

Chapter

Preferable Berry Fruits for Tolerance to Global Climate Change and Dry Conditions

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Abstract

Global climate change and possible drought scenarios have forced researchers, breeders and producers to create new plant patterns that will adapt to changing climate and soil conditions for production of horticultural plants in the future. Here, the most important topic is the shortening of the physiological growth period of plants due to abiotic stress. In other words, reductions experienced in both cooling needs and maturation periods cause negative impacts on flowering times and amounts, and this causes significant loss of yield. In recent years, the production of berry fruits that will adapt to drought conditions has attracted the attention of breeders and producers. The aim of this study is to discuss in detail the possibilities of producing berry fruits that are resistant to drought and negative climate conditions and to present research results and recommendations about this topic. In this study, the production opportunities in arid and negative climate conditions for the berry fruits of strawberry (*Fragaria vesca* L.), mulberry (*Morus* spp.), fig (*Ficus carica* L.), blackberry (*Rubus fruticosus* L.), chokeberry (*Aronia melanocarpa* L.), rosehip (*Rosa canina* L.), raspberry (*Rubus idaeus* L.) and blueberry (*Vaccinium corymbosum* L.) were researched and recommendations are made about production methods for some varieties and types resistant to drought in berry fruit cultivation.

Keywords: climate change, aridity, berry fruit, adaptation, production models

1. Introduction

Agricultural activity, an ecosystem linked to nature, is one of the sectors most affected by global climate change. Climate change occurring as a result of greenhouse gas emissions negatively affects all agricultural activities. Additionally, fruit cultivation is the agricultural activity most sensitive and most intensely impacted by global warming and climate change. As a result, fruit trees are negatively affected by unsuitable climate conditions during winter rest, flowering, budding and fruiting periods and large economic losses occur. It is predicted that climate change will cause global

food crises, that food crises will become more severe with climate change and that small-scale farmers will be the first and most severely impacted group as a result of climate change. Among agricultural products, the agricultural products most negatively impacted by climate change and greenhouse gas emissions come from horticultural plants. One of the most negative physiological responses to climate change is experienced in the growth and development periods of fruit and vegetable production. These effects will create negative outcomes for the growth and development of horticultural plants with water loss from soil due to temperature increases. As a result, within the framework of ecological change, it is mandatory to perform breeding and adaptation studies of species and varieties suitable for climate change on a product basis [1].

The IPCC predicts that in the period from 2070 to 2100, the mean temperature in Türkiye may increase from 3 to 7°C. This increase will be higher in warm seasons compared to cold seasons, with temperatures in the summer months predicted to be 4.5°C higher while temperatures in winter months will be 3.5°C higher. According to a more pessimistic scenario, the expected increases may reach 7°C in the summer months and 4.5°C in the winter. According to the results of regional climate models, a clear reduction is expected in rainfall in the west and south regions where the Mediterranean climate is dominant, while an increase in rainfall is expected in the Black Sea region. Due to increasing temperature and reducing rainfall, the severity, frequency and duration of drought events are expected to significantly increase [2]. Drought events, frequently experienced due to anthropogenic climate change, the resulting increasing atmospheric temperatures, and changes in rainfall will significantly damage global agricultural systems and agricultural production [3, 4]. Due to the complicated climate structure of Türkiye, it appears to be one of the countries that will be most affected by climate change due to global warming [5, 6]. Additionally, as is known, climate change will impact different regions in different ways and at varying scales as Türkiye is surrounded on three sides by seas, has variable topography and orographic features. For example, just as the Southeast and Central Anatolian regions will be under threat of further desertification due to temperature increases, arid and semiarid regions and semi-humid Aegean and Mediterranean regions without adequate water will be more impacted [5]. It is considered that the significant reductions in rainfall in the Seyhan River basin in 2070–2100 and changes in the amount of snowfall and melt times will change the seeding/planting times for basic products like wheat and corn, and more importantly will change the planting localities [7]. In Türkiye, there are serious concerns related to the increases that will occur in summer and winter temperatures, reductions in rainfall and agricultural production, and increases in sea level [8].

In light of this knowledge, undoubtedly the negative climate conditions will take their toll on berry fruit production. However, berry fruit generally do not cover a large area in terms of production area, while the high possibility for horizontal or vertical agriculture for berry fruits like strawberry, raspberry, gooseberry and blueberry, especially, has attracted the attention of producers. The product with highest cultivation in berry fruit production around the world is the strawberry. For global blueberry production, the USA is in first place producing 308,760 tons, followed by Canada in second place with 176,127 tons, Peru in third place with 142,427 tons and Spain in fourth place with 53,380 tons. For global raspberry production, Russia is in first place producing 174,000 tons, followed by Mexico second with 128,848 tons, Poland third with 150,000 tons, Serbia fourth with 120,058 tons and USA in fifth place with 102,510 tons production. Türkiye has 8% share of global berry fruit production and it was reported that 24.92% of this is strawberries, while 25.18% is other berry fruit species [9]. As a result, the convenience of producing berry fruit

will increase their preferability in the struggle with global warming and drought. Additionally, berry fruits generally have bush and spreading forms and just as they can be cultivated in very large areas, they can also be cultivated in narrow and small areas, which makes these plants more advantageous. Berry fruits grow on small fruit plants with different colors like blue, purple and red. Berry fruits with more common production around the world in recent years may be listed as chokeberry, barberry blueberry, cranberry, blackberry, raspberry, white, red or black currant, and strawberry. Additionally, the shelf-life of berries is short and their use in processed food like fresh fruit, fruit juice, jam and drinks is limited. Additionally, the majority of berry fruits require different storage methods in processes like drying and packaging to preserve the quality of fruit during storage [10]. Berry fruits contain flavonoids (anthocyanins, flavonols and flavanols like concentrated tannins or proanthocyanidins), hydrolyzable tannins (ellagitannins and gallotannins), phenolic acids (hydroxybenzoic and hydrocinnamic acids, chlorogenic acid), and high levels of polyphenols like stilbenoids and lignans [11, 12].

