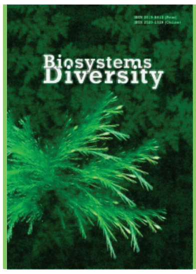

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Diversity of hazelnut varieties and changes in plant development during introduction in the semi-arid zone

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Global climate change provide the emergence of new opportunities for the introduction of new crops into horticultural production in the areas of insufficient precipitation. In addition to the economic aspect, it is also of interest to the biologists of the development of this plant in a qualitatively new environment.The paper considers the variability of the main traits of plant morphometry, yield for four varieties of hazelnuts in order to identify the most promising forms for cultivating in the northern part of the Steppe of Ukraine characterized by an insufficient precipitation and harsh winters. Recent milder winter conditions and a certain balance in summer droughts have made the required horticultural production possible, thereby increasing the production of hazelnuts and addressing the dietary problems of people in terms of supply of necessary vitamins and micronutrient element from hazelnuts. Promising varieties for the production plantations have been specified, the mechanisms for the yield formation have been studied. Key traits of morphometry have been identified that condition the success of a variety under insufficient humidity. These were such traits as crown volume, leaf surface area, shell thickness, average weight of one nut, weight of dry nuts, yield, kernel yield. It has been established that the yield formation on account of large, well-shaped nuts is best in terms of yield. Some aspects of yield formation and the possibility of combining different varieties, especially when more intensive growing methods are applied, are of additional interest. High variability significantly prevents the modeling of traits, for example, such as yield per tree, from being significant in terms of the formation of high yield. Semi-intensive pruning of hazelnut bushes shows its suitability for use in modern garden plantings. Variety Barselonskiy showed extremely high variability for many key parameters, which may indicate insufficient stability of this variety from a genetic point of view and the presence of a fairly significant number of hidden biotypes, which is additionally negative for cultivation in modern semi-intensive and intensive technologies. Climate change makes it possible to continue to significantly expand the area under hazelnuts due to the previously considered unfavourable southern subzones of the Forest-Steppe and the Steppe zone of Ukraine. Such new and previously unnoticed effects have been noted as fruiting in the first year in production crops, the formation of up to 5–6 inflorescences for each nut-bearing branch in the second or third year. For further investigations, it is planned to analyze the nutritional qualities of the obtained products, in terms of the composition by microelements and the presence of biologically-active substances, to trace the dynamics of the accumulation of heavy metals and the potentially associated risks.

Keywords: hazelnut; zone of insufficient moisture; productivity; morphometry; introduction; yield structure.

Introduction

A worldwide trend is the rapid growth of hazelnut cultivation areas. Thus, between 2013 and 2020, the total area of hazelnut plantations worldwide increased by 60%. In recent years, the number of people who consume hazelnuts more or less regularly (mainly in the form of confectionery) has risen rapidly from 200 million to 1 billion, according to FAO. FAO forecasts a doubling of the modern cultivation areas for this nut crop by 2035, as well as an increase in the number of consumers on a regular basis to 2 billion, with a significant increase in the number of people who use hazelnuts in their diet as a food additive, a source of valuable food elements, rather than consuming confectionery products. This trend is more characteristic of the North American and Western European countries (Campa Negrillo et al., 2021; Jenderek et al., 2022; Horshchar & Nazarenko, 2022c).

Very often, the introduction of new crops and the use of biodiversity also lead to new observations and qualitative changes in the biology of plant development (Chernysky & Gumentyk, 2020; Beiko & Nazarenko, 2022a). The new ecological environment is able to quite significantly change the already established ideas about stages in plant ontogenesis and give new pecularities at plant development, sometimes even positive (Lykhovyd, 2021; Nazarenko et al., 2022).

The significance of exports of this crop is increasing (against the background of rapid growth in cultivation and yield) for such economically growing countries as Turkey (the leading country in terms of cultivating areas), Azerbaijan, and Georgia. TOP 5 hazelnut-growing countries include the USA and Italy. The area of hazelnut plantations in Ukraine is about 1,000 hectares, and it has been constantly expanding in recent years (taking into account high-level exportability), but the domestic needs are met at the level of 10–15%. Hazelnuts are mainly imported (Nera et al., 2020; Wani et al., 2020; Di Lena et al., 2022).

