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Ranking of Shrubs by Degree of Stability

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ABSTRACT

The relevance is due to the introduction of the subtropical fruit crop *Zizyphus jujuba* (unabi) to the Volgograd region. For the first time in the conditions of the Volgograd region, the material on the biochemical properties of various varieties of unabi fruits was analyzed and generalized. The ranking of shrubs by change to conditions is based on the fixation of environmental factors and the bioecology of plant individuals based on their physiological and biochemical parameters in field and laboratory conditions. The purpose of the research is to rank the shrubs according to the degree of resistance to stress factors. The objects are plant genotypes of *Z. jujuba*: large-fruited, medium-fruited and small-fruited. Experimental plantings with their participation are cultivated at the collection site of the Federal Research Center of Agroecology of the Russian Academy of Sciences (Volgograd, Russia).

Keywords: shrubs, soils, environment, stability, landscaping.

INTRODUCTION

The study of identifying limiting factors limiting development; analysis of critical periods of plant development by changes in water metabolism and temperature regime; comparative assessment of the biochemical characteristics of fruits in the northern point of the cultivation area, taking into account adaptation to stress factors (genotype-environment). The productivity of plants under stress strongly depends on maintaining the water status of plants. Any assessment of the water status should take into account the reaction of plants to environmental conditions and the characteristics of these conditions.

Unabi (*Zizyphus jujuba* Mill.) has good gardening qualities, including adaptation, resistance to arid conditions, biotic and abiotic stresses, and also has a positive effect on human health. Unabi is a valuable and economically important fruit tree native to China. It is estimated that its introduction into culture began 7000 years ago and the existing genotypes were formed by hybridization with wild relatives. Valuable economic properties have contributed to the expansion of the distribution area to more than 50 countries around the world. Continuous natural and artificial selection contributed to an increase in genetic diversity. Currently, there are about 1000 varieties of *Zizyphus jujuba*.

Taxonomic and Ecological Analysis of the composition of natural, anthropogenically disturbed or formed plant communities, including cultivated plants, is an integral stage of knowledge of their structure, communication systems, determination of development trends, development of measures to stabilize, protect, optimize or change the composition and structure of these groups in accordance with the reference or certain "ideal" states" that a person imagines, studies or tries to achieve.

Enrichment of phytocenosis crops with new valuable plants and preservation of the gene pool of the plant world in artificial reserves, among which the leading place is occupied by botanical gardens, lawns, agroecosystems, etc., is possible due to the introduction of species, varieties, cultivars, varieties, lines, hybrids. For effective introduction of the genetic plasma of cultivated species into anthropically transformed ecosystems, the so-called targeted introduction is used, taking into account the native properties of ecotopes, which is reflected in their requirements for environmental factors. In the practice of Ecological

Research of cultivated species, an important stage in expanding their functional capabilities and harmonization with the conditions of existence is the consideration of the “responses” of plants according to their adaptations to a certain amplitude of fluctuations in environmental conditions along the life Spectra. In the conditions of modern growth of anthropogenic impact, including anthropic pressure on the environment there is a need to search for new approaches to assessing the most important factors from the point of view of not only agroecological potential (improving the elements of managing the vital state of cultivated plants using certain agricultural technologies), but also a biocentric approach – biological and ecological zoning, which would include the features of “selecting” the most favorable conditions for the realization of the genetic potential of species and forms of cultivated plants, that is, their maximum harmonization with environmental conditions (light, heat, water, salt regimes, etc.). It is this approach that will ensure the rational use of natural resources, reduce the pesticide load on the environment, increase genetic diversity and maintain dynamic balance in ecosystems and optimize the vital state of biodiversity.

From the point of view of improving the elements of plant life management within certain ecosystems, there is a development of ways to maintain and increase the adaptive and productive potentials of forms of cultivated species, attracting additional anthropic investment. Because very often the spectra of abiotic factors (their microclimatic, edaphic, etc. diversity) are represented by significant differences, a prerequisite for Biological and ecological zoning is the development of an ecological passport of plant varieties of cultivated species, where they are considered according to the criteria of possible mechanisms of endogenous and exogenous adaptations.

A prerequisite for the development of criteria is the study of ecological, morphological, physiological-biochemical, molecular-genetic markers and marker features and properties as exogenous and endogenous mechanisms of adaptability in different physical and geographical research zones for a long time, since years differ significantly in hydrothermal and other factors. Only such a systematic approach will allow us to comprehensively assess the adaptive potential of plants to the climatic conditions of the studied ecotopes and fully realize their viability. Among the most informative individual parameters of the viability of organisms are ontomorphogenesis, reproductive activity of individuals of different vitality, seed productivity, anatomical and morphological, allometric (reproductive effort) and rhythmological features.