Berry fruits grew wild in forests in the first years and were cultivated mainly as fence plants along field boundaries. It is known that cultured varieties of berry fruits were derived from soft- and hard-seeded fruits toward the end of the 16th century. Currently berry fruits are very commonly grown, especially in Europe; however, apart from strawberries, cultivation of the others is still new in Türkiye. As berry fruits are very rich in aroma agents, they are used at broad scale mainly in the marmalade, jam, fruit juice and drink industries [9, 13, 14]. Additionally, berry fruits contain phytochemicals like phenolic acids (hydroxybenzoic and hydroxycinnamic acid), flavonols (quercetin, kaempferol, myricetin), flavanols (catechins and epigallocatechin [EC]), anthocyanins (cyanidin glycosides and pelargonidin glucosides) and flavonoids like tannins. Anthocyanins responsible for the color of the fruit are found in abundant amounts in the skin of the fruit [15–20]. Due to these rich bioactive components, there is increasing demand for berry fruits in recent years. Hence, berry fruits are products with high added value and economic value. While the wild berry fruits found in the natural flora of Türkiye are collected from forest areas and sold for fresh consumption in local markets, cultivated species are processed or frozen for use in products like fruit juice, jam, jelly, puree and ice cream due to being seasonal [21–24].

Additionally, due to the wealth of active components in berry fruits, several studies have been performed as consumption of berry fruits like mulberry, chokeberry, barberry blueberry, cranberry, blackberry, raspberry, white, red or black currents and strawberry is very beneficial in terms of health [25–28]. Additionally, in recent years, drying processes have been performed for berry fruits, as for many types of fruit. New technologies used for drying processes contribute to the struggle against global warming and climate change. For export of fresh fruit, high cost storage and transport processes are implemented to prevent degradation of fruit during storage and transport. This process increases both costs and energy consumption as input costs increase and more energy is used. At this point, trade in dried fruit has gained more importance for market presentation in recent years. For example, for quality features of dried fruit, drying conditions and techniques used require great care due to fruit being very sensitive to degradation of phytochemical content like anthocyanins and phenolic compounds [10, 12]. Classic drying processes generally cause losses of the functional properties and antioxidant activities of fruit. As a result, the drying process conditions and methods used are known to significantly affect the bioactive compounds in the fruit, linked to the fruit species. Additionally, fruit dried with the lyophilized drying

method, for example, generally do not have any changes in color, nutrients, vitamin values, aroma, odor and fruit shape. This and similar methods are considered to contribute to methods in the struggle against global climate change and drought in the future, though costs are high at the moment [12, 29]. Additionally, it is known that climate factors have very significant effects on biochemical properties of fruit. For example, bioclimatic data about atmospheric forcing on the vine in the long term identified different climate variables in certain places in the long-term period had significant effects on the growth cycle of vines, biomass production and grape properties based on temperature and radiation intensities and durations in a spatial and temporal sense in viticulture [30, 31]. Some of the most important factors affecting fruit production and quality of berry fruits are extreme climate conditions during winter rest, flowering, budding and fruiting periods [32]. In fact, it was reported that budding would be delayed as a result of not meeting cooling needs linked to temperature increases for viticulture in the Margaret River region in Australia [33]. To better prepare for possible impacts of climate change, it was reported that it was necessary to perform more research about breeding varieties with lower cooling requirements, developing rootstocks that can cope with inadequate winter cold and understanding the responses of products to temperature better [34]. For example, in Downeast, Maine region of the USA, research about wild blueberry fruits reported that summer temperatures significantly increased over 40 years in natural blueberry fields due to climate change and this situation caused farmers to experience significant economic losses [35].

Every year in different regions and provinces significant losses are experienced in many agricultural sectors due to the negative impact of climate change on drought, hail, heavy rainfall, floods, frost, storms and other abiotic stresses. Additionally, changing climate events, unbalanced rainfall and high-low temperature regimes threaten all sectors of agricultural production [36]. Climate change causes a reduction in fruit and vegetable production from annual and perennial horticultural plants for agricultural production, shortening the growth duration of plants due to negative effects on growth and development of plants linked to terminal heat stress, especially. The results will provide a beneficial guide for planning vine development in the future in Serbia. However, contrary to what is known, this research reported that cold damage, usual to date, may be reduced in cold regions, especially. However, it was reported that there is a need for more detailed studies and to develop concrete adaptable strategies to clearly say that there will be positive effects for viticulture in Serbia. Additionally, it was reported that research in the future should use multi-model and multi-scenario climate modeling with the holistic approach, identify the accuracy of data obtained from this modeling and measure the correlation between grape quality and yield by revealing the impacts on vine phenology due to climate change in the region. Other factors that need to be explained include identification of the impacts on plants of other meteorological factors like humidity and wind, in addition to temperature and rainfall; direct effect of increasing atmospheric carbon dioxide concentrations on vines; impacts of soil, topography and other environmental factors on vine products; impacts of climate change on disease and pests; and determining the possible physiological reactions of some vine varieties to predicted climate changes [37]. In many European countries, though strawberries are cultivated in strawberry gardens using plastic cover material as they are early producers and to protect from cold, strawberry cultivation is still performed in open areas. As is known, plastic cover materials are commonly used with the aim of preventing damage from frost in the flowering period in spring and to ensure early yield in strawberry cultivation. Additionally, in many countries in Europe, around the world and in Türkiye,

