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Prerequisites for cultivating frost-resistant peach varieties in the Right-Bank part of the Western Forest-Steppe of Ukraine

Abstract. The necessity of cultivating frost-resistant peach varieties in the Forest-Steppe zone of Ukraine arises due to frequent sharp fluctuations in air temperature during the winter-spring period. Their cultivation can mitigate the impact of weather conditions, ensuring stable fruit production of this crop. The study aimed to analyse the prospects for growing peaches (*Prunus persica* Mill.) using intensive technologies under changing climate conditions. An analysis of the peach-growing situation revealed that it is a widely cultivated drupe in Ukraine and globally. The main countries leading in peach fruit production were identified: China, Italy, Turkey, Greece, and Spain. Despite a 24% increase in global peach production between 2013 and 2023, the demand for this crop has also risen, leading to a deficit and increased imports to Ukraine. Calculations of the scientifically justified annual consumption norms for peaches showed a shortfall of 187 thousand tonnes in production, with current production standing at 11.2 thousand tonnes. Several factors hindering the expansion of peach orchards were identified. The development of frost-resistant varieties by breeders, suitable for cultivation in the Forest-Steppe of Ukraine, alongside changing weather conditions, offers opportunities for the safe cultivation of peaches in the region. An analysis of the weather conditions in the Right-Bank part of the Western Forest-Steppe of Ukraine was conducted. It was found that between 2013 and 2023, there was a significant increase in the total active temperatures, with 2023 recording a maximum of 3,777°C. At the same time, precipitation decreased by 58%, amounting to only 325 mm. Considering the changing weather conditions and the development of new frost-resistant varieties, which have expanded the peach cultivation zone to northern regions of Ukraine, it is essential to prepare and implement specific measures to adapt the horticultural industry to peach cultivation in these new regions to meet domestic

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market demands. It is recommended to initiate trials in irrigated horticulture and develop new methodological guidelines to provide scientific support for establishing perennial peach orchards in the Right-Bank part of the Western Forest-Steppe of Ukraine

Keywords: *Prunus persica* Mill.; productivity; fruit market; climate change; intensive technologies; drought resistance

INTRODUCTION

In the context of climate change and unstable temperature regimes, studying the preconditions for growing frost-resistant peach varieties is crucial for ensuring the effective adaptation of this crop to various climatic conditions, especially in regions with cold winters. Researching these preconditions will help develop agronomic approaches to optimise the growing process. Frost-resistant peach varieties have the potential to expand cultivation areas in new regions, such as the Forest-Steppe of Ukraine, where peaches were previously less suitable for cultivation. In addition, studying the preconditions for cultivation will help reduce the risk of crop losses from adverse weather conditions and stabilise the production of this crop, which is important for meeting the growing needs of the domestic market.

According to J. Mohammed *et al.* (2021) and W. Liu *et al.* (2022), the value of peaches as a fruit crop lies in their nutrient-rich and biologically active components. They also contain vitamin P (anthocyanins, catechins, flavones), vitamin C (ascorbic acid), provitamin A (carotene), malic and citric acids, and pectin substances (Geçer, 2020; Aubert & Chalot, 2020).

Peach fruits are primarily consumed fresh or used in the confectionery or canning industry. Recently, new methods of storing and using the fruit have been developed. In studies by P. Wang *et al.* (2018), Y. Zhong *et al.* (2021), and K. Zhu *et al.* (2023), it was shown that quick freezing fully preserves the dietary, nutritional, and taste qualities of the fruit. The diverse composition of peach fruits indicates not only their nutritional value but also their medicinal properties, which is especially important in the complex ecological situation in the world.

The peach, traditionally recognised as a southern crop, is gradually expanding into other regions of Ukraine due to the introduction

of new varieties and the adaptation of cultivation technologies. V. Blinova (2019) emphasises that climate changes and improvements in agrotechnical practices have enabled the successful cultivation of peaches in more northern regions. Research by D. Hromov (2023) highlights the importance of selecting adapted varieties for the western and northern parts of the country, where climatic conditions differ from those in the southern regions. These areas experience cooler temperatures and higher humidity, which affect the growth and development of peach trees. According to I.V. Liadska & O.Yu. Holovko (2023), most of Ukraine offers favourable conditions for stable fruit production, including peach cultivation using intensive technologies. However, the combination of intensification factors and their role in yield formation vary significantly depending on the region, soil fertility, utilisation of the variety's biological potential, and the availability of material resources for the technology used.

