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Plum Breeding

Madalina Butac

Abstract

Worldwide, plum is one of the main species, occupying an area of about 2,600,000 ha and ensuring production about 11,700,000 tons. Even though there are over 6000 plum cultivars belonging to 19–40 species, there is still the need to create new cultivars due to the demands of growers and consumers. In addition, the large plum-growing countries (Romania, Serbia, Germany, Bulgaria, etc.) have decreased production due to plum pox virus (PPV) attack. Therefore, these countries developed breeding programs with the following objectives: resistance/tolerance to PPV, productivity, fruit quality, late blooming, self-fertility, different ripening times, short growing period, spur fructification, etc. Using different breeding methods (controlled hybridization, open pollination, selection in wild population on *Prunus* sp., and mutagenesis), in the last years, over 450 plum cultivars were released, from which 70% represent European cultivars and 30% Japanese cultivars.

Keywords: plum, breeding, objectives, genetic resources, achievements

1. Introduction

Plum is one of the main groups of fruits with about 6000 cultivars, belonging to 19–40 species, originating from Europe, Asia, and the USA [1–5].

Plums are appreciated for fresh consumption and also for dehydration and processing in the different forms (jams, compotes, jellies, candied fruits, frozen fruits, liqueurs, brandy, etc.) [6].

Plums are the fruits with the highest nutritional value, having a high content in carbohydrates, minerals, and vitamins that stimulate the body's health [3, 7].

Fresh fruits contain sugar (16–20%), proteins (0.7%), lipids (0.28%), pectins and tannoid substances, etc. Dehydrated fruits have a high content in sugar in competition with figs and jujube (**Table 1**).

Recent studies at Tuft University, Boston, have shown that dehydrated plums have the highest antioxidants content, contributing to the neutralization of free radicals and thus to the prevention of cancer.

The therapeutic and prophylactic value of plums has been known since ancient times; they have alkalizing, mineralizing, laxative, diuretic actions.

Plum genetics and breeding have been reviewed over time by different specialists: Cullinan (1937), Weinberger (1975), Ramming and Cociu (1991), Okie and Weinberger [8], Okie and Ramming [9], Okie and Hancock (2008), Hartmann and Neumuller (2009), Neumuller (2010), Topp et al. [5], Butac et al. [10], Milosevic and Milosevic [3]. During the time, in the plum breeding programs, these researchers change different knowledge, breeding techniques, biological material, etc.

| | Water content % | Pectic substances (%) | Fat substances (%) | Carbohydrates (%) | Calories |
|----------------------|--------------------|-----------------------------|--------------------------|----------------------|----------|
| Flesh fruits | 87 | 0.7 | 0.28 | 16-20 | 75 |
| Dehydrated fruits | 28 | 2.1 | 0.6 | 65-70 | 255 |

| | Vitamins (mg %) | | | | Mineral substances (mg %) | | | | | |
|----------------------|-----------------|------|------|-----|---------------------------|----|----|-----|-----|-----|
| | A | B1 | B2 | B6 | C | Ca | P | Fe | Na | K |
| Flesh fruits | 350 | 0.03 | 0.03 | 0.5 | 10 | 12 | 18 | 0.5 | 0.1 | 170 |
| Dehydrated fruits | 1600 | 0.09 | 0.17 | 0.2 | 3.0 | 51 | 79 | 3.9 | 8.0 | 604 |

Table 1.
Chemical composition of plums.

2. Economic importance

Currently the world area planted with plum is 2,619,471 ha, which is up from the 1980s. Of the continents, the largest plum growing are Asia (2,125,006 ha) and Europe (353,919 ha) (**Figure 1**).

The situation in the countries is as follows: China 1,987,284 ha; Serbia, 72,024 ha; Romania, 66,680 ha; and the USA. 25,500 ha (**Table 2**).

In the world production, plum has about 2%, practically a modest place. As a temperate species, it still occupies the fourth place, after the apple, pear and peach, in this area. Plum production increased to 11,758,135 tons in 2017 (**Figure 2**). Due to the main contribution to this growth, Asia has practically become the largest producer of plums (8201 million tons, respectively, 69.75% of the world production), followed by Europe (2199 million tons, respectively, 18.70% of the world production), the USA (423 million tons), etc. (**Table 2**). It should be noted that while the average plum yield in Asia increased, the one in Europe has decreased by 5%.

According to data reported in December 2019 by FAO Yearbook, the largest producing countries (in thousand tons) are China (6804), Romania (434), the USA (423), Serbia (330), Turkey (292), Italy (207), France (205), Ukraine (200), Spain (172), the Russian Federation (146), the Republic of Korea (83), the Republic of Moldova (76), Bosnia and Herzegovina (74), Poland (58), Hungary (43), Bulgaria (49), and Germany (24) (**Table 2**).

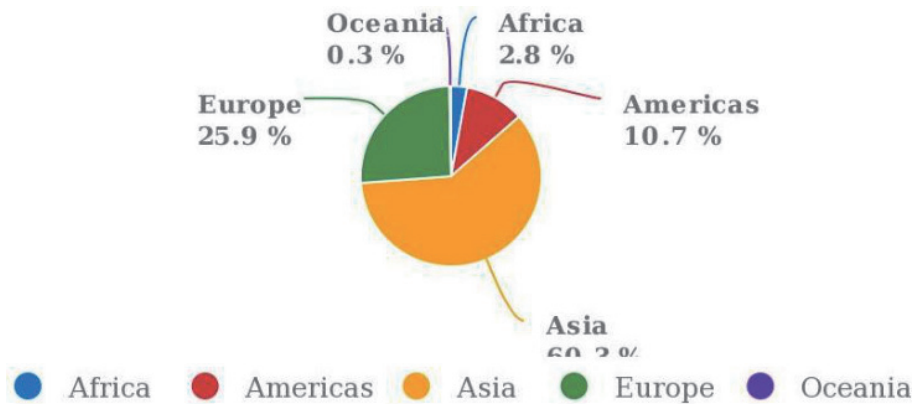


Figure 1.
Production share of plums and sloes by region: average 1994–2017. Source: [11].