automation in production of berry fruit like strawberry, blueberry, blackberry and mulberry uses steel, wood and similar constructions to create gothic, arc roof, tunnel and glass greenhouses produced from plastic and glass (with shades) appropriate to the geographical and climate conditions suitable for the berry fruit type and variety [38]. The aim of this study is to provide information about which production methods and models should be applied in climate regions for the cultivation of berry fruits linked to temperature, rainfall and aridity, and what the appropriate rehabilitation work is for a variety of rehabilitation, drought and limited irrigation methods considering aridity and vegetation indexes. Information is also given about care and training systems for berry fruits, irrigation, methods against disease and pests, marketing and processing techniques.

2. Cultivation models for berry fruit compatible with aridity and climate change

In this section, the focus is on botanic and ecological needs and nutritional content of berry fruit with easy cultivation and high adaptation to different climate conditions to be able to use them in arid and global climate change scenarios. In general, the ability of individual genotypes of all plants to create distinct phenotypes when exposed to varied environmental situations is referred to as phenotypic plasticity. Environmental influences on the expression and function of genes that regulate plastic characteristics cause these phenotypic variations [39]. As in all fruits, fruit phenotypic properties such as sugars, acids, phenolics, anthocyanins and aroma compounds in berry fruits are significantly affected by variety and environmental conditions. The combination of these phenotypic parameters depends entirely on the stability of fruit traits. Researchers defined this situation as “the tendency to keep the characteristic of a physiological or morphological system constant [40]. Despite the fact that phenotypic plasticity is a significant ecological phenomenon, genetic and molecular mechanisms are insufficient to fully explain it [41]. Moreover, phenotypic variation between species and organisms within the same species can effect variances in gene expression as well as differences in gene structure. However, it is hypothesized that phenotypic plasticity between clones of the same genotype is far more dependent on variable gene expression in different contexts [42]. Recent research has shown the presence of high-throughput expression profiling tools, which making it possible to analyze the genetic mechanism (activity and spatio-temporal features) on a global scale. As a result, the impact of transcriptome plasticity may now be studied directly [42–44]. In order to adapt to climate change, new research and applications continue to be developed in terms of all kinds of plant and animal production techniques. Especially in the production of berry fruits, researches on the choice of soil location, tillage, seedling production from production techniques, planting system, pruning and training systems, changes in the planting environment (soilless culture, horizontal or vertical agriculture, plant nutrition and garden management systems with machine learning content, artificial plant environments) continue at full speed. For this purpose, in a study conducted by [45], they stated that regarding the berry orchard, applications that increase the organic matter level of the soil should definitely be made, the berries in the garden are different in terms of soil compaction in the management applications should be considered; and for example, different doses should be tried for the soils of different berry species for an economical approach in the barnyard manure applications. Furthermore, they recommended

that preliminary soil analyses be performed before establishing berry orchards, and that berry varieties suitable for these soil qualities be favored. For instance, berry types with stronger root structure than other berry types, such as aronia, blackberry, and goji berry, should be favored in semi-arid environments. Besides, except very hot, arid, and foggy environments, blackcurrant growing does not provide significant climatic challenges. It is more cold-resistant than other berry fruits. Black currants are vulnerable to hard winters. Currant cultivation is dangerous in areas prone to spring frost [46]. The discovery of “primocane” types, which take fruit from flower buds grown on one-year shoots, is the most significant breakthrough in blackberry production today. These variations are favoured not because they produce higher-quality items, but because they allow harvest to extend a longer period of time through the use of techniques such as tip picking into breeding systems. In recent years, thornless primocane cultivars have also been developed. Adaptations of these cultivars continue in greenhouse cultivation, particularly along the Mediterranean coast. The private sector is developing healthy and high quality seedling production, variety adaptation and introduction, extension of the harvest period with different breeding techniques, greenhouse, fertigation, correct harvesting and preservation techniques. Planting healthy, suitable seedlings at the correct time is a critical aspect in strawberry production. Strawberry seedlings used in cultivation include frigo, fresh, green, and “plug” seedlings. The frigo seedling is the most often utilized seedling type in strawberry growing in Turkey and many other nations across the world. However, in recent years, the use of frigo seedlings has been completely abandoned, especially for early growing; and the use of fresh and “plug” seedlings has begun. Due to the ecology and planting period during which flower bud production occurs, it is feasible to obtain fruits earlier in culture with these seedlings, and harvest is extended a wider period [47]. Thus, changes are made in the production and breeding techniques mentioned above, taking into account climate change and ecological conditions in the production of berry fruits. Furthermore, numerous production practices, such as mulch treatments, soil processing processes, and irrigation systems, have had to modify as a result of climate change and temperature increases.