Special attention is paid to the choice of variety in the research of O.M. Aleksieieva & I.V. Yudytska (2023), as varieties created in Ukraine are the most adapted to its conditions and contribute to increasing the efficiency of fruit production. Each zone has its own characteristics. In the Forest-Steppe zone of Ukraine, new frost-resistant varieties of this valuable crop are being introduced, which is due to their high adaptability to temperature fluctuations in the winter-spring period. D.G. Bielenberg & K. Gasic (2022) have proven that this is facilitated by the duration of dormancy, the rate of morphogenesis, and the winter hardiness of the generative buds.

At the same time, the Forest-Steppe of Ukraine experiences unfavourable weather conditions during the growing season each year. D. Natalchuk & L. Pavliuk (2024) found that the spring and summer periods are marked

not only by rising temperatures but also by frequent droughts. Although the average annual precipitation for 2013-2023 was 418 mm, its distribution was highly uneven. High air temperatures and low humidity levels lead to atmospheric drought, which eventually turns into soil drought. While peach is a drought-tolerant crop, a lack of rainfall can result in not only a decline in the commercial quality of fruit in a drought year but also affect the formation of generative buds for the following year. D. Natalchuk & L. Pavliuk (2024) found that although peach is noted for its drought tolerance, there are differences among varieties in terms of leaf tissue water content and water deficit indicators. These varieties are classified into three drought-resistance groups: highly drought-resistant, drought-resistant, and moderately drought-resistant. The water loss dynamics observed, depending on the drought-resistance group, indicate that highly drought-resistant combinations possess the highest water retention capacity. Therefore, in the context of climate change, it becomes increasingly important to develop varieties that are well-adapted to adverse abiotic environmental factors, particularly frost and drought resistance.

The aim was to analyse the prospects for peach cultivation using intensive technology under the conditions of climate change.

The study is based on a detailed analysis and identification of frost-resistant peach

varieties listed in the State Register of Plant Varieties Suitable for Propagation in Ukraine (2024), as well as the most promising and introduced varieties. For these varieties, key factors that enable the expansion of peach cultivation to more northern regions of Ukraine have been identified based on a review of literature sources. The analysis of FAO data (n.d.) on global peach production is limited to 2022, as this was the most recent data available at the time of publication.

Peach Cultivation in Ukraine and Worldwide

Between 2012 and 2022, the global area under peach cultivation saw a slight increase. According to the FAO (2024), the area dedicated to peach orchards globally expanded by 1.8 thousand hectares, reaching 1,542,648 hectares by 2022. During this period, gross peach production grew by 24%, reaching 26.3 million tonnes. China remains the world's leading peach producer, with an average annual output of 15.4 million tonnes, which increased to 16.8 million tonnes in 2022 (Fig. 1). In contrast, Ukraine produces only 21 thousand tonnes of peaches. Other major peach-producing countries include Italy (1.2 million tonnes), Turkey (1 million tonnes), Greece (895 thousand tonnes), Spain (871 thousand tonnes), Iran (577 thousand tonnes), Chile (312 thousand tonnes), and Egypt (272 thousand tonnes).

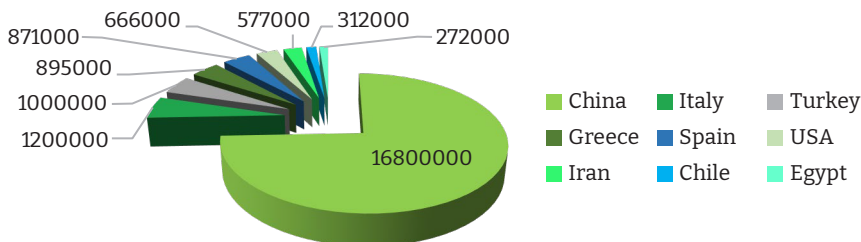


Figure 1. Global peach production, tonnes, 2022

Source: compiled by the authors based on FAO (n.d.)

