six hours and 38.4% in seven hours respectively. The plants "Ukraine-50" were characterized by the maximum ability to retain moisture; the loss of 38.3% of water in the leaves of this variety was observed after eight hours of withering, which indicates a high potential for survival of this variety in conditions of moisture deficiency. In the process of studies to estimate the turgor-renovating ability of the leaves of the model varieties of hazelnut, it was found that the full restoration of turgor in the leaves of all varieties was observed after losing 10% of water, and in the "Trapezund" variety — after losing 10 and 15% of water (Table 6 and Figure 2).



Fiure 1. Dynamics of water loss from leaves of hazelnut varieties (2015–2016).

Table 6. Leaf area of hazelnut varieties with restored turgor depending on the levels of dehydration in 2015–2016 (%).

Variety	Dehydration level (%)						
	10	15	20	25	30	35	40
"Cherkeskyi-2"	100.0	98.5	95.6	85.2	70.1	62.5	56.6
"Sofiyivsky 15"	100.0	98.7	98.2	89.4	56.8	38.6	25.8
"Trapezund"	100.0	100.0	97.4	90.0	75.5	67,2	48.1
"Ukraina-50"	100.0	99.4	98.9	93.0	85.4	45.0	39.2
LSD_{05}	*	5.1	3.1	5.4	7.3	3.9	5.4

* LSD_{05} was not calculated

The rates of turgor restoration by leaves of all the varieties in dehydration variants of 15–20 % were also quite high and amounted to 95.6–100.0 %, which indicates an almost complete restoration of turgor by leaf tissues of the studied varieties after saturation with water. After losing 25% of the water, turgor recovery was observed on 85.2–90.0% of the leaf area with a progressive decrease in restoration rates in variants with more dehydration.

Figure 2. Full recovery of turgor in leaves "Trapezund" hazelnut variety after losing 15% of water (2015–2016).

The leaves of "Cherkeskyi-2" variety were the most resistant to dehydration: after losing 40% of moisture, they restored turgor to 56.6% of the leaf area (Figure 3), while for other varieties this indicator did not exceed 25.8–48.1%

Figure 3. Recovery of turgor in leaves of "Cherkeskyi-2" hazelnut variety after losing 40 % of water (2015–2016).

Evaluation of seed germination and growth and development of plants, depending on the level of illumination, was conducted on the variety "Dar Pavlenka", which was taken as a model object. When sown in close to optimal illumination conditions — $50.3 \cdot 10^3$ Lux, the fulfilment of full germination occurred at the beginning of the second ten-day period of May, while when the illumination was reduced to $5.1 \cdot 10^3$ Lux, the fulfilment of full germination was delayed until the end of the first ten-day period of June (Table 7). That is, the growth and development of hazelnut seedlings are directly dependent on the illumination of the area where they grow.

In addition, the plants in conditions of insufficient illumination significantly retarded in size as well as in number of lateral shoots and leaves, compared with plants that grew in a well-lit plot.

Table 7. The effect of illumination intensity on the germination, growth and development of one-year-old hazelnut seedlings "Dar Pavlenka" (2015–2016).

Index	**Illumination (lx)**	
	$50.3 \cdot 10^3$	$5.1 \cdot 10^3$
Height (cm)	5.12	3.37
Diameter of the root collar (cm)	0.57	0.25
Number of lateral shoots (pieces)	2.21	0
Number of leaves on the leading shoot (pieces)	5.30	1.90
Length of lateral shoots (cm)	0.62	0
Number of leaves on a lateral shoot (pieces)	1.33	0
The height at which branching begins (cm)	3.87	0
Field germination (%)	76.9	64.5

At the same time, in the conditions of light deficiency (illumination of $5.1 \cdot 10^3$ Lux), one-year-old hazelnut seedlings did not form lateral shoots at all.

Discussion

According to the analysis of the results obtained after abnormal wintering of 2015–2016, the studied hazelnut plants in the garden conditions were characterized by relatively high winter hardiness with low and very low levels of frost damage. The buds and anthers, which are most affected by the effects of wintering stress factors, were poorly and moderately damaged. According to the total score of frost damage to the tissues of one-year growths, especially cambium, as well as the frost resistance of the buds and anthers, the hazelnut plants "Dar Pavlenka" were the most resistant to the extremely changeable weather conditions in the winter of 2015–2016. Artificial freezing of the studied varieties at low negative temperatures at –25°C, –30°C, and –35°C provided unambiguous experimental data that fully corresponded to the main law of frost resistance: with increasing pressure of the temperature stress factor, frost damages to all tissues and organs of hazelnuts increased. A comprehensive evaluation of winter and frost resistance of hazelnut plants confirmed the sufficient adaptability of the studied varieties to wintering conditions in the studied horticultural zone. The best in frost resistance and total winter hardiness potential were new varieties "Sofiyivsky 1", "Sofiyivsky 15", which endured unfavorable wintering conditions at a level close to that of the variety most winter-hardy in Ukraine — "Dar Pavlenka". Based on the analysis of the conducted studies of the components of drought tolerance potential, it should be noted that the hazelnut varieties "Ukraina-50" and "Trapezund" are characterized by high potential drought tolerance in accordance with high indicators of the total water content, relative turghorescence and water-retaining capacity of leaves, and also they had the least indices of water deficit. "Cherkeskyi-2" was moderately drought-resistant and was characterized by high relative turghorescence and water-renovating ability, but, moreover, it was characterized by the greatest water deficit. This indicates that "Cherkeskyi-2" needs to be watered obligatorily during dry periods. The "Sofiyivsky 15" variety was the least drought-resistant, characterized by low water- retaining and water- renovating abilities, as well as a relatively high water deficit, that is, during the drought period, this variety needs regular watering for normal growth and development of all plant organs. We provided the analysis of the water regime of the leaves of the studied varieties of hazelnut in terms of total water content, water deficit and relative turgorescence and the intensity of loss and the percentage of moisture recovery. The results gives us the reason for conclusion of the total high level of adaptation of plants of all studied varieties to the dry periods in the Forest-Steppe Zone of Ukraine.

Conclusion

It was found that the plants of the studied varieties of hazelnuts in the conditions of insufficient illumination significantly retarded in size and number of lateral shoots and leaves as compared with plants grew in a well-lit plot. Some hazelnut varieties were created, the best of which — "Sofiyivsky 1" and "Sofiyivsky 15", combining tolerance to the abiotic factors with productivity and quality of fruits (Kosenko et al., 2017; 2019) were presented to the Ukrainian Institute for Plant Variety Examination for state scientific and technical expertise for the purpose of registration and distribution in Ukraine (Topchii et al., 2018).

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