The study of species and cultivars suitable for drought and adverse climatic conditions in berry fruits is one of the priority issues of plant breeders all over the world. Honey berry (*Lonicera caerulea* L.) production, for example, is increasing in certain European countries as well as Canada and Japan. The explanation for this is that it is a plant of Russian origin with a remarkable adaptation to severe environmental conditions. Besides its fruit is a sort of berry with a distinct flavor reminiscent of raspberry, blackcurrant, and blueberry. Its fruits range in flavor from bitter to sour to sweet [48]. Honey berry is notable for its early maturity, high ascorbic acid content in its fruits, and bioactive flavonoid content. One of the most important features of this berry is its exceptional frost resistance to cold, its suitability for mechanized harvesting, and its resistance to diseases and pests [49]. Its cultivation is still taking place in Russia, Japan, Poland, the Czech Republic and Canada. There are more kinds bred in Russia, where the population density is high. Tundra, Berry Blue, Indigo Gem, and Borealis were among the major cultivars launched in Canada in the early 2010s. New kinds include the honey bee, Aurora, Boreal Blizzard, Boreal Beauty, and Boreal Beast [50]. Boreal Beauty (*Lonicera caerulea* var. *edulis*) is a new variety with superior characteristics developed in Canada. Boreal Beauty carries the Russian, Japanese and Kuril gene. It is the most heat tolerant variety. Boreal Beast (*Lonicera caerulea* var. *kamtschatica*) grows upright in the form of a bush. It is very similar to Boreal Beauty. It is a variety with high tolerance to diseases and pests. It is a highly productive variety

tolerant to powdery mildew. As a result, studies are continuing in the breeding of species and varieties that are tolerant to climate change, drought, diseases and pests in berry production in the world.

2.1 Strawberry (*Fragaria x ananassa* L.)

In recent years, strawberry cultivation under protected conditions has increased for the fresh market in European countries. Producers choose very short day varieties in order to reach the market early. The aim of protected cultivation is to protect the strawberry from negative weather conditions. The selection of varieties with low cooling needs and high quality is becoming more common for strawberry cultivation in the winter and spring in the Mediterranean climate, while generally neutral varieties in terms of light needs are chosen for strawberry cultivation in the open air in cool places. Additionally, producers choose summer planting for strawberries rather than spring planting to prevent the effects of cold in continental climates. The use of refrigerated seedlings for summer and autumn strawberry production has significantly increased. This has contributed to the increase in strawberry cultivation in greenhouses and plastic tunnels. As a result, many different production techniques are used to offer fresh strawberries to the market in nearly every season by developing new production models for strawberry production in Europe in parallel with climate change [38]. As is known, the effect of climate change on plants is a topic that requires study by scientists and there is continuous research about this topic.

2.2 Black chokeberry (*Aronia melanocarpa* Michx)

Chokeberry is a plant species with superior adaptability to pedoclimatic conditions (wet habitats, sand dunes, rocky slopes and steep cliffs and extremely overgrown or bare rock outcrops). Additionally, chokeberry plants may be cultivated in marginal areas in terms of nutrients [51]. It is a plant that has the ability to tolerate dry or excessively humid soils [51] and very low temperatures and additionally is resistant to plant diseases and pests [52]. Due to these features, chokeberry is a berry brush that can be very easily used for rehabilitation with plant cover in abandoned areas [51]. The basis of the adaptation success of this plant species is linked to the ability to adjust to the soil pedoclimatic conditions and continuously changing environmental conditions. In this context, a study completed in Romania Research Institute for Fruit Growing Pitesti—Maracineni related to adaptation to specific climate conditions of Melrom and Nero chokeberry varieties used the Biologische Bundesantalt, Bundessortenamt and Chemische Industrie (BBCH) scale for phenological observations. The study calculated the mean flowering and fruiting initiation, flowering and fertilization duration, mean air temperature, total solar radiation and cold and heat accumulation. According to this study, budding began from 28 January – 8 February, bud opening began on 3 March, flowering began from 15 April to 1 May and finished from 27 April to 14 May. Phenological observations obtained a BBCH value of 53–87, while the mean air temperature over 154 days was reported to vary from 6.1 to 36.8°C. At the end of this research, they identified that chokeberry (*Aronia melanocarpa*) was a berry fruit species that was adapted to the temperate continental climate of south Romania [53].

In Türkiye, blueberry studies began in the 2000s in the Black Sea region, and in Rize. A study in Samsun province in Türkiye found the fruit harvest for blueberry varieties began from the end of June to beginning of July and continued until the middle of

August. For extension of the harvest period, they reported the cooling needs of Misty, Ozarkblue, O'Neil, Jubilee and Sharpblue, low height southern blueberry varieties and late maturing rabbit-eye blueberry varieties of Climax, Powderblue, Tifblue and Austin had full flowering in the ecological conditions in Samsun Türkiye. The Misty blueberry variety with earliest low cooling needs fully flowered on 3 March, while for latest full flowering the rabbit-eye blueberry Tifblue variety flowered on 5 April. The earliest leaf buds were found on the Misty variety on 25 January, while the latest leaf buds were present on the rabbit-eye blueberry variety of Tifblue on 28 March. For the fall time, the southern ones were earliest on 7 May for Misty, while for the rabbit-eye variety, the latest occurred on 10 June. The rabbit-eye blueberry varieties had highest fruit yield (1092.3 g/plant, Austin), while the heaviest and largest fruit were obtained from Climax (3.80 g and 20.70 mm), with hardest fruit obtained from the rabbit-eye blueberry variety of Powderblue (3.74 kgF). In conclusion, in the Samsun coastal ecology, the harvest period was earlier for the southern tall blueberry varieties, while the rabbit-eye blueberry varieties were slightly later and could extend the yield period until August [54].