In Ukraine, the largest area dedicated to peach orchards was recorded in 1998, totalling 20.5 thousand hectares. However, this area gradually declined to 3.3 thousand hectares by 2018 and further decreased to 1.5 thousand hectares

by 2023 (Fig. 2), primarily due to the annexation of Crimea and the occupation of southern regions of Ukraine. Currently, the majority of peach orchards are concentrated in the Odesa Region (1 thousand hectares), Dnipropetrovsk

Region (0.2 thousand hectares), Mykolaiv Region (0.2 thousand hectares), and Zakarpattia Region

(0.1 thousand hectares) (State Statistics Service of Ukraine, n.d.).

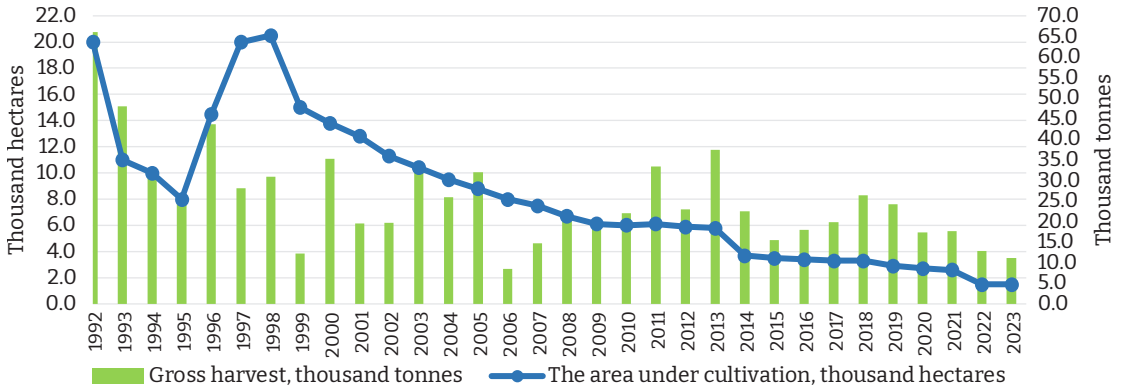


Figure 2. Peach orchard areas and gross harvest in Ukraine, 1992-2023

Source: compiled by the authors based on the State Statistics Service of Ukraine (n.d.)

Overall, as illustrated in the diagram, the area dedicated to peach orchards has decreased by a factor of 13.6, or nearly 93%. However, this decline has been accompanied by an increase in yield per unit area. In 1998, the gross harvest for an area of 20.5 thousand hectares was 30.9 thousand tonnes, resulting in a yield of only 1.5 tonnes per hectare. In contrast, by 2008, the figures were 6.7 thousand hectares, 22.7 thousand tonnes, and 3.4 tonnes per hectare, while in 2018, they stood at 3.3 thousand hectares, 26.4 thousand tonnes, and 8 tonnes per hectare, respectively. Consequently, the yield has increased by a factor of 5.3, primarily due to the intensification of production, which involves the use of new frost-resistant, high-yield varieties and rootstocks that promote precocity and enable orchard densification.

It is worth noting that, given the current level of production, the domestic market for peaches remains deficit. To meet the scientifically justified annual consumption norm of up to 6 kg per person, production must be increased to 198 thousand tonnes; however, in Ukraine, only 11.2 thousand tonnes were produced in 2023 (State Statistics Service of Ukraine, n.d.). This represents a niche that requires development and improvement, both in cultivation technologies and in the research of new promising variety-rootstock combinations, which would enable an increase in peach production in the more northern regions.

Analysis of Peach Varieties in Ukraine

Under certain socio-economic conditions, peach cultivation in Ukraine began to develop in the late 1940s. The main growing regions included Crimea, the western, central, and southern Steppe, as well as Transcarpathia. Here, varieties of Western European origin were predominantly cultivated, known for their excellent taste quality. However, these trees were susceptible to diseases and damage from low temperatures (Barabash *et al.*, 2000).