The ecological position of a species can be assessed using various ecological approaches, in particular point optimum scales, ecological and regional scales. Range ecological scales are based on a point assessment of the ecological amplitude of species based on environmental factors.

In modern ecological studies for natural species, ecological-cenotic groups (IFGS) of plants are widely used. In this case, environmental conditions are evaluated by the composition of plant communities or their components. To describe the viability of plants and animals, the term life–history strategy is widely used. Still learned evolutionists it has been proved that the ability of living organisms to spend different amounts of resources on reproduction is formed in the process of natural selection and is a specific feature of the species. According to the amount of resources required for reproduction, species of living organisms can be divided into two groups: competitors (K-strategists) and ruderals (r-strategists).

MATERIALS

In recent years, advanced biotechnological tools have made a great contribution to understanding the composition and expression of genes affecting the properties of unabi. Genome analysis of the oldest Dongzao variety presented new ideas for predicting the characteristics of Zizyphus jujuba fruits, including high vitamin C content, resistance to biotic and abiotic factors.

Measurements of soil moisture content cannot provide adequate information to assess the impact of water supply on plant processes and their yield. The water content in plants is determined by limiting abiotic environmental factors (air, soil, water, etc.). To determine the water deficiency in the plant, monitoring and analysis of the water content in the leaves were carried out. It was found that the water content in the leaves during the growing season ranges from 53.3–64.5% (Figure 1).

The flow of water in the plant is carried out due to the potential gradient between the soil and the plant, which leads to the evaporation of water

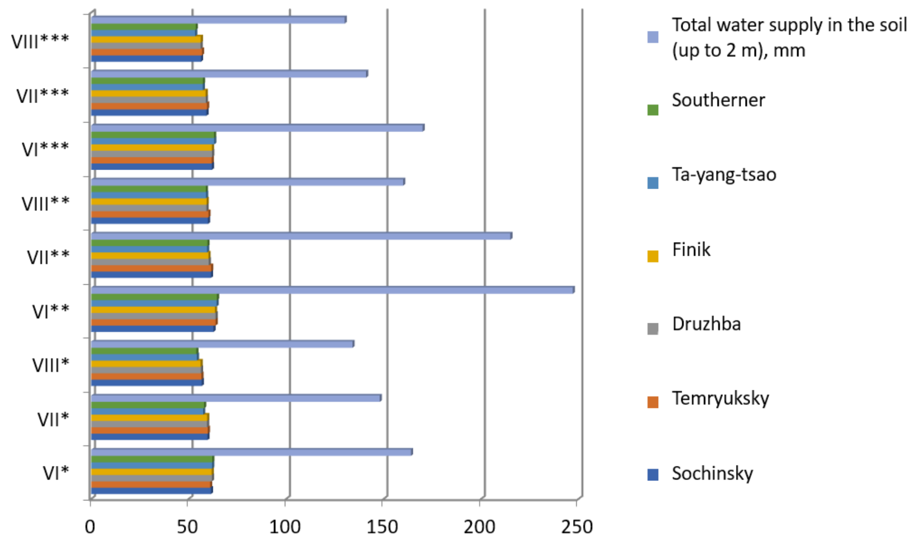

Figure 1. Total water content in leaves (in% of raw weight): (*) year with arid conditions, (**) favorable in hydrological terms (wet), (***) less favorable in hydrological terms

through the stomata into the atmosphere. The transpiration rate is controlled by the gradient of the water potential. The productivity of plants under stress strongly depends on maintaining the water status of plants. Any assessment of the water status should take into account the reaction of plants to environmental conditions and the characteristics of these conditions (Figure 2). Water deficiency in the leaves varies depending on the increase in temperature and decrease in soil moisture (Figure 3).

The lack of moisture in the leaves from June to August did not exceed 15.6%. In large-fruited plant organisms, it was higher than in small-fruited ones. In May-June, with a high total moisture reserve, the water deficit in all varieties was at the level of 7.4–8.0%.mIn the dry period, with a decrease in the water supply in the soil to 141–130 mm and relative humidity (up to 10% at noon) at a temperature of 40.4 °C, the indicators of water deficiency in the leaves of all varieties were 2–2.5 times higher.

Materials on the ranking of indicators of the water regime of plant organisms depending on the total moisture reserve for the month of July are shown in Figure 4. Lack of water leads to an increase in the concentration of soluble substances. Dehydration leads to a violation of the integrity of the membranes and affects the composition of the pigment complex.