At this time, the total area of hazelnut plantations in Ukraine is 1,039 hectares. The total volume of nuts produced is around 2,500–3,000 tons, mainly for export (10–15% at most is for domestic consumption). Mostly to meet domestic needs, hazelnuts are imported as commodity products (the main countries of origin are Turkey, Azerbaijan, and Italy) (Campa Negrillo et al., 2021; Mehlenbacher & Molnar, 2021). The volume of production is characterized by a slow growth. Despite the strategic plans for the development of nut farming in Ukraine and the high profitability of this nut crop, the growth rates are very low. Most hazelnut plantations are located in the Polissia, Forest-Steppe areas, and the key problem of these regions is that lighting is critical for hazelnuts. However, modern varieties of hazelnuts allow the area of cultivation of this crop to be significantly expanded into the area with insufficient precipitation and allow the introduction of hazelnut plantations within the Ukrainian Steppe, which is of great importance in the framework of our project in the Northern Steppe. Conditions here are characterized by both favourable factors (light) and unfavourable ones (moisture, winter), but recently, under climate change, the effect of adverse factors has been significantly mitigated – the rate of precipitation has increased, the period of temperatures below 0 has become significantly shorter, and the frost-free periods have become more frequent (Nazarenko et al., 2019a, 2019b). The climate change has already resulted in the migration of promising crops to the south, to semi-arid regions, which are used quite slowly and to a limited extent in our agriculture (Rapiti, 2021). The total hazelnut production volumes are 600–700 thousand tons worldwide, depending on the conditions of the year. Over the last decade (2010–2020), the production of hazelnuts increased by 40–50% (for Ukraine by 4–5%), and the price of nuts rose by 45% (for the domestic market of Ukraine by 60–70%). In the future, an annual increase of 10–15% in the price of hazelnuts and of 5–10% in the production is expected, with a doubling of total production by 2035 (Milošević & Milošević, 2017; Mehlenbacher & Molnar, 2021; Rapiti, 2021).

The values of hazelnut cultivation production indicate that this crop is economically profitable for both developed (USA, Italy) and developing countries (Turkey, Georgia, Azerbaijan). The margin between the costs of the producer and exports is up to 40–60% annually, the Ukrainian market demands more hazelnuts, not only of its own production, but also imported ones, which leads to some crisis phenomena in the confectionery industry, and the replacement of hazelnuts with less nutritious analogues. The total Ukrainian market demand over the last 5 years amounted to 38.8 thousand tons of processed nuts worth 104.8 million dollars only as raw materials for the food industry and consumption (Krol et al., 2019; Guiné & Correia, 2020; Jenderek et al., 2022).

These indicators provide for only 7–8% of consumption in the EU and North America, which is not quite normal. That is, in order to meet only domestic needs (taking into account that other nut crops cannot be used as nutritious substitutes for this crop) at a comparable level without taking into account the withdrawal of products due to the imports, it is necessary to expand the areas of hazelnut plantations by 10–15 times without a significant increase in yield (Črepinšek et al., 2011; Bacchetta et al., 2015; Erbaş et al., 2020).

The purpose of the research was to identify the most productive varieties of hazelnuts for cultivation in the northern part of the Steppe of Ukraine – a region with insufficient precipitation and a harsh continental climate, which was previously considered not quite suitable for cultivation of this crop.

Materials and methods

The research was carried out during the period from 2020 to 2021 on the hazelnut plantations of Transrezerv LLC in the village of Shulhivka, Dnipropetrovsk region (geographic coordinates were 48°44′36″ N 34°23′33″ E). The soil is ordinary black soil on loess. The technology of hazelnut cultivation in the experiment corresponded to the generally accepted techniques for the areas of planting in Ukraine. Hazelnut yield was registered through by field harvesting, with the scheme of planting of 4 variants of 10 bushes of each variety. The varieties Barcelona, Catalan, Cosford, and Halle were studied (planting scheme was 4 × 5 meters (inter bushes×interrow). Trimming was carried out by a semi-intensive method.