However, the development and utilisation of frost-resistant peach varieties under favourable weather conditions enable the production of high and consistent yields (Shoferistov & Bunchuk, 2013; Liadska & Holovko, 2023). Many varieties begin to bear fruit within two to three years of being planted in a permanent location, and by the fifth or sixth year, they can produce exceptionally high yields, making this crop highly profitable in commercial orchards (Hulko, 2009). For this reason, peach fruits enjoy unrestricted demand among the population, creating the conditions for further comprehensive study of this crop in various fruit-growing zones.

As of 2024, the list of peach varieties suitable for propagation in Ukraine comprises 26 officially recommended varieties. Among these, 16 are recommended for the Forest-Steppe zone, with frost-resistant varieties including Kniazhehradskiy, Dniprovskiy, Druzhba, Kyivskiy ranniy, Lesia, Liubymets II, Oksamytoyvi,

Pamiat Hryshko, Pecherskyi, and Slavutych. Most of these varieties were developed at the M.M. Hryshko Central Botanical Garden and the Institute of Horticulture of the National Academy of Agrarian Sciences (NAAS) in Kyiv (State Register..., 2024). Significant work has also been undertaken to create high-quality winter-hardy peach varieties that are resilient to the climatic conditions of Ukraine at the Nikita Botanical Garden (Yalta), the Institute of Irrigated Horticulture (Melitopol), Odesa State Agrarian University, and Uzhhorod State Agrarian University (Turovtseva & Turovtsevoi, 2002; Rikhter, 2013). Notable varieties developed at these institutions include Iiunskyi Rannii, Krymskyi Feierverk, Charivnyk, Skazka, Zlatodar, Posol Myru, Vireneia, and Zolotystyi. Furthermore, peach breeding is ongoing, with new varieties being created that have already been registered or are proposed for inclusion: Mostyskyi, Mostyskyi diamant, Kniazhe bahatstvo, Kniazhe Zoloto, Pontiiskyi, Osvizhaiuchy and Karnavalnyi (Lytovchenko *et al.*, 2011).

The assortment of peaches in Ukraine is also being supplemented by varieties of foreign breeding. The primary criteria for selecting a variety for cultivation in commercial orchards are, first and foremost, frost resistance, marketability, and transportability (Klochko, 2014). The most commonly introduced varieties include Redhaven, Early Crest, Rich May, Ruby Prince, George Line, Harbinger, and Harness. Additionally, there is considerable popularity for varieties marketed under the general brand name Flemin Fury: PF 58, PF 11N, PF 19 007, PF 24C, PF 23, and PF 24 007. H.H. Klochko (2013), in studying the introduced peach varieties Gold Line, Harrow Beauty, Montar, and Harrow Diamond, noted their high adaptability to cultivation

conditions and indicated that they could serve as parent varieties exhibiting high fruit quality for future breeding efforts.

Frost and Winter Hardiness of Peaches in the Context of Climate Change

Cultivating peaches in the majority of Ukraine is a risky endeavour. A crucial factor influencing both productivity and the regularity of fruiting is the tree's winter hardiness. According to I.M. Holubkova (2016), I.V. Liadska & O.Yu. Holovko (2022), peaches are the most thermophilic deciduous fruit crop in temperate climate zones. Temperature regime is one of the primary factors that determines the cultivation of peaches in a particular area. When there is insufficient warmth during the growing season, peach trees may grow, but their fruits do not ripen. For instance, in Denmark and southern Sweden, peach plants can withstand winter temperatures; however, due to a lack of the necessary warmth in the summer months, their fruits fail to mature (Aleksieieva & Yudytska, 2023).

In her research, O. Bezkrovna (2014) established that an optimal sum of effective temperatures of up to 2,500 °C is required for the normal growth and ripening of peach fruits. However, prior to 2013, the sum of active temperatures in the Kyiv Region did not support the cultivation of peaches. Between 2013 and 2023, however, a significant increase in the sum of active temperatures was recorded in Kyiv. According to data from the meteorological station located in the experimental orchards of the Institute of Horticulture of the NAAS, the sum of active temperatures was 3,192 °C in 2013 and remained at that level until 2017. From 2018 onwards, it increased to 3,681 °C and continues to rise with periodic fluctuations (Fig. 3).