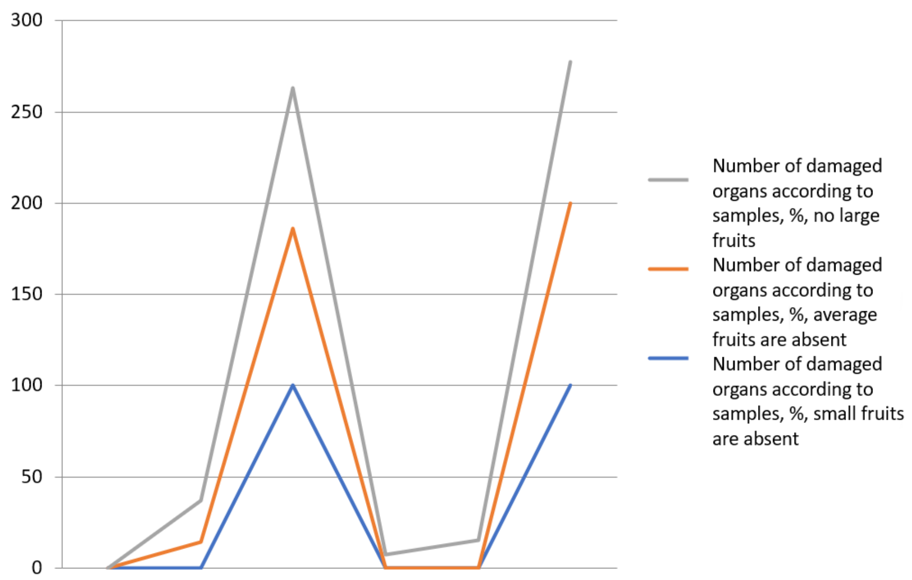

Figure 2. The state of various organs in dry periods

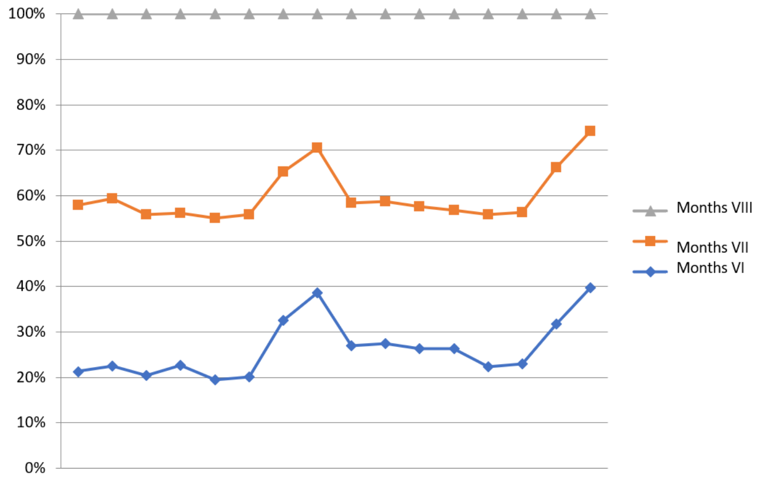

Figure 3. Dependence of seasonal changes in water scarcity in leaves on the total moisture reserve in a 2-meter soil layer during the growing season