| World/country | Surface (ha) | Production (thousand tons) |
|---------------------|--------------|----------------------------|
| Total | 2,619,471 | 11,758 |
| Asia | 2,125,006 | 8201 |
| Europe | 353,919 | 2199 |
| SUA | 25,500 | 423 |
| China | 1,713,600 | 5664 |
| Romania | 66,680 | 434 |
| Serbia | 72,024 | 330 |
| Turkey | 21,385 | 292 |
| France | 16,958 | 205 |
| Italy | 12,676 | 207 |
| Ukraine | 18,000 | 200 |
| Spain | 15.199 | 172 |
| Russian Federation | 36,442 | 146 |
| Republic of Korea | 7495 | 83 |
| Republic of Moldova | 15,955 | 76 |
| Bosnia Herzegovina | 38,081 | 74 |
| Poland | 14,344 | 58 |
| Bulgaria | 6805 | 49 |
| Hungary | 7980 | 43 |
| Germany | 4191 | 24 |
| United Kingdom | 640 | 13 |

Table 2.
Area and production of plums in the world and in major growing countries.

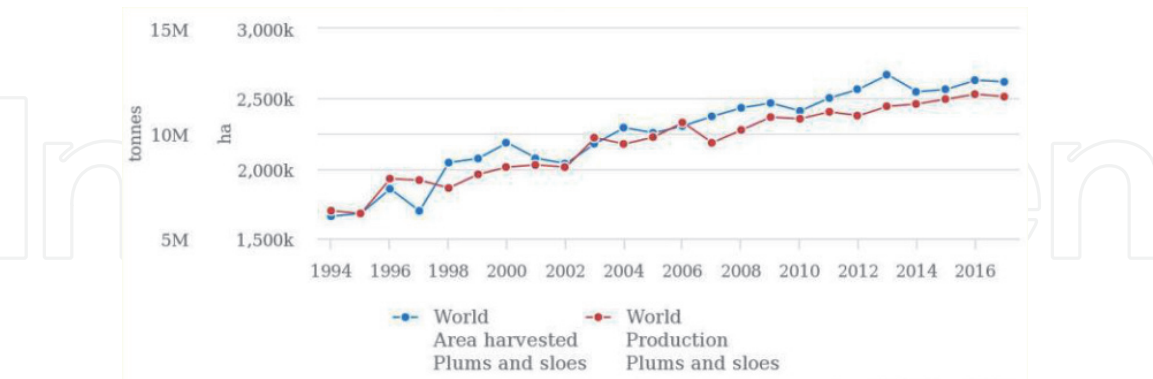


Figure 2.
Production/yield quantities of plums and sloes in the world (total): 1994–2017. Source: [11].

China is the country with the fastest development in the plum production, but the major producers of plums, from *Prunus domestica* and *Prunus insititia* species, are Romania, Serbia, the Republic of Moldova, Spain, Russia, Poland, France, Germany, and Bulgaria alarming declines in plums production. These decreases are due to the competition of the citrus, peaches, bananas, and other fruits but especially to the viral diseases that have destroyed the plum orchards and depreciated fruit quality in those countries.

3. Origin and history of plum

Plums belong to the genus *Prunus* L., subfamily Amygdaloideae (syn. Prunoideae), and family Rosaceae Jussieu [3, 12]. The basic chromosome number of plum is 8 ($x = 8$). Plum is a member of *Prunophora* subgenus, which itself is subdivided into the sections *Prunocerasus* and *Euprunus*. The *Prunocerasus* section contains the following species: *P. americana*, *P. angustifolia*, *P. hortulana*, *P. munsoniana*, *P. mexicana*, *P. nigra*, and *P. maritima*. The *Euprunus* section contains the following species: *P. domestica*, *P. spinosa*, *P. cerasifera*, *P. salicina*, *P. cocomilia*, *P. insititia*, *P. simonii*, and *P. ussuriensis* (Table 3).

Plum has a large spreading area. According to Vavilov's research, there are three spreading centers for plum species: Euro-Asian, North American, and East Asian [13].

In the Euro-Asian center, the following species are present: *Prunus domestica*, *Prunus insititia*, *Prunus spinosa*, and *Prunus cerasifera*, which are widespread in South Europe, Western Asia, around the Caucasus Mountains, and Caspian Sea, but also in the Balkans, as well as in the Mediterranean countries.

In the North American center which starts from the Gulf of Mexico and the West coast of the USA to Canada in the North, the following species are spreading: *Prunus nigra*, *Prunus americana*, and *Prunus munsoniana*.

The third center, East Asian, includes the following species: *Prunus ussuriensis*, *Prunus salicina*, and *Prunus simonii*.

From this large diversity, the most important species in commercial orchards are European or domestic plum (*Prunus domestica* L.; hexaploid species with $2n = 6x = 48$) and Japanese plum (*Prunus salicina* Lindl.; diploid species with $2n = 4x = 16$) [4, 5, 8, 14, 15]. European and Japanese plums belong to the same taxonomic section, but they are differentiated by origin and requirements to environmental factors.

The European plum is the most important plum in Europe, but it is also grown on other continents. The origin place of this species is Caucasus Mountains near the Caspian Sea [3]. These species grown in cooler areas can be divided into several groups considering the fruit characters: plumes, prunes, greengages or reineclaudes and mirabelles [16].