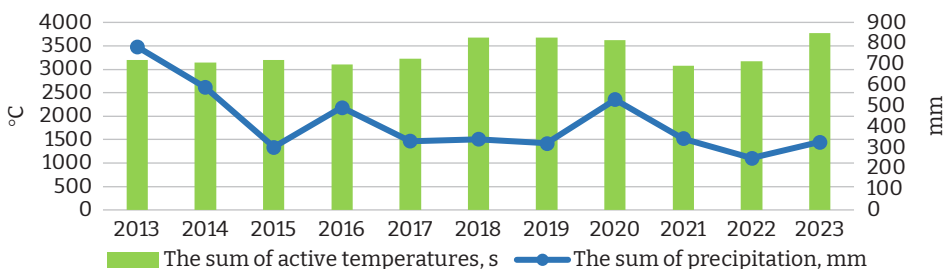


Figure 3. The sum of active temperatures and precipitation for 2013-2023

Source: compiled by the authors based on data from the meteorological station of the Institute of Horticulture NAAS

In 2023, a record maximum sum of active temperatures was recorded at 3,777 °C, enabling the unobstructed cultivation of not only peaches but also other heat-loving crops in this region. Such changes in temperature patterns have been noted by several researchers, including O.V. Shevchuk (2023), who states that during the period from 1991 to 2020, this positive anomaly (the deviation of air temperature from climatic norms) was the largest across the entire country in the history of instrumental meteorological observations.

However, for peaches, the temperature regime is significant not only during the growing season but also during the dormant period (Shoferistov & Bunchuk, 2013; Fadón *et al.*, 2020; Milech *et al.*, 2022). An analysis of long-term data on the productivity and condition of peach plantations indicates that even in the southern and southwestern regions of Ukraine, where the industrial cultivation of this plant is well established, critical conditions for the overwintering of trees periodically arise (Riabov, 2011). Approximately once every 5 to 10 years, critical conditions for plant overwintering develop, characterised by sharp fluctuations in low temperatures and their prolonged effect during the winter-spring period, especially with minimal snow cover, leading to the freezing of flower buds and wood in areas such as Transnistria, Kyiv, Zaporizhzhia, and even Crimea. O.M. Aleksieieva & I.V. Yudytska (2023) note that the most damage is often caused by temperature fluctuations in February when thaws alternate with significant drops in temperature at night. Several researchers from other countries also address spring frosts as a limiting factor in peach cultivation (Kuden *et al.*, 2018).

In a dormant state, depending on the variety and rootstock, peaches can withstand low temperatures ranging from 23 to 28°C. For swollen buds, temperatures of 18 to 19°C are detrimental, while for split buds, approximately 12°C is critical. During the flowering stage, buds are damaged at temperatures between 3 and 4°C, meaning that spring frosts can destroy a significant portion of the harvest (Feshchenko, 2004).

O.M. Aleksieieva & P.H. Bondarenko (2021) asserted that a decrease in peach yield is only observed when 75 to 80% of the floral buds are

killed. Additionally, the second wave of growth, or what is referred to as premature shoots, plays a crucial role in the trees winter hardiness. It is known that flower buds exhibit the greatest winter hardiness during the phase of archeosporium (the initial formation of pollen), which occurs during the deep dormancy of the plant. In the second wave of growth, this phase lasts longer (up until the end of January), allowing the buds on these shoots to maintain frost resistance for a significantly extended period. At the same time, several researchers indicate that the yield of peaches depends on the formation and differentiation of generative buds on these growths; poor bud formation makes it impossible to achieve high yields. Bud differentiation occurs in the second half of summer and is influenced by variety, weather conditions, plant nutrition, and other factors (Li *et al.*, 2016; Bep-pu, 2020; Surányi, 2020).