The weather conditions during the period of the studies were quite stable compared to the long-term annual average values. The weather conditions in 2020 were characterized by sufficient rainfall. Thus, during the period from April to July, there was 170.4 mm of precipitation, which is 86% of the long-term annual average value (199 mm).

Weather conditions in 2021 included a sufficient amount of precipitation. Thus, during the period from April to July, there was 198.5 mm of precipitation, which actually corresponded to the long-term annual average indicators (199 mm). 2021 was characterized by a lower number of active temperatures, but a higher relative humidity.

Statistical analysis of the results was conducted in Statistica 10.0. The differences between the selections were determined using ANOVA and were considered reliable at P < 0.05, discriminant analysis to detect the significance of the traits. The normality of the data distribution was examined using the Shapiro–Wilk W-test. Results were confirmed by the Tukey HSD test.

Results

During the cropping season, observations and corresponding registration of three groups of traits were carried out, the phenotypic variability of which is the pre-condition of successful use of a particular variety in production. The coefficient of variation for all traits was also calculated, taking into account the greater suitability for productive cultivation (with other equal traits) of varieties with a more determinate type of development. The first group (plant morphometry indicators) is shown in Table 1.

Such values as plant height, crown width along and across the line did not change significantly from variety to variety, in terms of variability they refer to low (variety Cosford and variety Halle for the third trait) and moderately variable traits (varieties Barcelona, Catalan and Halle for the first two traits). Thus, even when there are no statistically significant differences by variety, the variability (determinancy) of a certain trait in its manifestation still depends on the genotype, and in this regard, the variety Cosford was distinguished for its greater suitability for regular plantings for production.

Table 1
Main parameters of plant morphometry of different varieties in comparison (x ± SD, n = 20; 2020/2021 growing seasons)

Trait	Barcelona	Catalan	Cosford	Halle
Height, m	1.18 ± 0.08[a]	1.16 ± 0.11[a]	1.30 ± 0.06[a]	1.30 ± 0.07[a]
C_v, %	7.09	9.83	4.98	5.44
Crown width along the line, m	1.34 ± 0.11[a]	1.14 ± 0.09[a]	1.20 ± 0.06[a]	1.24 ± 0.11[a]
C_v, %	8.51	7.85	4.89	9.19
Crown width across the line, m	1.29 ± 0.13[a]	1.14 ± 0.11[a]	1.22 ± 0.04[a]	1.22 ± 0.04[a]
C_v, %	10.40	10.00	3.67	3.67
Crown volume, m^3	2.07 ± 0.25[a]	1.54 ± 0.27[b]	1.93 ± 0.12[a]	1.98 ± 0.25[a]
C_v, %	12.01	13.94	6.12	12.58
Stem diameter, cm	1.05 ± 0.07[a]	1.38 ± 0.15[b]	1.37 ± 0.06[b]	1.26 ± 0.05[b]
C_v, %	4.97	10.75	4.45	4.35
Average length of shoots, cm	87.00 ± 7.00[a]	88.00 ± 11.52[a]	91.60 ± 3.94[a]	96.60 ± 5.94[a]
C_v, %	8.05	13.09	4.49	6.15
Leaf surface area, m^2	0.42 ± 0.02[a]	0.43 ± 0.01[a]	0.40 ± 0.01[b]	0.44 ± 0.01[a]
C_v, %	4.98	4.16	4.08	2.95

Note: multivariate comparison was carried out using factor analysis at P < 0.05, taking into account the Bonferroni correction Results were confirmed by the Tukey HSD test.