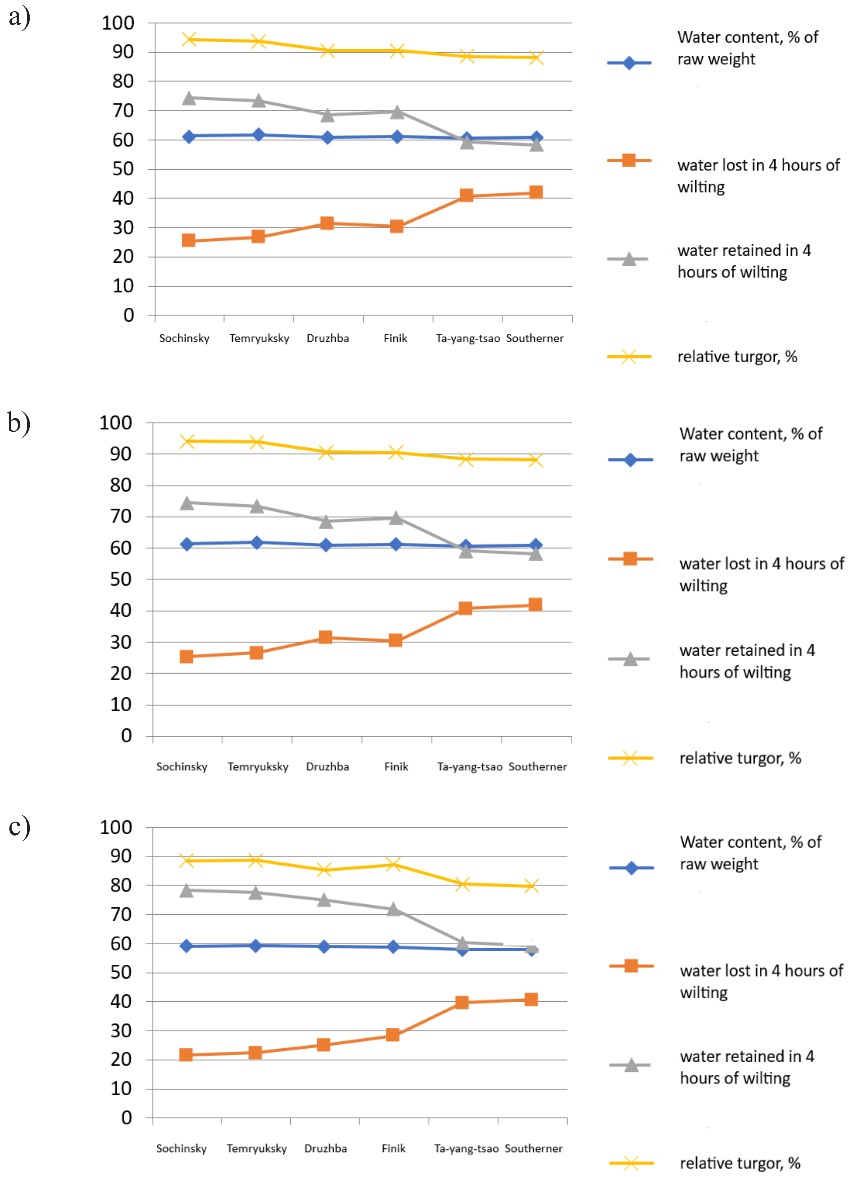

Figure 4. Water regime of Z. jujuba leaves: (A) the total moisture reserve in the 2nd layer of soil is 150 mm, (B) the total moisture reserve in the 2nd layer of soil is 218 mm, (C) the total moisture reserve in the 2nd layer of soil is 143 mm

The Dualex scientific pro instrument revealed differences in pigment content indicators depending on the influence of environmental stresses (summer droughts, illumination within the crown, climatic factors of the place of growth) in subtropical shrubs (Table 1).

During the growing season, the highest content of biological pigments was observed in the leaf apparatus of large-fruited forms (chlorophyll: 23.22–29.48 mg/cm²; flavonoids: 1.57–1.73 mg/cm²; anthocyanins: 0.10–0.16 mg/cm²). The leaves of small-fruited plants are characterized by a lower content of pigments (chlorophyll: 13.99–24.80 mg/cm²; flavonoids: 1.79–1.96 mg/cm²; anthocyanins: 0.14–0.21 mg/cm²). During the dry period, the content of chlorophyll decreases; the content of flavonoids and anthocyanins increases, which causes the mechanisms of adaptation of plants to stress factors of lack of water. In response to arid conditions, the leaves of small-fruited forms accumulated and synthesized flavonoids and anthocyanins more intensively, which confirms their adaptation to unfavorable environmental conditions.

Factors controlling stressful conditions change the normal balance and lead to a number of morphological, physiological, and biochemical changes in organisms that negatively affect growth and productivity. In the conditions of

Table 1. Dynamics of unabi leaf pigments under exposure conditions high temperatures