The winter hardiness of drupes, including peaches, refers not only to their resistance to low temperatures but also to their ability to withstand a range of adverse factors during the winter period. Among these factors, the most significant are the characteristics of the temperature regime, the desiccating effect of wind, frost, and sunburn.

Drought Resistance as a Factor in Achieving Stable Yields

However, the winter hardiness of peaches is significantly influenced by the plant's development and its progression through various stages of organogenesis. Beginning in the second half of summer, processes commence within peach plant tissues to prepare for winter – shoot growth ceases, structural reorganisation occurs within the cells, and a series of physiological processes take place. These include the accumulation of starch, sugars, and phosphorus compounds, a reduction in the levels of growth stimulators, and an increase in the number of inhibitors (Opanasenko, 2005). As a result of metabolic changes, plants enter a state of dormancy, reaching a physiological condition that confers high frost resistance; however, this resistance may be insufficient in the absence of favourable weather conditions. For instance, during noticeable drought or cool, rainy weather in summer,

trees may fail to complete their vegetative cycle adequately and may perish during frosts that trees cultivated under favourable summer conditions can withstand. It has been established that following drought periods, frost resistance decreases by 4–6°C (Kryvoshaka *et al.*, 2018).

Consequently, drought resistance is a crucial economically valuable trait of a variety, as it reflects adaptive properties to moisture deficiency and impacts the overall health of the plants, as well as their yield and fruit quality. Among fruit crops, peaches are classified as drought-resistant, characterised by an enhanced ability of their leaves to retain water, relatively rapid restoration of turgor after wilting, and the capacity to utilise low levels of available water in the soil (Smykov *et al.*, 2013). The resistance to drought is facilitated by a well-developed vascular system, primarily attributed to the organism's genetics, as well as the physiological, biochemical, and anatomical characteristics of the aerial organs (Liu, 2023). In this context, there is a significant reduction in moisture loss through transpiration and an increased heat resistance of the tissues, which in turn contributes to the overall high drought resistance of the organism (Bunchuk, 2013).

At the same time, to achieve high yields of market-quality produce, particularly under drought conditions, peaches require a substantial amount of water. Atmospheric precipitation constitutes the primary component of the water balance. Insufficient rainfall from May to August leads to significant crop losses, while temperature fluctuations and inadequate precipitation adversely affect plant growth and development (Silaev, 2003). Water serves as both a solvent and a medium for the movement and exchange of substances, and its high specific heat capacity helps stabilise plant temperatures (Kryvoshaka, 2012). When moisture is deficient, fruit-bearing plants cease to grow, their leaves and fruits wilt and drop, and the formation of generative buds diminishes, consequently reducing yields not only in the drought year but also in the following year (Fernandez *et al.*, 2020).

An analysis of the total precipitation from 2013 to 2023 reveals a clear trend of decreasing rainfall (Fig. 3). Previously, from 1961 to 1990, the average annual precipitation across Ukraine

was 578 mm (Shevchuk, 2023); however, this figure has now dropped to 418 mm in the Kyiv Region. The year 2022 was notably the driest, with a total precipitation of 249 mm, representing a reduction of 67% compared to the long-term averages. A significant decline in rainfall has been observed since 2015 when the total was 301 mm. Moreover, not only is the total amount of precipitation decreasing, but it is also unevenly distributed throughout the growing season of the trees. A detailed month-by-month analysis indicates that the driest months are July and August, during which the future harvest is established.

Consequently, considering climate change – specifically the increase in active temperature accumulation, the reduction of minimum winter temperatures, and the development of frost-resistant peach varieties by both Ukrainian and foreign breeders – conditions are becoming favourable for cultivating this crop in the Forest-Steppe zone of Ukraine. The insufficient moisture during the growing season presents new challenges for researchers, particularly in establishing irrigation horticulture experiments in this area. It is essential to develop new methodological recommendations and provide scientific support for the establishment of perennial plantings, including peach orchards by both commercial farms and private amateur gardeners.