The volume of crowns in all varieties shows an average variation (5–15%), while this indicator is statistically significantly less than that of the Catalan variety (F = 10.77; $F_{0.05}$ = 5.31; P = 0.005), which allows us to expect the best options of using this variety for more intensive types of planting. The diameter of the stem varies slightly only in the Barcelona variety, and is statistically significantly less than the other three varieties, in which this feature constitutes an average value (F = 31.13; $F_{0.05}$ = 5.31; P = $1.17*10^{-5}$). The average shoot length for all varieties is roughly the same, except for the variety Cosford, which is slightly variable.

The parameter of the leaf surface area, which in the future will allow measurement of the effectiveness of the use of light energy by a certain variety, in the Cosford variety is significantly less than that of the three varieties (F = 14.10; $F_{0.05}$ = 5.31; P = 0.003). This parameter in all varieties is weakly variative.

Thus, with this set of features, the Cosford variety has distinguished itself, clearly demonstrating the determinate type of development and is more suitable for use in modern high-intensity production plantations.

To identify the classification capacity and the significance of individual morphometry parameters, a discriminant analysis was carried out (Table 2; Fig. 1).

Based on the data obtained, it can be concluded that the features (in this case) such as the crown volume and the leaf surface area were important for discrimination of plant architecture by specificity of varieties. Only these features are included in the model, which is evident from the value of the statistical criterion.

Table 2
Results of discriminant analysis for individual traits of plant morphometry of hazelnut varieties

Trait	Wilks' - Lambda	Partial - Lambda	F-remove - (3.90)	P
Height, m	0.14	0.59	2.80	0.09
Crown width along the line, m	0.13	0.63	2.39	0.12
Crown width across the line, m	0.12	0.65	2.19	0.14
Crown volume, m^3	0.22*	0.26	11.87	0.01
Stem diameter, cm	0.11	0.68	2.08	0.14
Average length of shoots, cm	0.10	0.77	1.15	0.37
Leaf surface area, m^2	0.20*	0.31	7.16	0.01

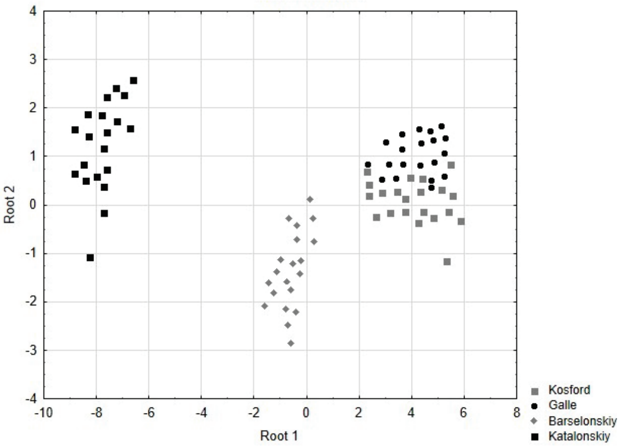

Fig. 1. Results of classification by canonical functions of discriminant analysis for plant morphometry

Based on the obtained canonical roots, it can be concluded that the Barcelona variety actually differs in terms of morphometric parameters in aggregate (plant architecture features) from the rest of the varieties, particularly from Cosford and Halle, which form a more or less homogeneous group.

The introduction of new plant material into a qualitatively different ecological environment can lead to qualitatively new phenomena in plant ontogeny. Extremely uncharacteristic effects noted are shown in Figures 2 and 3. First of all, it is early fruiting with the formation of completely full-fledged hazelnuts already in the first year after planting (Fig. 2). From an economic point of view, this effect is not significant, but it is qualitatively new for the biology of this culture.

The second such effect was that hazelnut arsenia, having access to significantly more light in the second third year, formed an increased number (up to 5–6) of inflorescences with efficient fruiting (Fig. 3). Although the nuts were somewhat smaller, this did not significantly affect the quality of the product and is easily compensated agrotechnically.

Table 3 shows the morphometry of the individual varieties of nuts. As can be seen, the height parameter of the nut is slightly variable, except for the Barcelona variety, and the varieties do not differ by this parameter. The width of the walnut is about the same, but in this case, as a mean variant, the Halle variety is distinguished. There are no differences between the genotypes.