Crane and Lawrence [17] suggested that *Prunus domestica* ($2n = 6x = 48$, genome formula CCSSSS) is genetically a hybrid between diploid cherry plum (*Prunus cerasifera* Ehrh. $2n = 2x = 16$, genome formula CC) and tetraploid sloe or blackthorn (*Prunus spinosa* L., $2n = 4x = 32$, genome formula SSSS) based on the fact that these species grow together in the Caucasian forests and can naturally hybridize with each other [3, 14, 18]. The same idea was supported by Rybin and Jukovsky, but later Georges Salesses questioned this hypothesis [18]. The origin of *P. domestica* remains somehow mysterious. There are three subspecies within *P. domestica*: ssp. *insititia* (mirabelles and the so-called spilling), ssp. *oeconomica* (prunes), and ssp. *italica* (plums, reineclaudes, and all other kinds of plum fruits) [18].

For European plum, the plum fruits are round to oval, in different sizes and colors; the flesh is juicy, soft, and mostly clingstone; and the ripening time is earlier than those of prunes, but there are also some exceptions [16]. *Prunus domestica* is a very good source of genes for high sugar content, fruit flavor, late blooming, and high productivity but must be improved for frost and disease resistance (especially virus diseases) [14, 19].

Japanese plum has its origins in China (Yangtze River Basin), but for about 2000 years, it has been cultivated in Japan [1]. This species grew in warmer areas. It was imported to California in North America by Hough in 1870. The famous plum breeder Luther Burbank started his breeding in 1875 using all species available and produced thousands of seedlings and selected a lot of varieties [16]. The fruits are

| Species | Common name | Origin | Chromosome number | Subspecies/ varieties |
|---|---|--|-------------------|---|
| 1 | 2 | 3 | 4 | 5 |
| <i>P. cerasifera</i> Ehrh. | Cherry plum, Myrobalan | West Asia, Balkans (Serbia, Romania, Bulgaria, Greece), Caucasus | 16 (24, 32, 48) | <i>atropurpurea</i> , <i>pissardi</i> , <i>pendula</i> , <i>elegans</i> , <i>divaricata</i> |
| <i>P. cocomilia</i> Ten. | Italian plum | Italy, Serbia | 16 | – |
| <i>P. domestica</i> L. | Garden plum, European plum | Europe, West Asia | 48 | – |
| <i>P. insititia</i> L. | Bullace, damson, mirabelle, reineclaudes (gag plum) | Europe, West Asia | 48 | <i>subsylvestris</i> , <i>italica</i> , <i>syriaca</i> |
| <i>P. monticola</i> Koch | Taurus plum | Asia | 16 | – |
| <i>P. salicina</i> Lindl. | Japanese (Chinese) plum | China | 16 (32) | – |
| <i>P. simonii</i> Carrière | Apricot plum, Simon plum | North China | 16 | <i>purpurea</i> |
| <i>P. spinosa</i> L. | Blackthorn, sloe | Europe, North Africa, West Asia | 32 (16, 24, 48) | – |
| <i>P. ussuriensis</i> Kovalev and Kostina | Ussurian (Manchurian) plum | China | 16 | – |
| <i>P. americana</i> Marshall | Common wild plum | East USA, to the Rocky Mountains | 16 | <i>mollis</i> , <i>lanata</i> |
| <i>P. angustifolia</i> Marshall | Chickasaw plum | USA (New Jersey to the Florida); Illinois, Texas | 16 | <i>watsonii</i> , <i>varians</i> |
| <i>P. hortulana</i> L.H. Bailey | Hortulan plum | USA (Kentucky, Tennessee to the Iowa, Oklahoma, Texas, Louisiana); Alabama | 16 | <i>mineri</i> , <i>pubens</i> |
| <i>P. maritima</i> Marshall | Beach plum | USA (Virginia) | 16 | <i>flava</i> (with yellow fruit) |
| <i>P. mexicana</i> S. Wats. | Big-tree plum | USA, Mexico | 16 | <i>polyandra</i> , <i>fultonensis</i> |
| <i>P. munsoniana</i> Wight and Hedrick | Wild Goose plum | USA (Texas, Ohio, Kentucky) | 16 | – |
| <i>P. nigra</i> Aiton | Canadian plum | Canada, USA | 16 | – |

Table 3.
Plum species with their common name, origin, and chromosome number. Sources: [5, 6, 19–21].

various, mostly large and firm with yellow base color overlaid by red and purple, very attractive, designated for the fresh market [1, 14].

4. Breeding objectives

Breeding new plum cultivars needs to anticipate the future requirements from the growers, market, and consumers.

A large number of breeding programs are developed in many countries from Europe (**Table 4**). Some of plum breeding programs have been reduced or stopped in the countries where production has declined or funding is no longer available. At the same time, some breeding programs became more private with less public funding [22].

The breeding objectives are general and specific. The general objectives include the following:

- Productivity
- Fruit quality
- Disease resistance, especially to plum pox virus.

The special objectives concern the following (**Table 3**):

- Late blooming and frost resistance in United Kingdom, Bulgaria, Moldova, and Belarus
- Winter hardiness in Latvia, Belarus, Moldova, Russia, Sweden, and Norway
- Short period of vegetation in Sweden
- Good storage in Norway
- Extended ripening period in Bulgaria and Romania
- Self-fertility in Latvia and Romania

Eighty percent of all breeding activities are carried on by *Prunus domestica* and only twenty percent by *Prunus salicina* [2, 13, 23–25].