Type, grade	Measurement time				
	9^{45}	11^{40}	13^{35}	15^{35}	17^{20}
Temperature, °C	36.0–36.7	37.7–37.8	39.1–39.7	38.8–39.4	37.0–37.1
Illumination, lux·103	60–87	91–95	91–99	82–93	63–75
Unabi finely-fertile	Chlorophyll a+b content, mcg/cm²				
	11.70±0.33* 11.47–12.08	8.92±0.21 8.03–9.63	8.05±0.34 6.45–9.91	8.77±0.38 8.29–9.24	9.11±0.19 8.91–9.27
	Flavonoid content, mcg/cm²				
	1.90±0.08 1.81–1.96**	1.79±0.01 1.68–1.83	1.75±0.008 1.69–1.79	1.72±0.007 1.71–1.72	1.78±0.01 1.67–1.86
	Anthocyanin content, mcg/cm²				
	0.18±0.006 0.17–0.19	0.22±0.01 0.21–0.23	0.25±0.01 0.24–0.25	0.21±0.01 0.20–0.22	0.23±0.01 0.22–0.25
Unabi medium–fruited Finik	Chlorophyll a+b content, mcg/cm²				
	17.76±0.80 16.61–17.88	21.80±0.85 20.47–23.13	20.66±0.90 20.54–2.79	16.52±0.60 16.40–16.64	16.81±0.35 16.56–17.06
	Flavonoid content, mcg/cm²				
	1.95±0.01 1.93–1.96	1.78±0.01 1.93–1.96	2.01±0.01 2.00–2.03	1.91±0.01 1.87–1.96	1.76±0.005 1.61–1.91
	Anthocyanin content, mcg/cm²				
	0.15±0.004 0.13–0.15	0.14±0.005 0.11–0.16	0.13±0.002 0.12–0.14	0.13±0.004 0.12–0.15	0.13±0.005 0.06–0.18
Unabi large-fruited Ta-yang-tsao	Chlorophyll a+b content, mcg/cm²				
	12.73±0.38 11.09–14.36	9.68±0.25 8.72–10.79	8.65±0.04 5.15–8.86	10.92±0.62 9.19–12.40	9.06±0.35 8.83–9.45
	Flavonoid content, mcg/cm²				
	1.88±0.02 1.85–1.91	1.82±0.01 1.73–1.95	1.92±0.05 1.87–1.96	1.94±0.03 1.92–1.97	1.92±0.01 1.90–1.93
	Anthocyanin content, mcg/cm²				
	0.20±0.009 0.17–0.23	0.22±0.01 0.20–0.23	0.23±0.006 0.22–0.24	0.19±0.004 0.18–0.20	0.22±0.007 0.21–0.23
Unabi Druzhba	Chlorophyll a+b content, mcg/cm²				
	17.58±0.77 16.87–17.19	19.52±0.98 17.24–20.79	20.35±0.73 20.08–20.63	9.51±0.04 8.37–10.90	7.68±0.30 6.71–8.170
	Flavonoid content. mcg/cm²				
	1.90±0.01 1.77–2.00	1.83±0.01 1.76–2.03	1.84±0.07 1.78–1.91	1.92±0.09 1.86–2.00	1.77±0.08 1.64–1.87
	Anthocyanin content, mcg/cm²				
	0.13±0.008 0.13–0.14	0.11±0.005 0.10–0.13	0.10±0.003 0.10–0.11	0.25±0.01 0.24–0.27	0.22±0.01 0.20–0.24

* Average value and measurement error, ** minimum and maximum values.

the Volgograd region, *Zizyphus jujuba* varieties bloom and bear fruit annually.

In all cases (drought, salinization, frost, etc.), the same mechanisms are functioning, aimed at lowering the intracellular water potential and protecting cell structures.

Plant yields can decrease as a result of water shortage by up to 50 percent. Plants are able to adapt to stressful conditions through a variety of biochemical and physiological changes that include the functions of stress-related genes. On the other hand, productive and sustainable agriculture requires growing plants in arid and semi-arid regions with less expenditure of valuable resources, for example, fresh water.

The variability in the content of ascorbic acid over the years was established: in large-fruited and medium-fruited plants from 31.9 to 66.5 mg%. In small-fruited plants under cultivation, the variability over the years is less pronounced. During the dry period, the content of ascorbic acid decreases. Small-fruited plants showing a high degree of adaptation have high levels of ascorbic acid (up to 740.3 mg%).

The quantitative determination of vitamin P was based on the use of indigo-carmine (indicator). The highest content of vitamin P (about 72 mg%) in the fruits of the Sochi and Ta-yang-tsao varieties. Its lowest content in the fruits of the varieties Yuzhanin and Temryuksky (70.4 and 70.8 mg%). The average vitamin P content of the studied varieties is characterized by Druzhba and Finik (68.6 and 69.4 mg%). A higher temperature during fruit ripening contributes to the accumulation of bioflavonoids (Figure 5).

a)

b)

Figure 5. Fruiting of Zizyphus jujuba with small fruits in conditions Volgograd (2021): (A) “Sochi”, (B) “Temryuksky”