In terms of shell thickness, however, although the trend remains the same in variability, the Halle variety is statistically significantly different from the other varieties – the shell is much thicker ($F = 44.46$; $F_{0.05} = 5.31$; $P = 1.34*10^{-7}$). Regarding the gross yield I, the Catalan and Halle varieties are superior to the Barcelona ($F = 36.22$; $F_{0.05} = 5.31$; $P = 3.15*10^{-6}$), while Csford is as productive as the Halle and Catalan varieties ($F = 45.17$; $F_{0.05} = 5.31$; $P = 5.04*10^{-7}$), and is not superior to variety Barselonskiy ($F = 4.11$; $F_{0.05} = 5.31$; $P = 0.07$).

Fig 2. Hazelnut plant of the first year and its fruiting

Fig. 3. Increased fruiting activity for hazelnuts productive branches

For yield II, however, all parameters are the same, which is due to the absence of differences in the general morphology of the nut in terms of the height of the kernel. The parameter is slightly variable in the first two varieties and is moderately variable in the last two varieties. As to the waste ratio, the pattern is the same, however the parameter in all varieties is weakly varied. As for the average weight of the nut, Cosford is inferior to all other varieties ($F = 55.31$; $F_{0.05} = 5.31$; $P = 1.04*10^{-10}$), while Halle is superior to them ($F = 24.58$; $F_{0.05} = 5.31$; $P = 8.37*10^{-3}$). The sign is weakly variative. As to the weight of 100 dry nuts, the data is the same, when the Cosford variety is inferior to all other varieties ($F = 46.41$; $F_{0.05} = 5.31$; $P = 5.17*10^{-8}$), while Halle is in turn superior to them ($F = 14.07$;

$F_{0.05}$ = 5.31; P = 0.005). The parameter varies a little. Thus, in terms of nut morphometry, the Halle variety is certainly promising for the region, while the Cosford variety is inferior to the others.

To identify the classification capacity and certain morphometry parameters of a kernel, a discriminant analysis was carried out (Table 4, Fig. 4).

Table 3
Key variables of plant morphometry of different varieties compared (x ± SD, n = 20, 2020/2021 growing seasons)

Trait	Barcelona	Catalan	Cosford	Halle
Height of hazelnut, mm	22.4 ± 1.1[a]	24.4 ± 0.6[a]	23.0 ± 1.2[a]	24.4 ± 1.1[a]
C_v, %	5.09	2.24	4.87	4.67
Width of a nut, mm	19.4 ± 0.9[a]	19.6 ± 0.9[a]	19.2 ± 0.9[a]	20.2 ± 1.1[a]
C_v, %	4.61	4.56	4.79	5.42
Shell thickness, mm	1.24 ± 0.05[a]	1.21 ± 0.05[a]	1.20 ± 0.05[a]	1.54 ± 0.09[b]
C_v, %	4.42	4.89	4.89	5.81
Gross yield from one hazelnut by height by diameter I (along the seam)	19.0 ± 0.7[a]	20.7 ± 0.9[b]	19.6 ± 1.1[ab]	21.2 ± 0.8[b]
C_v, %	3.72	4.71	5.82	3.95
Gross yield from one hazelnut by height by diameter II (on the sides)	17.1 ± 0.6[a]	17.6 ± 0.6[a]	16.8 ± 1.3[a]	18.3 ± 1.2[a]
C_v, %	3.20	3.11	7.76	6.79
Main/additional waste kernel, %	36.4 ± 1.1[a]	36.3 ± 1.1[a]	36.8 ± 1.1[a]	37.0 ± 1.0[a]
C_v, %	3.13	3.13	2.98	2.70
Average weight of one nut, g	3.72 ± 0.16[a]	3.76 ± 0.17[a]	2.84 ± 0.12[b]	4.24 ± 0.17[c]
C_v, %	4.42	4.52	4.30	3.95
Weight of dry nuts (100 pcs.), g	353.0 ± 16.2[a]	369.0 ± 14.6[a]	279.0 ± 15.1[b]	416.0 ± 17.8[c]
C_v, %	4.17	3.86	4.21	4.28

Note: multivariate comparison was carried out using factor analysis at P < 0.05, taking into account the Bonferroni correction; results were confirmed by the Tukey HSD test.