2.3 Raspberry (*Rubus idaeus* L.)

Raspberry is a berry fruit that can be cultivated in different climate conditions by ensuring production conditions, and is suitable for boutique-style production in bush form. The Latin name is *Rubus idaeus*, and the raspberry fruit is in the Rosaceae family. It is a plant with easy cultivation and low cost. It does not require much technical knowledge for rootstock use and production, does not have a grafting problem and is easy to prune. It may provide fruit in a short duration after planting. As the roots of the plant comprise fringe roots with multiple and frequent thin roots, they may reach 1–1.5 m depth in appropriate soil conditions. The roots are perennial but stems last 2 years. As a result, the stems are renewed each year. As it is not very tall, care and harvest are easy. The harvest period may last 4–6 weeks duration. As a result, harvesting is flexible as labor requirements are not focused within a few days. Generally, raspberry cultivation may be successfully performed in areas with abundant sunlight, protected from wind and with adequate soil humidity [55–57]. According to historical records, it has been used as a medicinal plant since 1898. Tea made from the leaves is reported to have good odor and flavor. Additionally, the leaves contain tannin, flavonoid, organic acids and vitamin C, while fruits contain organic acids, sugars, pectin, vitamin C, anthocyanin, volatile and stable oils [58–60]. Dioscorides mentioned that the flowers of the plant mixed with honey were used for eye infections, were good for skin diseases and the fruits facilitated the digestive system in his book called *Materia Medica*. Raspberry fruits are commonly consumed as fresh fruit, as functional drink and fermented wine due to perfect nutritional properties rich in antioxidant phenolics and with attractive color and tasty flavor [61, 62]. In traditional medicine raspberry is frequently used for treatment of flu-like infections, and is said to be a very popular fruit in Poland and Europe [63]. Raspberry is reported to be commonly cultivated in Türkiye, especially Mount Ida (Kaz Dağları) [64].

2.4 Blackberry (*Rubus fruticosus* L.)

In Türkiye, the importance of blackberry cultivation is increasing due to the suitable ecology for blackberry cultivation, ease of cultivation, giving fruit in a short duration, high yield per unit area, higher price compared to other fruit species and consumption in different forms as food [65, 66]. Blackberry is in the Rosaceae *Rubus* genus with species assessed within the *Rubus* subgenus. The basic

feature separating blackberry from raspberry is whether the torus (fruit stem) remains on the fruit or not. When collecting blackberry fruit the torus remains on the fruit, while with raspberry the torus remains on the plant and the section where the torus entered the fruit forms an internal cavity. The general Latin name for the fruit is *Rubus fruticosus*. Fruit may weigh 3 to 12 g linked to the variety, while it is actually a cluster of fruitlets consisting of several drupelets, each containing a seed [67, 68]. It may be grown in soils that are inadequate in terms of nutrients. The plant has white or pink flowers from May to August, and has fruits from black to dark purple in color. The blackberry plant may grow to 3 m in height. Fruits are generally consumed fresh, while they are used frozen or freeze dried in the food industry. They are commonly used in cake products, jam, marmalade, fruit juice, ice cream, puree, sweets, concentrate and wine production due to color and aroma. The main production regions for blackberry are countries in North America, Europe, Asia, South America, Oceania, Central America and Africa. Additionally, wild blackberry may negatively affect sales of commercially-grown fruit in some regions [69–72]. The leaves of the plant have astringent features and are used in ethnic medicine for diarrhea, hemorrhoids, wound treatment and to balance blood sugar levels. Additionally, fruit are known to be used as antiseptic for eye infections, and as mouthwash for gum, tonsil and throat infections. Blackberry is a fruit with high antioxidant capacity due to containing high anthocyanins and ellagitannins (ET) with other phenolic agents. Epidemiological and clinical studies show that the consumption of anthocyanins and other flavonoids found in most fruit and vegetables may reduce the risk of obesity, coronary heart disease, degenerative status and a variety of cancer types [15].

2.5 Rosehip (*Rosa canina* L.)

Rosehip is called many different names by the public including wild rose, chillan, crazy rose, rosehip, rose apple, doghip and dogrose. It grows naturally in all regions of Europe and Asia and in Türkiye. In Türkiye, it grows on its own up to 2000 m elevation, on mountain slopes, in the internal openings in forests, on forest edges, in heathlands, and along stream and road edges in areas with abundant sunshine-semi-shade and humic soils [73]. As flowers open in May, June, and July, they are not damaged by late spring frosts. The flowering time is delayed as the elevation increases and the fruit quality increases. Adequate rainfall in the vegetation period increases the size of fruit. In locations with high and abundant sunshine and with south aspect, fruit color and size increase along with the vitamin C content. Rosehip is an important source of income for forest villages in rural areas. Rosehip (*Rosa* spp.) belongs to the *Rosa* species in the Rosoideae subfamily of the Rosaceae family in the Rosales order. Of the 70–100 species of rosehip globally, nearly 25% (27 species) grow in our country [74–77]. Varying according to rosehip species, it is a deciduous bush-like plant that may reach 0.5–4.0 m with vertical and weeping forms, with few or many thorns on stem and branches. The stem and branches have weeping appearance, while most have frequently thorny and creeping, climbing forms. Branches from the stem are thorny and sturdy and only reach 1 cm diameter at 3 years. Leaves comprise 5–11 hairless leaflets, leaflets are 2–4 cm in length, with shiny green color on the tops of the leaves [77]. Rosehip has strong root structure. It has both surface fibrous roots and deep (up to 4 m) taproots. Roots are resistant to disease, pests and difficult conditions. The roots with red color and soft fleshy structure are used in the dye industry. Due to nodules on the roots, they tend to produce root shoots [78].