5. Breeding methods

There are several breeding methods:

A. Conventional methods:

- Selection
- Hybridization
- Mutagenesis

B. Biotechnological methods:

- In vitro cells and tissue culture
- Induction of somaclonal variations
- Somatic hybridization
- Genetic engineering

| Country | Breeding centers | Breeder | Objectives |
|---------------------|---|---|--|
| 1 | 2 | 3 | 4 |
| Romania | Research Institute for Fruit Growing, Pitesti Fruit Growing Research Station, Valcea Research Station for Fruit Growing, Bistrita | M. Butac M. Botu I. Zagrai | - Improvement of old cvs. Tuleu gras, Grase romanesti, Vinete romanesti - Fruit quality - PPV resistance - Ripening season extension - Self-fertility |
| Serbia | Fruit Research Institute, Cacak Faculty of Agronomy, Cacak | N. Milosevič I. Glisič T. Milosevič | - Improvement of old cv. Pozegača - Fruit size and quality - Ripening time - Resistance to PPV - Productivity |
| Germany | University of Hohenheim, Stuttgart Hochschule Geisenheim University | W. Hartmann M. Neumuller H. Jacob | - Fruit quality - PPV resistance by hypersensitivity |
| France | INRA, Bordeaux | R. Bernhard R. Renaud | - Fruit quality - PPV resistance by transgenic plants |
| Italy | University of Bologna University of Firenze University of Forli Private program | S. Sansavini E. Bellini V. Nancetti A. Liverani | Japanese and European plum breeding program: - Fruit quality - Fresh consumption - Resistance to PPV |
| United Kingdom | East Malling Research Station, Kent | K. Tobutt R. Jones T. Laxton | - Late blooming - Frost resistance - PPV resistance |
| Bulgaria | Fruit Growing Institute, Dryanovo Fruit Growing Institute, Troyan Fruit Growing Institute, Kyustendil Fruit Growing Institute, Plovdiv | V. Bozhkova A. Zhivondov | - Late blooming - Extended ripening period - Fruit quality - Resistance to PPV |
| Latvia | Latvia State Institute of Fruit Growing, Dobele | E. Kaufmane I. Gravite L. Ikase | - Winter hardiness - Low vigor - Precocity - Fruit quality - Self-fertility - Early ripening |
| Belarus | Institute for Fruit Growing, Minsk | Z. Kazlouskaya V.A. Matveev M. Vasiljeva | - Fruit quality - Frost resistance |
| Republic of Moldova | Research Institute for Horticulture and Alimentary Technologies, Chisinau | M. Pintea, A. Juraveli | - Frost resistance - Fruit quality |
| Czech Republic | Research and Breeding Institute of Pomology, Holovousy | J. Blazek | - Fruit quality - Sharka tolerance |
| Poland | Research Institute of Horticulture, Skierniewice | T. Jakubowski E. Zurawicz J. Dominikowski E. Rozpara Z. Grzyb J. Szymanski | - Fruit quality - Productivity - PPV resistance |
| Russia | North-Caucasus Zonal Horticulture and Viticulture Research Institute, Krasnodar Krymsk Experiment Breeding Station, | R. S. Zaremuk E. M. Alekhina G. Eremin | - Winter hardiness - Fruit quality - Productivity |

| Country | Breeding centers | Breeder | Objectives |
|---------|--|----------------------------------|---|
| 1 | 2 | 3 | 4 |
| | Krymsk Far East Experiment Station, Pavlovsk, St. Petersburg Maicop Experiment Station Krasnodar Region Volgograd Experiment Station, Krasnoslobodsk | | |
| Sweden | University of Agricultural Sciences, Balsgard | I. Hjalmarsson, V. Trajkovski | - Short period of vegetation - Fruit quality |
| Norway | Ullensvang Research Centre Division Njos, Lofthus | S.H. Hjeltne | - Fruit quality - Good storage |
| Hungary | Research and Extension Centre for Fruit Growing, Ujfeherto | T. Lakatos | - Fruit quality - Processing |

Sources: [3, 10, 26, 27].

Table 4.
Plum breeding centers and objectives in Europe.

Conventional breeding methods are still largely used in the majority plum breeding programs, and the most important of these are intra and interspecific hybridization and open pollination. These methods contributed in a substantially way to modify the genetic structure of quantitative traits of new plum cultivars and rootstocks [3, 10, 20, 28].

Intraspecific hybridization steps are parents’ choice according to the breeding objectives, isolation and emasculation of flowers from the mother parent, collecting pollen from father parent, artificial pollination, control of fruits set, pick up of hybrids fruits, extracting the hybrids stones, and cultivation of seedlings.

Out of artificial sexual hybridization, several variants have been utilized: simple crossing, double crossing, pyramid type crossing, recessive crossing (back cross), and diallel crossing [29].

Between 1950 and 2000, most plum varieties have been created by intraspecific simple crossing (A × B): ‘Stanley’ (‘d’Agen’ × ‘Grand Duke’) in the USA; ‘Valor’ (‘Imperial Epineuse’ × ‘Grand Duke’) in Canada; ‘Čačanska Lepotica’ (‘Wagenheim’ × ‘Pozegača’), ‘Krina’ (‘Wagenheim’ × ‘Italian Plum’) in Serbia; ‘Jojo’ (‘Ortenauer’ × ‘Stanley’) in Germany; ‘Centenar’ (‘Tuleu gras’ × ‘Early Rivers’) and ‘Roman’ (‘Tuleu gras’ × ‘Early Rivers’) in Romania, etc. [2, 29].

Using double crossing, in Romania, the ‘Valcean’ plum cultivar was obtained [‘H8-12’ (‘Renclod Althan’ × ‘Wilhelmina Spath’) × ‘H 5-23’ (‘Renclod Althan’ × ‘Early Rivers’)] [2, 29].

In the last 25 years, the pyramidal type cross [(A × B) × C] was more utilized.

Thus, in Romania, using this type of crossing, several varieties were registered: ‘Minerva,’ ‘Sarmatic,’ ‘Pitestean’ [‘Tuleu timpuriu’ (‘Tuleu gras’ × ‘Early Rivers’) × ‘Early Rivers’] [2, 29].

In the last years, the interest for obtaining complex genotypes has increased, and for this reason, the interspecific hybridizations have been used.

Initially, interspecific hybridization was used to improve plum rootstocks. Thus, the plum rootstock ‘Ishtara’ is a complex interspecific hybrid between *P. domestica*, *P. cerasifera*, and *P. armeniaca* [30]. ‘Jaspi’ plum rootstock was obtained from the crossing between *P. salicina* Methley and *P. spinosa*. ‘Marianna’ rootstock was obtained from the combination between *P. cerasifera* and *P. munsoniana* [3].