Table 4
The discriminant analysis data by individual indicators of morphometry of hazelnut varieties

Trait	Wilks' - Lambda	Partial - Lambda	$F_{0.05}$ (3.90)	P
Height of hazelnut, mm	0.13	0.86	0.45	0.72
Width of a nut, mm	0.13	0.86	0.48	0.69
Shell thickness, mm	0.45*	0.25	8.53	0.01
Gross yield from one hazelnut by height by diameter I (along the seam)	0.14	0.81	0.65	0.59
Gross yield from one hazelnut by height by diameter II (on the sides)	0.17	0.67	1.46	0.28
Main/additional waste kernel, %	0.19	0.60	1.99	0.18
Average weight of one nut, g	0.36*	0.32	6.11	0.01
Weight of dry nuts (100 pcs.), g	0.23*	0.52	2.50	0.10

Parameters such as the thickness of the nutshell, the average weight of one nut, and the weight of 100 dry nuts have been identified and are likely to be the key parameters in classifying these varieties under conditions of insufficient precipitation. It is worth noting that all the parameters are the key ones for processing the obtained raw materials and will have a considerable effect on the product quality.

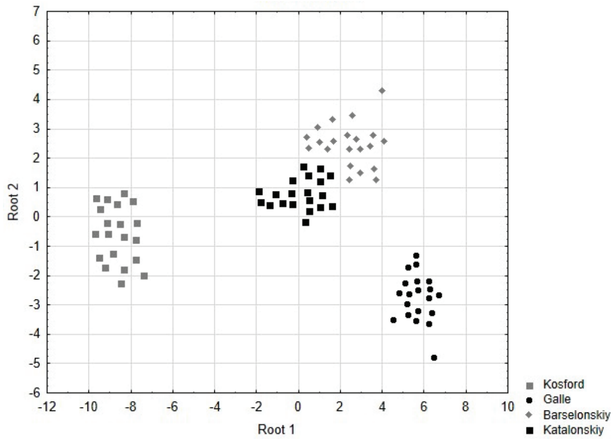

Fig. 4. Results of analysis of canonical functions by nut morphometry

On the basis of the above, Cosford and Halle quite clearly have been distinguished as more specific varieties. In this case, the Barcelona and Catalan varieties are referred to the same set and it is impossible to clearly distinguish between them.

In other words, after the analysis of these parameters, we have obtained the priorities for studying the Halle and Cosford varieties, which have shown their best and worst qualities respectively.

The yield values for all 4 varieties are provided in Table 5 (tree yield, yield and kernel yield). The Cosford variety outperforms the Barcelona variety in terms of crop yield (F = 9.91; $F_{0.05}$ = 5.31; P = 0.008), the Halle variety outperforms the Barcelona and Catalan varieties (F = 26.20; $F_{0.05}$ = 5.31; P = 1.19×10^{-4}), but is less productive than the Cosford variety. The trait is slightly variable in the Halle variety, while in other genotypes it varies moderately. Thus, from the economic point of view, the Halle variety and, to some extent, the Cosford variety are more promising.

The Catalan, Cosford and Halle varieties outperform the Barcelona variety in terms of yield (F = 31.15; $F_{0.05}$ = 5.31; P = 7.56×10^{-5}), while the Halle variety outperforms all other varieties (F = 42.21; $F_{0.05}$ = 5.31; P = 3.43×10^{-8}). The parameter is slightly variable in all varieties except Barcelona.