Flowers are single or collected in umbrella-like bunches, and have light red, pink, yellow, cream or white color. The sepals have round or long egg-like appearance, tips later recline, and then shed or remain on the fruit, depending on the species. The rosehip has hermaphrodite flower structure, with many male and female organs. Flowering occurs from April, May and June linked to species and climate and lasts 15–25 days [75, 77].

2.6 Mulberry (*Morus* spp)

As is known, mulberry is one of the most perfect plants compared to other berry fruits for climate change and global warming conditions in barren areas. This is because care and cultivation conditions are easier compared to other berry fruits, and it is a beneficial berry fruit that does not require much water, is suitable for barren conditions, both fruit and leaves can be used in the food industry, in silkworm production and folk medicine. In spite of Türkiye, with fruit cultivation culture extending through history, being the home of the mulberry and having natural areas of distribution, the genetic potential has not been sufficiently evaluated. This fruit type, with highly superior qualities in terms of fruit quality, is cut only to use the wood leaving many valuable genotypes at risk of being lost [79]. In addition to fresh mulberry consumption, mulberry has significant potential as a processed food product due to nutritional features. Products like mulberry molasses, jam, pestil (fruit leather), mulberry paste, fruit ice cream, mulberry sujuk, vinegar, fruit juice concentrate, and spirits are made in the regions in which it grows. Black mulberry juice has become a very common drink in recent years especially [80]. Mulberry (*Morus* spp.) is in the *Morus* genus of the Moraceae family within the Urticales order. The number of species within the *Morus* genus was reported to be 12 by Freeman [81], 14 by Huo [82], 24 by Koidzumi [83] with 1 subspecies Machii et al. [84], more than 30 by Martin et al. [85] and 68 by Datta [86]. Mulberry is commonly encountered especially in east, west and southeast Asia, southern Europe, south of North America, northwest of South America and some regions in Africa. Mulberry plants grow to 15 m in height. They grow rapidly, with cylindrical, straight and thick trunks, with fractured bark and gray-brown color. The diameter of the crown is 6–8 m, with sparse and ball-like appearance. Roots are fleshy, brittle and fragile. As they age, strong lateral roots develop. As a result, they are resistant to wind. Leaves have stems, arranged in two rows, with rounded base or heart shape, top surface dark and bottom surface lighter green. The leaves generally have a pointed tip, with toothed edges. Shoots are shiny yellow in color and slightly hairy. When shoots are cut, they release a milk-like secretion. Mulberry has male and female flowers on the same tree. Flowers open in April–May. Pollination occurs with the wind direction generally. Mulberry fruit is in the form of a collection of fruitlets (multiple) each forming from a flower on the flower stem [79]. Mature fresh mulberry contain 85–88% water, 7.8–9.2% carbohydrate, 0.4–1.5% protein, 0.4–0.5% fat, 1.1–1.9% free acids, 1.4% fiber and 0.7–0.9% minerals [87]. Additionally, 100 g of fresh mulberry provides 93 calories, containing 0.9 g protein, 19.8 g carbohydrate, 1.1 g fat, 0.9 g fiber, 60 mg calcium, 1.1 mg iron, 0.05 mg vitamin B1, 0.07 mg vitamin B2, 0.2 mg vitamin B3 and 17 mg vitamin C. Additionally, there is 11.0–12.5 mg ascorbic acid, 0.7–0.8 mg nicotinic acid, 7.0–9.0 µg thiamine and 165–179 µg riboflavin within 100 g of fruit [88]. The syrup obtained by boiling black mulberry fruit harvested in the fully mature

period with water, sugar or honey mixture is rich in vitamins and minerals, in addition to being recommended as a drink due to blood purifying and antioxidant properties. Additionally, it is stated to be beneficial when used 3–4 times per day as a mouthwash for sore throat and gum infections [89]. Mulberry juice, produced as a health drink in a commercial sense, has become popular in China, Japan and Korea. Original mulberry juice remains fresh for 3 months in cold storage conditions without any added preservatives; the bottled drink preserves its freshness for 12 months at room temperature. Just as fruit can be used fresh for jam and compote and leaves can be used fresh for stuffed leaves, they may be used in a variety of forms by drying. Fruit, leaves and roots can be used to obtain extracts and these are used in a variety of cosmetic products. Just as white dried mulberry, eaten as trail mix, can be used to lower inflammation in blood and to increase breastmilk, it may be assessed for use in late-healing wounds in diabetes patients and for eczema [90].