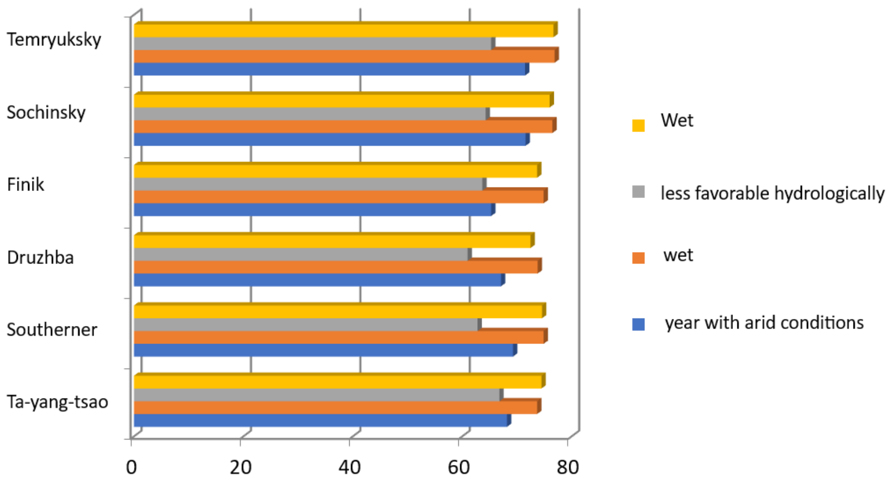

Figure 6. Vitamin P content (mg %) in the years of research

Comparative biochemical characteristics of fruits in areas with arid climate (Volgograd region) are shown in the Figure 7.

Carbohydrates in fruits are mainly represented by fructose, glucose, sucrose. It was found that mature fruits (Sochi, Temryuk) have a lower sugar content. The development of plant organisms of *Zizyphus jujuba* and the biochemical characteristics of fruiting in areas with arid climate (Volgograd region) depend on moisture availability and temperature regime. Limiting factors are temperature increases and a decrease in air humidity in summer with low rainfall and moisture reserves in the root layer of the soil. It was revealed that in all cases (drought, salinization, frost, etc.) the same mechanisms are functioning, aimed at lowering the intracellular water potential and protecting cell structures. A cluster ranking of subtropical organisms of *Z. jujuba* Mill was carried out. according to the degree of adaptation and tolerance limits to the effects of limiting stress factors (Table 2).

Cluster analysis contributes to the identification of specific plants, on the basis of which groups of organisms are distinguished by target characteristics. Promising varieties (Sochi, Temryuk, Druzhba, Finik) were identified, taking into account the results of cluster analysis and the degree of dispersion of parameters of ecological-physiological, taxation and reproductive indicators.

The level of resistance of species to changing environmental conditions is determined by tread ecological and adaptive properties. Adaptive potential can be assessed by various criteria, the most objective among which are a number of Integral indicators (seed productivity, environmental tolerance, acclimatization number, etc.). The key to successful adaptation in a new distribution area is “high” and “good” acclimatization of plants (naturalization) , which reflects their adaptability to new environmental conditions, the formation of seed reproduction and replenishment of biodiversity. Natural selection, introduction of new plant species into culture and their adaptation is an important task of Environmental Research, which is solved by successful introduction. Successful introduction of promising plant species into culture is possible with a deep understanding of the biology of their

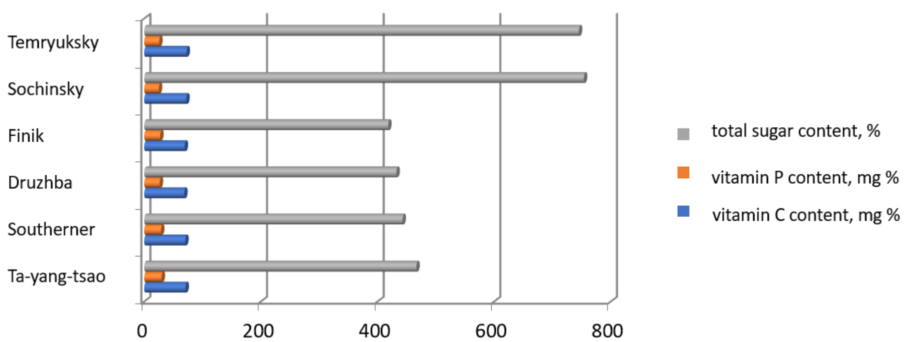

Figure 7. Ranking of fruiting by biochemical parameters (average for 4 years)

Table 2. Batch processing and reporting of 16 cluster criteria indicators *Zizyphus jujuba* by Euclidean distances