Within the European FP 7 project, a breeding program for the creation of rootstocks with resistance to plum pox virus was carried out. Thus, at the Technical

University of Munich, the 'Dospina 235' (*P. domestica* × *P. spinosa*) and 'Docera 6' (*P. domestica* × *P. cerasifera*) rootstocks were obtained [31].

In Romania, there were crossed varieties belonging to the *P. domestica* and *P. insititia* species with the same number of chromosomes, and several cultivars were named: 'Silvia,' 'Ialomita,' 'Diana' ('Renclod Althan' × 'Early Rivers'), 'Renclod de Caransebes' ('Renclod Althan' × 'Wilhelmina Spath'), 'Doina,' 'Zamfira' ('Anna Spath' × 'Renclod Althan'), 'Romaner,' and 'Iulia' ('Tuleu gras' × 'Renclod Althan') [2, 6].

Hybridization between diploid species (*P. cerasifera*, *P. salicina*, *P. simonii*, *P. besseyi*, *P. americana*, *P. nigra*, *P. munsoniana*, *P. angustifolia*, and *P. hortulana*) can be very easy. For example, 'Santa Rosa' variety with American origin is a mixture between *P. salicina*, *P. simonii*, and *P. americana* [32].

In recent years, fruits of plum hybrids obtained from interspecific crosses have appeared on the world market:

- Interspecific hybrids between *P. domestica* and *P. armeniaca* called 'Plumcot®' (e.g., 'Red Velvet,' 'Royal Velvet,' 'Flavor Supreme,' 'Flavor Queen,' 'Rutland,' 'Plum Parfait,' 'Spring Satin,' and 'Yiksa'). In Bulgaria, Argir Zhivondov made crosses between *P. domestica* ('Stanley' cv.) and *P. armeniaca* ('Modesto' cv.) and obtained the cultivar named 'Standesto' [21].
- Interspecific hybrids between (*P. domestica* × *P. armeniaca*) × *P. domestica* and (*P. salicina* × *P. armeniaca*) × *P. salicina*. The name of these hybrids is 'Pluot®'.
- Interspecific hybrids between (*P. domestica* × *P. armeniaca*) and *P. armeniaca* called 'Aprium®' (e.g., 'Flavor Delight,' 'Flavor Candy,' and 'Honey Rich Aprium').

Regarding clonal selections, these have been done into the old plum orchard from Romania with 'Vinete romanesti' cv., and the following clones were obtained: 'Vinete românești 300,' 'Vinete românești 303,' and 'Vinete românești 4.' Clonal selections produced also several rootstocks: 'Oteșani 8,' 'Oteșani 11,' and 'Voinești B' [7, 29].

Mutagenesis was applied also in Romania on buds and seeds, using gamma radiations (Co^{-60}) and X-rays (Roentgen). For examples, the Romanian plum cultivars 'Alina' and 'Tita' have been obtained through irradiation of 'Tuleu gras' seeds with X-rays [19, 29].

In recent years, genetic engineering and biotechnologies have an important role in plum breeding.

Thus, in vitro culture techniques are used to obtain rootstocks virus free. Also, the protocol for pollination and fertilization in vitro of some plum varieties was elaborated during the many years of investigations. For pollination in vitro, it is important to take the non-pollinated flowers at the stage of ovule receptivity for pollen tube. The ovules of 'Sweet Common Prune' were pollinated with pollen of 'Stanley.' Excised ovules were placed on white medium with 15% of sucrose and pollinated with pollen extracted from anthers. The fertilized ovules should be cultivated in the test tubes, in complete darkness, at a temperature of 25°C, for 60 days. After 7 days, percentage of growing embryos was determined [33–35].

Embryo culture is used to create varieties with very early ripening. Results in this direction had Gercheva and Zhivondov [36] taking immature embryos from the 'Burmosa' (*P. salicina*) and 'Ruth Gerstetter' (*P. domestica*) varieties and cultivating them on a culture medium Murashige and Skoog. Burmosa's embryos had a very

good germination. In the last time, due to a very low germination percentage of some plum hybrid seeds in the breeding process, a new research using embryo culture method was started in Romania [36].

Molecular markers have a wide range of possible applications in plum breeding using markers such as RAPD and AFLPs [5]. In plum, gene transfer was applied especially for resistance to plum pox virus in order to create plum cultivars resistant to PPV. The PPV-CP (coat protein) gene was isolated, sequenced, cloned, and used for *Agrobacterium tumefaciens*—mediated transformation of plum [37]. Transgenic European plums were obtained that were grafted on the rootstocks of *P. domestica*, and their behavior at PPV was studied in the greenhouse. After 2 years of testing in greenhouse, a transgenic line C5 was resistant to PPV. This clone was registered as ‘Honeysweet’ cv. Later, this clone was also tested in the field, in Poland, Romania, and Spain under high-pressure infections and had a high level of PPV resistance [38–42].

6. Genetic sources of breeding

Germplasm collections are a major source of plant genetic diversity, which have an effect to improve crop. Collection, conservation, and evaluation of plant genetic resources are the most important conditions for breeding program. Plant breeders use these genetic resources in hybrid combinations because they are looking for new traits to be included into new varieties [1, 2, 43–47].

The existing ex situ collections can be a source of genes potentially useful as material in breeding work or sources of cultivars for a sustainable production.

In Europe there are a lot of plum genetic resources preserved in ex situ collections from about 30 countries.

A large number of plum accessions (estimated to be 4500) are kept in Russia and adjacent states, in four experimental stations located in different climatic conditions coordinated by Vavilov Institute of Plant Industry, Saint Petersburg. From this total, 2325 accessions (about 1600 original Russian cultivars) belong to *P. domestica* ($2n = 48$), and 2175 accessions are diploid plums ($2n = 16$), from which 500 genotypes belong to *P. cerasifera* [1].