Table 5
Yield parameters of different varieties in comparison (x ± SD, n = 20)

Trait	Barcelona	Catalan	Cosford	Halle
Yield per tree, kg	0.93 ± 0.12[a]	1.10 ± 0.10[a]	1.16 ± 0.06[b]	1.24 ± 0.05[b]
C_v, %	12.50	8.37	5.83	4.42
Yield, t/ha	2.26 ± 0.23[a]	2.62 ± 0.10[b]	2.64 ± 0.11[b]	2.84 ± 0.11[c]
C_v, %	10.54	4.68	4.88	4.01
Kernel yield,%	46.4 ± 2.5[a]	38.2 ± 1.1[b]	53.4 ± 1.5[c]	53.3 ± 1.4[c]
C_v, %	1.14	2.87	2.84	2.64

Note: multivariate comparison was carried out using factor analysis at P < 0.05, taking into account the Bonferroni correction; results were confirmed the Tukey HSD test.

As for the kernel yield, the parameter varies slightly in all varieties, but Cosford and Halle are significantly superior to Barcelona and Cosford (F = 14.26; $F_{0.05}$ = 5.31; P = 0.003), being about the same level, while the Barcelona variety outperforms the Catalan variety (F = 25.04; $F_{0.05}$ = 5.31; P = 3.48×10^{-4}). Thus, in terms of yields, the Halle variety is extremely promising for introduction into production in the regions with insufficient precipitation, the yield characteristics of the Cosford variety need additional research, which, probably, can also be promising in general, but it is inferior to the Halle variety (possibly, with variation in planting and pruning patterns).

The parameters are less variable than in the case of plant morphometry, however this is more important for processability than for cultivation directly. From this point of view, it cannot be said that there are significantly more promising varieties.

As one can see, we included in the model such parameters as the gross yield and kernel yield, which was of particular importance, obviously, for the less successful linear parameters of the Cosford varietyof hazelnuts. The per-tree yield parameter is not included in the model, obviously due to the greater variation (Table 6, Fig. 5).

Table 6
Parameters of yield of different varieties in the discriminant analysis model

Trait	Wilks' - Lambda	Partial - Lambda	F-remove - (3,14)	P
Yield per tree, kg	0.17	0.82	0.97	0.43
Yield, t/ha	0.25*	0.31	9.21	0.01
Kernel yield, %	0.42*	0.03	127.92	0.01

Thus, according to the results of the discriminant analysis, the Barcelona and Catalan varieties are clearly distinguished in the classification, and the mixed group is formed by the Cosford and Halle varieties, which are more interesting for the study in terms of introducing hazelnut varieties into the regions of insufficient precipitation.

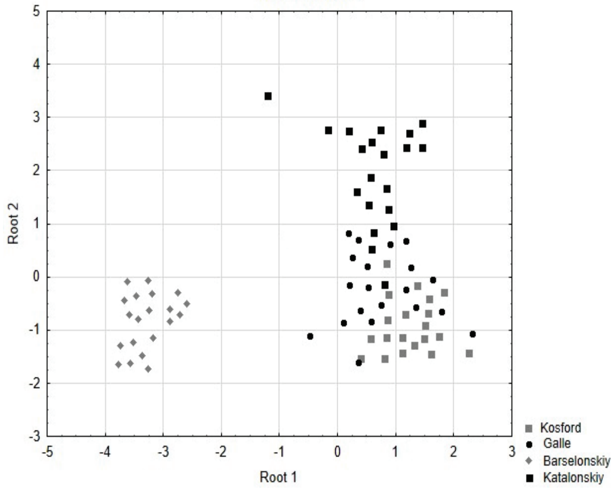

Fig. 5. Results of canonical functions for yield indicators

As can be seen from the data compared, the Cosford variety significantly underperforms in terms of the parameters of an individual nut, but outperforms in terms of the amount of nuts, which is a qualitative difference in the mechanism of formation of yields from other varieties. This can be extremely promising for a balanced harvest. This property should perform better in terms of higher yields in this variety when tested with others under more adverse climatic conditions, for example, with droughts during the second half of the fruit formation period, since it provides significant advantages due to faster development.