CONCLUSIONS

The analysis of various literary sources indicates that the peach is a widely cultivated drupe globally, with both the area under cultivation and yield continuously increasing. In contrast, Ukraine has experienced a reduction in cultivated area; however, the implementation of intensification elements has led to a 5.3-fold increase in yield, while the needs of the domestic market remain unmet. The primary objectives set for researchers and horticulturists involve expanding cultivated areas not only in the southern regions but also in more northern areas due to changing climatic conditions. Among the key factors facilitating the spread of peach cultivation into northern regions of Ukraine is the development of frost-resistant varieties that can adapt to unstable weather conditions during the winter-spring period. Additionally, the temperature regime plays a significant role, particularly the

increase in active temperature accumulation during the spring-summer period, both within Kyiv Region and in other regions of Ukraine, allowing peaches and other heat-loving crops to grow and bear fruit uninterruptedly, as well as ensuring even ripening of the fruits.

At the same time, it has been established that the high temperatures and insufficient rainfall observed during the period 2013-2023 create conditions for the formation of dangerous phenomena in horticulture – air and soil droughts. Therefore, drought resistance is also an important characteristic of the crop and variety in particular, as it affects the overall condition of plants, yield, and fruit quality. Thus, considering the weather changes of recent years and the creation by breeders of new frost-resistant varieties, which has contributed

to the shift in the distribution range of peach culture to more northern regions of Ukraine, it is necessary to prepare and implement special measures to adapt the horticultural industry to the cultivation of this crop in new regions for it.

It is recommended to start laying down experiments on irrigated horticulture and develop new methodological recommendations to provide scientific support for the establishment of perennial peach plantations in the conditions of the Right-Bank part of the Western Forest-Steppe of Ukraine.

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CONFLICT OF INTEREST

None.

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Передумови вирощування морозостійких сортів персика у правобережній частині Західного Лісостепу України

Анотація. Необхідність використання морозостійких сортів персика у зоні Лісостепу України обумовлена частими різкими коливаннями температури повітря у зимово-весняний період, а їх вирощування дозволить нівелювати вплив погодних умов для стабільного виробництва плодів цієї культури. Тому метою досліджень було проаналізувати перспективи вирощування персика (*Prunus persica* Mill) за інтенсивними технологіями в умовах зміни клімату. Проаналізувавши ситуацію з вирощування персика встановлено, що він є досить поширеною кісточковою культурою, як в Україні так і в світі. Виділено основні країни, що є лідерами по виробництву плодів персика: Китай, Італія, Туреччина, Греція та Іспанія. Не зважаючи на приріст валового виробництва (на 24 %) плодів персика у світі за 2013-2023 рр. відбулось і підвищення попиту на цю культуру, що провокує дефіцит і зростання рівня імпорту в Україні. За розрахунками із забезпечення науково-обґрунтованих річних норм споживання плодів персика виявлено, що нестача їх у виробництві становить 187 тис. т при нинішньому виробництві 11,2 тис. т. Виявлено фактори, що стримують розширення площ під персиковими насадженнями. Проте створення селекціонерами морозостійких сортів, придатних для вирощування в Лісостепу України, разом зі зміною погодних умов дають можливість для безпечного культивування персика в регіоні. Проведено аналіз погодних умов правобережної частини Західного Лісостепу України. Установлено, що за 2013-2023 рр. суттєво підвищилась сума активних температур, а 2023 рік відзначився максимальним значенням – 3777 °С. При цьому сума опадів знизилася на 58 % та становить всього 325 мм. Враховуючи погодні зміни і створення селекціонерами нових морозостійких сортів, що сприяло зміщенню ареалу поширення культури персика в північні регіони України, необхідна підготовка та реалізація спеціальних заходів щодо адаптації садівничої галузі до вирощування цієї культури у нових для неї регіонах з метою задоволення потреб внутрішнього ринку. Рекомендується розпочати закладання дослідів із зрощувального садівництва та розробити нові методичні рекомендації для забезпечення наукового супроводу при закладанні багаторічних насаджень персика в умовах правобережної частини Західного Лісостепу України

Ключові слова: *Prunus persica* Mill; продуктивність; ринок плодів; зміна клімату; інтенсивні технології; посухостійкість