Other European countries that have a large number of plum accessions are Belgium (616), Hungary (579), France (555), Italy (506), Bulgaria (377), the United Kingdom (380), Switzerland (326), Nordic countries (324), the Czech Republic (276), Portugal (263), Serbia (249), Turkey (232), Latvia (223), Germany (165), etc. [48, 49].

In Romania there are plum collections in two centers: RIFG Pitesti and UCv-SCDP Valcea. Ex situ conservation of accessions is done by different methods: conservation in the field collections (at RIFG Pitesti and UCv-SCDP Vâlcea), conservation in plastic containers, and cryoconservation, at -196°C , in liquid nitrogen (at UCv-SCDP Valcea) [50–53]. The plum cultivar collection at RIFG Pitesti, established in 1997, includes 550 accessions, and the plum rootstock collection, established in 2009, includes 92 accessions. The plum collections at SCDP Vâlcea, established in 1989, 1993, and 1996, include 361 accessions (species, cultivars, and rootstocks). So, from the total of 1003 accessions (cultivars and rootstocks), 34 are species and interspecific hybrids, 407 are local cultivars, 476 are foreign cultivars and rootstocks, and 86 are other genotypes (biotypes, hybrids, mutants, etc.). Most of the accessions belong to *Prunus domestica*, *Prunus insititia*, *Prunus cerasifera*, *Prunus spinosa*, and *Prunus salicina*.

The observations and measurements in ex situ collections were done according to the IBPGR *Prunus* descriptors updated by the ECP/GR *Prunus* Working Group

members within the Genres CT95 No. 61 project titled “International network on *Prunus* genetic resources”.

Most of these genetic resources have been evaluated and included in a European *Prunus* database (2254 accessions). In 1994, the European Cooperative Programme for Crop Genetic Resources Networks (ECP/GR) had the initiative to maintain this European *Prunus* database at the National Institute of Agronomic Research (INRA) Bordeaux, France, the manager being Emilie Balsamin [1].

From the ex situ collections, local varieties are very valuable, and many of them are characterized with good adaptability to environmental factors, high productivity, high resistance to pests and diseases, and fruits rich in nutrients necessary for human nutrition and different diets [54, 55].

The observations and determinations carried out over the years in the germ-plasm collections have revealed potential genitors with valuable traits for achieving the objectives from plum breeding programs.

Yield potential is a result of several factors, such as growth vigor, precocity, self-fertility, etc.

- *Growth vigor*. For, plum there are no sources of genes for low vigor or dwarf type. The following are sources of genes for low vigor: ‘Stanley,’ ‘Marry Mather,’ ‘d’Ente 698,’ ‘Sugar,’ ‘Ealta Dorata di Coe,’ ‘Early Golden,’ ‘Belle de September,’ ‘Sticolase de Voinesti,’ ‘Prun negru,’ ‘Perje de toamna,’ ‘Galbene de Aninosani,’ ‘Grase de Becs,’ ‘Grase de Pesteană,’ etc. [2, 6].
- *Precocity*. The growers require varieties with precocious. Good donors for precocity are ‘Stanley,’ ‘Bluefree,’ ‘Čačanska Lepotica,’ ‘Čačanska Rodna,’ ‘Verity,’ ‘Valor,’ ‘Centenar,’ ‘Minerva,’ etc. [6, 16].
- *Self-fertility*. Good donors for self-fertility are ‘Stanley,’ ‘Anna Späth,’ ‘Standard,’ ‘Ontario,’ ‘Ialomița,’ ‘Diana,’ ‘Romanța,’ etc. [6, 16].

Frost resistance. The frost resistance of the plum varieties is in accordance with their origin and the place where they were created. Thus, the varieties originating in Western Europe have a low or medium resistance (‘Reine Claude Verte’ and ‘d’Agen’), while those originating in North America and China are very resistant (‘Opata,’ ‘Sapa,’ and ‘Waneta’) [56]. The species *P. americana* and *P. nigra* transmit to the offspring the frost resistance [32]. *P. ussuriensis* species have a very high resistance to low temperatures, but its use in breeding is limited due to the fact that it blooms very early, a trait that is transmitted to the offspring; there is a risk of flower destruction if low temperatures occur during flowering [56]. The European varieties that have good resistances to frost are the following: ‘Bonne de Bry,’ ‘Mount Royal,’ ‘Pozegača,’ ‘Stanley,’ etc. Considering that the plum blooms early, immediately after the almond and apricot, the goal is to improve the resistance to the late frosts in the spring which, in recent years, have been more and more frequent. For example, in April 2009 and 2017 in Pitesti, Mărcăneni, Romania, temperatures of -1.7°C in the air and -3.4°C (2009) and -4.2°C (in 2017) in the soil were recorded. At these temperatures in 2009, the flowers of the varieties ‘d’Agen’ and ‘Anna Späth’ were destroyed in a proportion of 70–80%. In 2017, the low temperatures destroyed the young fruits. In this regard, the resistance of flowers to the late frosts can be achieved by creating late-flowering varieties. The late-flowering varieties that transmit this trait to the descendants can be mentioned: ‘De Bistrița,’ ‘Vinete românești 300,’ ‘Bistrițene de Hațeg,’ ‘Prune roșii,’ ‘Busuioace de Geoagiu,’ ‘Perje de toamnă,’ ‘Tuleu timpuriu,’ ‘Pescăruș,’ ‘Tămâioasă de Bistrița,’ ‘Albe de Bilcești,’ ‘Superb,’ ‘Prune roșii,’ ‘Prun de stepă,’ ‘Tuleu gras,’ ‘Pozegača,’

'd'Agen,' 'Late d'Agen,' 'Drjanovska Sliva,' 'Korai Besztercei,' 'Troianskaia Sliva,' 'Hamanova Svetska,' 'R.C. Violet,' 'OK,' 'Belle de Liege,' 'Belle de Louvain,' 'Mohawk,' 'R.C. d'Oullins,' etc. [6, 53, 57].