2.7 Fig (*Ficus carica* L.)

The *Ficus* genus in the Moraceae family includes nearly 600–2000 species. Most of these species are found in the tropics and subtropics and the fruit of only a very small number among these species can be eaten [91]. Among these species, the fig most commonly consumed by people is *Ficus carica* L. The *Ficus carica* L. species has great importance as a source of human nutrition and is the only *Ficus* species cultivated for fruit [92]. As understood from records dating to the 30th century BC, fig trees were the first trees planted in the world. Though the origin is not fully known, fig trees are thought to have emerged from the productive region of south Arabia in western Asia. At the same time, many wild species are found in the Middle East and Mediterranean regions [92–95]. Another berry tree resistant to climate change and arid conditions is the fig. Fig (*Ficus carica* L.), one of the first cultivated trees in the world, grows in many locations around the world with temperate climate. Figs are eaten both fresh and dried; however, as fresh figs are products that degrade quickly, they are mainly consumed close to the production areas. Figs are nutritional fruit rich in terms of fiber, potassium, calcium and iron. Fresh figs are very vulnerable to physical damage and are sensitive to rot infections after harvest. Conditions before and after harvest improve fruit quality and post-harvest life. At this point, there is great difficulty for plant cultivators, physiologists and post-harvest technology experts to reduce post-harvest losses and develop global fresh fig marketing [96]. In 2022, there was 350 tons of production from 572,472 thousand area with 57.3% of production from Aydın and 19.5% of production from İzmir. The majority of figs produced in Aydın and İzmir are dried due to climate and ecological conditions, with fresh production from other provinces. In 2021, 21.4 thousand tons of fresh fig and 57 thousand tons of dry fig were exported [97]. On a global scale, fig is produced from 299,541 hectares and production was more than 1,348,254.74 tons in 2021. Fig trees are commonly planted in gardens in the Mediterranean region (and similar climates) and have good adjustment to aridity and high temperature. Türkiye and Egypt are the countries with highest fig production representing nearly 50% of global production, followed by Iran, Algeria and Morocco. While Türkiye is in first place for fig exports, it is followed by the USA, Spain, Syria and Greece. Fig trees are commonly planted in gardens everywhere. They are berry trees well adapted to aridity and high temperatures in the Mediterranean region and similar climates [93].

3. Production models compatible with climate change

Now the focus is on production methods for these berry fruits that are compatible with aridity and global climate change. As is known, temperature increases will increase the degradation rate and process in soil; the resulting erosion hazard will reduce organic matter linked to humidity loss in soil. A reduction in soil productivity will be caused by these negative conditions. Innovative methods like soil-free agriculture, an increasingly common alternative production model in the agricultural field in recent years, restorative agriculture and vertical agriculture are thought to support the struggle against climate change. Of these production models, it is thought that new production models like soil-free agriculture, restorative agriculture and vertical agriculture will be appropriate for fruit cultivation, especially for some berry fruits with ground-spreading or small-bush forms. For example, in strawberry production, strawberry cultivation and traditional cultivation methods use soil; this involves several problems caused by soil-derived pathogens and nematodes causing significant product loss. To prevent these losses, alternation, solarization of soil or disinfection with chemicals is necessary. These solutions both increase production costs and damage the environment and soil. As a result, soil-free agriculture may be an important alternative solution for these problems. In addition to solving problems expected in greenhouse soils, targets like extending the production season in strawberry cultivation and yield per unit area, soil-free strawberry cultivation has become more common in commercial greenhouse production [98]. Additionally, production of fruit like blueberry, blackberry and raspberry under cover is becoming increasingly common. For example, blueberry production is very important in soil-free agriculture. The advantages can be listed as follows; pH control of the production environment, convenience for fertilizer, water, pesticides and labor, suitability for automation systems (pruning, harvesting, medicating), ease of protection from negative climate conditions, control of weeds, and ease of harvesting. Studies about breeding new varieties suitable for greenhouse production with low chilling requirements continue at full speed. As productive agricultural areas are being chosen for both residential areas and for production areas for industry, the agricultural production area is becoming smaller. As a result, producers have begun to choose intensive production methods for small areas like vertical agriculture and undercover production among agricultural production methods. In this way, producers choose new production models with the aim of offering fresh products to the market in all four seasons, to meet consumer demands and to obtain high income. With this, aim, producers in Türkiye and Far East and European countries have given up traditional production for figs and begun production with wired training systems. Here, the aim is to both obtain a very early product (in 2–3 years) and to sell fresh products to the market at high price. At the same time, these methods increase the amount of product obtained per decare or hectare by using more plants in a smaller area, as mentioned above. Thus in wired training systems, nearly 83 seedlings can be planted per decare with dense planting at 3–4 m intervals. Thus, more product is obtained from a smaller area. Though the first year installation cost is a bit higher in this type of production method, the producer has the opportunity to harvest in a shorter duration and sell to market at a higher price, increasing the profitability rate of wired training dwarf production methods. At the same time, producers choose these methods as there are lower labor costs for harvest and weed control. Again, undercover mulberry cultivation is performed with the aim of controlling climate conditions and offering fresh berry fruit to the market in a short period. The mulberry variety grown in greenhouses especially in Türkiye is

the variety belonging to the *Morus laevigata* Wall. species, known as finger mulberry or black mulberry among the public. Greenhouse mulberry production in Türkiye is used in Anamur and Silifke counties in Mersin. These mulberry fruits are sold to buyers at high prices in the market as fresh fruit, not as dried mulberries. In greenhouse mulberry production, harvest begins in February and ends in June. If a single harvest is desired in open and greenhouse production in the Mediterranean region, hard pruning should be performed. If the target is a second harvest in a greenhouse, normal pruning should be performed. Additionally, the second greenhouse harvest occurs in December, January and February. As can be seen, these types of new research and new production models provide an alternative gain for producers and offer fresh fruit to consumers.