Discussion

In the context of global climate change, there has been a considerable shift in the geography of cultivation of different crop species (Jha et al., 2021; Cristofori et al., 2022). Along with the related problems (for example, increased intensity of droughts), by mitigating harsh winter conditions, sharp continental climate, shifting and minimizing the period of intense droughts, it is also possible to transfer crops to new, previously not very suitable regions for their cultivation (Nazarenko et al., 2021). Thus, it is possible to solve the problems associated with the insufficient production of these crops at the national level, to obtain additional resources for the development of territories (particularly considering that any program associated with planting gardens is qualitatively more effective – due to the length of the production cycle compared to field crops and greater capacity in terms of technology), to significantly improve the diet of the local people by increasing the content and reducing the cost of a source of the nutritious food that is hazelnuts due to the content of the useful micronutrients and vitamins (Ozturk et al., 2017; Bodaghabadi et al., 2019; Mehlenbacher & Molnar, 2021; Aydemirm & Yılgın, 2022; Calà et al., 2022).

Again, as previously noted for other crops, such a significant change in important environmental factors, primarily quantitative ones, led to extremely significant shifts in the biology of plant development. In this case, it turned into a qualitative one, primarily from the point of view of the ontogenesis of the cultivar (Beiko & Nazarenko, 2022b; Horshchar & Nazarenko, 2022a). This can lead to a change in ideas about the formation of a plant in farms during introduction. The very significant differences in quantitative differences in lighting conditions, temperature and humidity conditions lead to qualitative changes in ontogenesis, primarily for the later stages (Pirych et al., 2021). As a rule, for the situation with the Steppe – to the acceleration and intensification of development (Horshchar & Nazarenko, 2022b).

Since 2015, there have been significant shifts in climate resources in the region. The frost-free period has significantly increased, the vegetation of winter crops has become extended, the timing of the spring crops sowing has shifted, the period of adverse droughts has shifted, which rarely coincide with the critical stages in the development of agricultural plants (Banyal et al., 2021; Kizilkaya et al., 2022). In this regard, there was a question on expansion of the range of the crops,which are constantly grown in the region to increase profitability of economic activities in the North of Steppe of Ukraine, and to improve the diet of local population (Nazarenko et al., 2019a, 2021).

The implementation of these plans is greatly facilitated through the search for better adapted varietal resources, the use of biodiversity at both the local and global levels, the clarification of mechanisms for the formation of yields and the implementation of genetically determined advantages of a particular variety (Mehlenbacher & Molnar, 2021; Giulia et al., 2022; Kizilkaya et al., 2022). The latter also allows the creation of plantations including several varieties, which significantly mitigates the risks of changes in climatic conditions over the years and, even with the critical, uncharacteristic adverse changes, the fall in crop yields may be not too catastrophic (Orlandi et al., 2019; Raparelli & Lolletti, 2020; Nepal et al., 2022).

However, in this case, as our studies have shown, it is desirable to leverage different characteristics of varieties for the development and generation of yields, which allows for a more flexible strategy (Kizilkaya et al., 2022; Valeriano et al., 2022). The generation of yield depends on many parameters of both the plant itself and its fruit, which has been repeatedly noted above. However, the specific mechanism is sometimes difficult to identify, since depending on the genotype, quite different sets of features can be the key ones (Mehlenbacher & Molnar, 2021; Romero-Aroca et al., 2021; Taghavi et al., 2022). The key features for each of the varieties have been specified in this study (Yao et al., 2008; Valeriano et al., 2022). This is the only way to achieve the steady production and operation of agrocenosis of agricultural crops.

Conclusion

Summarizing the above, the application of a yield generation mechanism related to the ability to produce large, well-shaped nuts is promising in the conditions of insufficient precipitation regions. However, there is also an interesting mechanism where superiority is achieved due to the number of fruits rather than on account of perfection of each nut individually. The mixed method seems less promising. There are plans to further study the possible compensatory effect in adverse weather conditions when applying the second method, to clarify the variability of the first method in different environmental conditions, to conduct a biochemical analysis to establish the nutrition value of each variety and the peculiarities of generating such value in the regions of insufficient precipitation, to study the resistance to environmental pollution by heavy metals, which is relevant for the region.

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