Ripening time. In the plum breeding program, it is desirable to extend the ripening season, creating very early varieties, but also very late. Donors for earliness are recommended: 'Ersinger,' 'Petrovača' [3], 'Early Rivers,' 'Ruth Gerstetter,' 'Čačanska Lepotiča,' 'Čačanska Rana,' 'Ialomita,' 'Diana,' 'Scolduș de vară,' 'Boboloase,' etc. [2, 6]. Potential genitors for lateness are: 'Grand Duke' [58], 'Anna Späth,' 'President,' 'Record,' 'Vinete românești,' 'Grase românești,' etc. [2, 6, 57].

Fruit characters. Fruit quality represents an important breeding objective, as the consumer requirements are constantly increasing [59–62]. The new variety will be successful only if certain characteristics are met, such as fruit size, skin color, commercial aspect, sweetness, acidity, firmness, flavor, and juiciness [26, 63–65].

- *Fruit size.* Generally, regarding this trait, the most influence on the progenies is exercised by the mother parent and the cumulative effect of both parents [6]. Therefore, in order to obtain hybrids with large fruits, it is desirable for parents to have large fruits. At the European plum, the fruit size is absolutely necessary, especially since most varieties with special tasting qualities have small fruits (e.g., 'Tuleu gras'). They are of interest as genitors of fruit size for the following varieties: 'Jubileum' from Sweden; 'Tophit'; 'Haganta' from Germany [16]; 'Valor' and 'Vision' from Canada; 'Čačanska Najbolja' from Serbia; and 'Record,' 'Vâlcean,' 'Tita,' 'Carpatin,' and 'Romanța' from Romania [6, 57].
- *Fruit shape.* At *Prunus domestica* species, the ellipsoidal fruit shape is dominant over the spherical one, whereas at *Prunus salicina* there is no dominance for the spherical or elongated shape [32]. On the fruit market in Middle Europe elongated shape fruits are preferred. The following varieties can be used as parents for the elongated shape: 'Stanley,' 'Pozegača,' 'Vinete românești,' 'Tuleu gras,' 'Centenar,' etc. [6]. The following varieties can be used as parents for the spherical shape: 'Anna Späth,' 'Kirke,' 'California Blue,' 'Gras ameliorat,' 'Grase de Becs,' etc. [6, 57].
- *Fruit color.* For fresh market, the fruit color is an important trait. The fruit color of plums ranges from dark blue to blue, purple, red and yellow. At *P. domestica* and *P. salicina* species, the skin color is determined by an allelic series, which the allele for the yellow color is recessive to the allele for the blue, red, or purple colors [32]. In the European fruit market, consumers prefer two skin colors: green with different shades (France and parts of Germany) and blue in most countries. The following can be used as parents for the blue color of the skin: 'Stanley,' 'Standard,' 'Oneida,' 'Valor,' 'Vision,' 'Kirke,' 'Hackmann,' 'Bluebell,' 'Bluefree,' 'Negre de Seini,' 'Negre de Bilcești,' 'Vinete românești,' 'Tămâioasă de Bistrița,' 'Piteștean,' 'Pescăruș,' 'Centenar,' 'Dâmbovița,' etc. [6, 53, 57].
- *Fruit taste.* The taste is the most important aspect of fruit quality. The fruit taste, expressed as a ratio between the main components (sugar, acidity, tannins, vitamins, and aroma) has a great variability, according to the consumers' requirements but also on the origin of the varieties. For example, people from Southern Europe and those from Asia prefer sweet fruits. In other

countries, people prefer fruit with a balance between sugar and acidity [16]. Also, a balanced taste has varieties originating from *P. domestica* and *P. insititia* [6, 57]. Thus, the following varieties are recommended as genitors for good and very good taste: 'Tuleu gras,' 'Centenar,' 'Gras ameliorat,' 'Grase de Becs,' 'Uriășe de Sibiu,' 'Agent,' and 'Andreea' in Romania [6]; 'Bijelica sitna' and 'Prskulja' in Bosnia and Herzegovina; 'Moravka,' 'Metlaš,' 'Obični piskavac,' and 'Čačanska Najbolja' in Serbia; 'Auerbacher,' 'Ortenauer,' and 'Wangenheims' in Germany; 'Italian prune,' 'President' in the USA, and 'd'Agen' in California and France [3].

Sharka (PPV) resistance. One of the major objectives in plum breeding, both in our country and worldwide, is the resistance to viral diseases, especially to plum pox virus, one of the most damaging pathogens causing yield losses over 70%, especially to susceptible cultivars [66, 67]. The yield of sensitive varieties, which externalize disease's symptoms on fruit, loses commercial value for fresh market. The fruits affected are blemished, misshapen, and distorted with sunken lesions in flesh. If don't drop prematurely and rich harvest maturity, the fruits have poor flavor, small size, low sugar content and anthocyanin. These fruits can be sold at low price, only to distilleries for brandy processing [67].

The only efficient way to fight against this virus is to develop resistant or tolerant cultivars. The following can be used as a gene source for the resistance to plum pox virus (Sharka): 'Popești,' 'Vienez,' 'Roman,' 'Cisnadie,' 'Lachi,' 'Alina,' 'Ungurești,' 'Cioraști de Prahova,' 'Flora,' 'Negre de Saru,' 'Negre de Bilcești,' 'Krimka,' 'Peche,' 'Chabat,' 'Hüttner,' 'Belle de Liege,' 'Kirke,' 'Marry Mather,' 'Giant plum,' and 'Condata' [53].

In Germany, at Hohenheim University, Stuttgart, Professor Hartmann achieved very good results on the PPV resistance line, surprisingly, by using the 'Stanley' variety as a parent. An "absolute resistance" through hypersensitivity (HR—hypersensitive reaction) was identified in the 'Jojo' variety obtained from the cross between the 'Ortenauer' and 'Stanley' varieties [16, 68].