Modern gene technologies, also called biotechnology in recent years, offer important opportunities to increase agricultural production in order to provide adequate and balanced nutrition for the rapidly increasing world population. In this case, in addition to the use of sustainable farming techniques, the creation of high yielding and high quality plant types resistant to biotic and abiotic stress conditions is the main goal. In the near and medium term, it will be more correct to focus mostly on molecular plant breeding approaches, rather than simply transgenic plants obtained by transformation, in the development of these plants. Developing countries having abundant gene resources, such as Turkey, will assist them in making the greatest use of their genetic potential by identifying priority areas, providing adequate infrastructure for molecular biology studies, and training a critical mass of competent researchers. However, in parallel with technological advancements, it is necessary to make legal regulations regarding biosecurity are required, both during the creation of these techniques and products and their release into nature, as well as the training of competent personnel who will apply this legislation. In this case, the proposed legislation must be founded on scientific grounds. Likewise, it is very important for agriculturally developing countries such as Turkey to make the legislation such as Plant Breeder's Rights and Patent Law for biotechnological applications in berry fruits and intellectual property rights related to products immediately applicable, to inform and support researchers in these fields, and to make regulations and bring them to a competitive position in the globalizing world trade. The necessity of adapting to climate change is essential for berry fruits to other fruit species. Because the composition of the grape grain is a major predictor of the quality, distinctiveness, and market value of juice, frozen or dried grapes, and wine, and is strongly reliant on the natural environment or ecology, as well as the harvest season. There is a considerable desire for lowering pesticide use in berry fruits, as there is in all fruit farming around the world. There are three inseparable inputs to the equation that berry growers must solve: first, adapting to climatic change, second, minimizing pesticide use, and thirdly, preserving the aroma unique to the species and variety. Although garden management can maintain these qualities to some amount, it is believed that addressing the short-medium-term effects of climate change would require long-term sustainable solutions, rather than short-term genetic improvement. On the one hand, the positive aspects of breeding new varieties of berry fruits that adapt to climate change are as follows: (a) species and variety richness not yet fully explored; (b) advances in sequencing technologies that allow high-throughput sequencing of whole genomes, faster mapping of targeted traits, and easier identification of genetic relationships; (c) advances in new production technologies that potentially allow for definitive changes to established genes; (d) automation of phenotyping allowing faster and more complete tracking of many traits in relatively large plant populations;

(e) functional characterization of an increasing number of genes involved in developmental control, fruit metabolism, disease resistance, and adaptation to the environment. On the other hand, challenges in breeding new varieties of berry fruits that adapt to climate change are as follows: (a) The perennial nature of the garden plant and its vast size, necessitating extensive and labor-intensive field experiments; (b) low transformation and regeneration efficiency, as well as the limited size of breeding populations; (c) the complexities of transferable traits and the need to more clearly define future ideotypes; (d) a lack of shared and integrative platforms that allow full assessment of genotype–phenotype–environmental linkages; and (e) legal, market, and consumer acceptance of new genotypes [99].

The responses of berry farmers to climate change adaptation can be divided into two groups. It can be summarized as (1) short-term incremental responses (incremental responses) that farmers usually choose autonomously based on the observed changes and local knowledge and experience, and (2) long-term transformative responses that require strategic planning, usually applied on a larger spatial scale. Models can be used to aid decision making at both response levels; thus, certain model elements are either more or less helpful depending on the type of adaption response. In order to adapt to climate change, berry farmers are expected to focus on five different models: (1) empirical crop models; (2) regional conformity models; (3) biophysical models; (4) meta models; and (5) decision models. These models' potential and limitations in deciding on short- and long-term adaption planning are examined. The biggest challenge in applying these models is to consider climate variability and uncertainty, which are future research, integrated risk and vulnerability assessments that support climate change adaptation efforts. To achieve long-term compliance success, systems for monitoring management adjustments and their outcomes must be institutionalized [100].

4. Conclusion and recommendations

Climate change has intensified global food crises, while the food crises are intensified by climate change and small-scale farmers are predicted to be the group first and most severely affected by climate change. Finally all branches of the agricultural sector will be negatively affected by global warming and climate change. Here, one of the agricultural sectors most impacted by negative climate conditions are horticultural plants. Among horticultural plants, berry fruit production is an agricultural branch where production can be performed by controlling negative climate conditions. In these negative conditions, a range of new production models can be implemented to control yield loss of berry fruits and to provide high yield in a shorter duration and smaller area. For this reason, it is thought that the use of innovative production methods such as soil-free agriculture, regenerative agriculture and vertical agriculture, which are becoming increasingly common in the field of agriculture, are alternative production models that can contribute to the fight against climate change. The importance of using new agricultural models like different training systems, dwarf production allowing dense planting, undercover production, soil-free agriculture, restorative agriculture and vertical agriculture is increasing. Additionally, it is necessary to choose restricted irrigation systems like drop and leach systems for correct water management. In breeding studies for new varieties, it is very important to give weight to breeding new varieties with resistance to salinity, aridity, plant diseases and pests, good flavor and aroma, and high yield. It is necessary to implement tighter

precautions to protect national and international plant gene sources paying attention to local varieties more resistant to negative natural and climate conditions in these breeding studies. It is necessary to implement multidisciplinary studies especially for berry fruit production about improving techniques for drying and processing and using new methods that are environmentally friendly and do not damage human health to ensure products reach consumers fresh and without nutritional loss or degradation. In conclusion, we believe this study will guide more detailed studies about this topic and continuation of berry fruit production with least impact from global warming and climate change conditions.

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