Case No.	Euclidean distances															
	vd	ve	n	d	dk	p	c	ch	u	dd	fk	ol	pc	oc	op	ool
vd	0.00	0.22	1.12	1.16	1.16	0.66	0.39	0.39	0.36	0.63	0.57	0.52	0.22	0.67	0.52	0.39
ve	0.22	0.00	1.13	1.16	1.16	0.69	0.36	0.35	0.28	0.59	0.54	0.62	0.28	0.73	0.62	0.49
n	1.12	1.13	0.00	1.14	1.14	0.58	0.82	0.82	0.91	0.81	0.90	1.39	0.95	0.66	1.39	1.15
d	1.16	1.16	1.14	0.00	0.00	0.66	0.84	0.84	0.92	0.79	0.93	1.47	1.00	0.76	1.47	1.22
dk	1.16	1.16	1.14	0.00	0.00	0.66	0.84	0.84	0.92	0.79	0.93	1.47	1.00	0.76	1.47	1.22
p	0.66	0.69	0.58	0.66	0.66	0.00	0.51	0.51	0.53	0.71	0.41	0.82	0.45	0.14	0.82	0.58
c	0.39	0.35	0.82	0.84	0.84	0.51	0.00	0.00	0.14	0.33	0.48	0.84	0.32	0.60	0.84	0.63
ch	0.39	0.35	0.82	0.84	0.84	0.51	0.00	0.00	0.14	0.33	0.48	0.84	0.32	0.60	0.84	0.63
u	0.36	0.28	0.91	0.92	0.92	0.53	0.14	0.14	0.00	0.46	0.39	0.77	0.28	0.62	0.77	0.58
dd	0.63	0.59	0.81	0.79	0.79	0.71	0.33	0.33	0.46	0.00	0.79	1.11	0.61	0.81	1.11	0.91
fk	0.57	0.54	0.90	0.93	0.93	0.41	0.48	0.48	0.39	0.79	0.00	0.71	0.39	0.48	0.71	0.52
ol	0.52	0.62	1.39	1.47	1.47	0.82	0.84	0.84	0.77	1.11	0.71	0.00	0.53	0.76	0.00	0.24
pc	0.22	0.28	0.95	1.00	1.00	0.45	0.32	0.32	0.28	0.61	0.39	0.53	0.00	0.47	0.53	0.32
oc	0.67	0.73	0.66	0.76	0.76	0.14	0.60	0.60	0.62	0.81	0.48	0.76	0.47	0.00	0.76	0.53
op	0.52	0.62	1.39	1.47	1.47	0.82	0.84	0.84	0.77	1.11	0.71	0.00	0.53	0.76	0.00	0.24
ool	0.39	0.49	1.15	1.22	1.22	0.58	0.63	0.63	0.58	0.91	0.52	0.24	0.32	0.53	0.24	0.00

Average rank	Sum of ranks	Mean	Std. Dev.
4.093750	65.50000	0.593750	0.240745
4.031250	64.50000	0.587500	0.236291
3.625000	58.00000	0.525000	0.208167
3.625000	58.00000	0.525000	0.204939
2.812500	45.00000	0.437500	0.202896
2.812500	45.00000	0.437500	0.202896

development, reproduction, as well as the study of the features of their cultivation and use.

The stability of plants under the influence of unfavorable environmental factors is determined by adaptive reactions at the molecular-genetic, physiological-biochemical, morphological, ontogenetic, biocenotic, population levels, which makes it necessary to study the structural-functional features and activity of metabolic processes in plants introduced to the region from other floral areas. Plant resistance assessment is an important final stage of introductory research. It makes it possible to identify ecological and biological features, phenotypic variability, and the feasibility of cultivating new species in the conditions of the introduction area. There are various methodological approaches to evaluating the results of introduction, which usually use indicators of visual observations, that is, data on a qualitative (point) assessment of plant viability. Such traditional introductory studies become more important if they are supplemented with quantitative assessments (structural and functional criteria) at different levels of integration of living matter and the study of the mechanisms of stability of introducers in new growth conditions.

CONCLUSIONS

For tree and herbaceous species, when assessing the success and prospects of Plant Introduction, the method of Integral numerical assessment of the viability and prospects of Plant Introduction based on visual observations is used. The methodological scheme for developing a scale for assessing the adaptation of woody plants shows the dependence of plant reproductive capacity on winter and drought resistance and emphasizes the important role of these properties in the adaptation process.

However, due to the high lability of Morpho-physiological processes, it is difficult to interpret under what specific factors of the multifactorial soil-climatic system plants are affected. To understand the principles of organizing biological systems, a comparative approach is needed in the context of adaptive changes, in particular in different areas of research, because the specificity of adaptive processes is not absolute and any influence of adverse environmental factors causes a complex of appropriate protective reactions. Knowledge of the mechanisms underlying the response of plants to long-term stress factors and ensuring their stability is important in understanding the fundamental foundations of adaptation, developing approaches for obtaining resistant varieties and forms of plants, especially in the current global climate change, its aridization. Quantitative characterization of environmental parameters in order to regulate them in accordance with the genetic potential of plants of cultivated species requires further in-depth research. At the same time, the bioecological justification of measures that provide for the most complete realization of the genetic potential of new adaptive forms of cultivated plants is updated.

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REFERENCES

1. Costa L.G.S., Miranda I.S., Grimaldi M., Silva M.L., Mitja D., Lima T.T.S. 2012. Biomass in different types of land use in the Brazil's 'arc of deforestation'. Forest. Ecol. Manag. 278, 101–109. doi: 10.1016/j.foreco.2012.04.007
2. Eilts J.A., Mittelbach, G.G., Reynolds, H.L., and Gross, K.L. 2011. Resource heterogeneity, soil fertility, and species diversity: effects of clonal species on plant communities. Am.Nat. 177, 574–588. doi: 10.1086/659633
3. Korshunov G.I., Eremeeva A.M., & Drebenstedt C. 2021. Justification of the use of a vegetal additive to diesel fuel as a method of protecting underground personnel of coal mines from the impact of harmful emissions of diesel-hydraulic locomotives. Journal of Mining Institute, 247(1), 39–47. https://doi.org/10.31897/PMI.2021.1.5
4. Krugilin S. 2018. Silvicultural growth models of the formation of Quercus Robur in the black earth zone conditions of the steppe of the South of Russia. World Ecology Journal, 8(3), 23–45. https://doi.org/https://doi.org/10.25726/NM.2019.49.29.002
5. Lawrence D., Vandecar K. 2015. Effects of tropical deforestation on climate and agriculture Nat. Clim. Chang. 5, 27–36. doi: 10.1038/nclimate2430
6. Lovanov I. 2018. Solution of the problem of the theoretical profile of non-dimensional speed on the thickness of the boundary layer at the turbulent flow in the boundary layer based on the solution of the differential equation of Abel of the second generation with the app. World Ecology Journal, 8(1), 43–51. https://doi.org/https://doi.org/10.25726/NM.2018.1.1.004
7. Oliveira R.L. de, Von Pinho R.G., Ferreira D.F., Pires L.P.M., Melo W.M.C. 2014. Selection index in the study of adaptability and stability in maize. Sci World J., 1–6. pmid:24696641
8. Semenutina A., Khuzhakhmetova A., Semenutina V., Svintsov I. 2018. A method of evaluating pigment complex wood plants as an indicator of adaptation to dry conditions. World Ecology Journal, 8(1), 69–82. https://doi.org/https://doi.org/10.25726/NM.2018.1.1.006
9. Semenyutina A., Noyanova N., kurmanov N. 2018. Scientific justification of selection of plants for sanitary protection zones in arid region. World Ecology Journal, 8(1), 52–68. https://doi.org/https://doi.org/10.25726/NM.2018.1.1.005
10. Van Eeuwijk F.A., Bustos-korts D.V., Malosetti M. 2016. What Should Students in Plant Breeding Know About the Statistical Aspects of Genotype x Environment Interactions? Crop Sci. 56, 2119–2140.
11. Willis C.G., Ellwood E.R., Primack R.B., Davis C.C., Pearson K.D., Gallinato A.S., Yost J.M., Nelson G., Mazer S.J., Rossington N.L., Sparks T.H., Soltis P.S. 2017. Old plants, new tricks: phenological research using herbarium specimens. Trends in Ecology & Evolution, 32, 531–546. doi: 10.1016/j.tree.2017.03.015.
12. Yang Z.Y., Liu X.Q., Zhou M.H., Ai D., Wang G., Wang Y.S. et al. 2015. The effect of environmental heterogeneity on species richness depends on community position along the environmental gradient. Sci. Rep. 5:15723. doi: 10.1038/srep15723
13. Zalamea A.P., Munoz F., Stevenson P.R., Paine C.E.T., Sarmiento C., Sabatier D., Heuret P. 2016. Continental-scale patterns of Cecropia reproductive phenology: evidence from herbarium specimens. Proceedings of the Royal Society B: Biological Sciences, 278, 2437–2445. doi: 10.1098/rspb.2010.2259.
14. Zelenyak A., Kostyukov S. 2018. Features of the development of architectonics of crowns of bushes as a criterion of decorativeness in green building. World Ecology Journal, 8(3), 1–22. https://doi.org/https://doi.org/10.25726/NM.2019.99.51.001
15. Zhao M.F., Peng C.H., Xiang W.H., Deng X.W., Tian D.L., Zhou X.L., Yu G.R. 2013. Plant phenological modeling and its application in global climate change research: overview and future challenges. Environmental Reviews, 21, 1–14. doi: 10.1139/er-2012–0036.
16. Zohner C.M., Renner S.S. 2014. Common garden comparison of the leaf-out phenology of woody species from different native climates, combined with herbarium records, forecasts long-term change. Ecology Letters, 17, 1016–1025. doi: 10.1111/ele.12308.