Zagrai et al. [42] showed that transgenic plants, with incorporated coatprotein (CP) genes, through mediation with the bacterium *Agrobacterium tumefaciens*, confer protection against Sharka [42]. A transgenic clone, C5 (named 'Honeysweet'), was also studied under the conditions of different countries from Europe, remaining free of PPV after years of testing [42].

7. Achievements and prospects

A large number of breeding programs are developed in different countries from Europe. Some of the plum breeding programs have been reduced or stopped in the countries where production has declined or funding is no longer available. At the same time, some breeding programs became more private with less public funding [10, 22].

In Romania, during 60 years of breeding work, over 2,000,000 plum flowers were pollinated at different centers: Pitești, Vâlcea, Bistrița, and Strejești. From the hybrid seeds, approximately a thousand hybrids were obtained which, thanks to their variability, enabled the selection of many new valuable hybrids. As a result 40 new plum cultivars were registered. In the first two breeding stages (1955–1970), the cultivars 'Tuleu timpuriu' (1967, 'Tuleu gras' × 'Peche'), 'Superb' (1968, 'Tuleu gras' × 'Abbaye d'Arton'), 'Gras ameliorat' ('Grase românești'—self-pollination), 'Vinete românești 300' (1970, 'Vinete românești'—selection), and 'Tuleu dulce' (1968, 'Tuleu gras' × 'd'Agen') were selected. Among the basic genitors, 'Tuleu

gras' cv. was by far the best, giving the greatest number of promising selections. During this period, the cultivars 'Renclod Althan,' 'd'Agen,' 'Early Rivers,' and 'Wilhelmina Späth,' used as character genitors, proved of particular value. In the third breeding stage (1970–1980), the cultivars 'Centenar' (1978, 'Tuleu gras' × 'Early Rivers'), 'Silvia' (1978, 'Renclod Althan' × 'Early Rivers'), 'Albatros' (1979, 'Tuleu gras'—open pollination), and 'Pescarus' (1979, 'Renclod Althan' × 'Wilhelmina Späth') were registered. This was a very fruitful stage, because the experimental plots and field trials within the national research network gave the possibility to both select the new autochthonous cultivars and also to choose the adequate area for testing each of them. In the fourth stage (1980–1990), the following varieties were registered: 'Ialomița' (1981, 'Renclod Althan' × 'Early Rivers'), 'Diana' (1981, 'Renclod Althan' × 'Early Rivers'), 'Piteștean' (1981, 'Tuleu timpuriu' × 'Early Rivers'), 'Carpatin' (1981, 'Tuleu gras' × 'Early Rivers'), 'Dambovița' (1981, 'Tuleu gras' × 'Anna Späth'), 'Record' (1982, 'Renclod Violet'—open pollination), 'Minerva' (1984, 'Tuleu timpuriu' × 'Early Rivers'), 'Flora' (1989, 'Tuleu gras' × 'Renclod Violet'), and 'Sarmatic' (1989, 'Tuleu timpuriu' × 'Early Rivers'), with large fruit and high yields. In the last stage (after 1990), which is still going on, the greatest number of cultivars was recorded: 'Renclod de Caransebeș' (1990, 'Renclod Althan' × 'Wilhelmina Späth'), 'Vâlcean' (1990, 'H 8/12' × 'H 5/23'), 'Bărăgan 17' (1990, 'Tuleu gras' × 'Early Rivers'), 'Tita' (1991, 'Tuleu gras'—irradiated stones), 'Alina' (1991, 'Tuleu gras'—irradiated stones), 'Andreea' (2000, 'H 27/87' open pollination), 'Delia' (2002, 'Vanat Italy' × 'Anna Späth'), 'Iulia' (2002, 'Tuleu gras' × 'Renclod Althan'), 'Ivan' (2003, 'Tuleu gras' × 'Vanat Italia'), 'Jubileu 50' (2003, 'Tuleu gras' × 'De Bistrița'), 'Dani' (2004, 'Tuleu gras' × 'Grase românești'), 'Doina' (2004, 'Anna Späth' × 'Renclod Althan'), 'Geta' (2004, 'Centenar' × 'Ialomița'), 'Matilda' (2004, 'Anna Späth' × 'd'Agen'—irradiated with Co⁶⁰), 'Roman' (2004, 'Tuleu gras' × 'Early Rivers'), 'Agent' (2004, selection within a population of seedlings resulted from open pollination), 'Romaner' (2005, 'Tuleu gras' × 'Renclod Althan'), 'Zamfira' (2005, 'Anna Späth' × 'Renclod Althan'), 'Elena' (2005, 'Tuleu gras' × 'Stanley'), 'Alutus' [2010 ('R.C. Althan' × 'Early Rivers') × ('R.C. Althan' × 'Wilhelmina Späth') × mixed pollen], 'Topval' (2010, 'Tuleu gras' × 'Stanley'), and 'Romanța' (2012, 'Stanley' × 'Vâlcean'). Some of these cultivars are proven to be tolerant to PPV besides their high-quality fruit and yields [19].

In *Serbia*, about 530 hybrid combinations were made in the European plum breeding program starting in 1949 at the Fruit Research Institute, Čačak, of which around 30,000 hybrids have been produced and 16 varieties have been released. The oldest varieties obtained are 'Čačanska Rodna' (1975, 'Stanley' × 'Požegača'), 'Čačanska Rana' (1975, 'Wangeiheim' × 'Požegača'), 'Čačanska Secer' (1975, 'd'Agen' × 'Pacific'), 'Čačanska Lepotica' (1975, 'Wangeiheim' × 'Požegača'), 'Čačanska Najbolja' (1975, 'Wangeiheim' × 'Požegača'), 'Jelica' (1986, 'Požegača' × 'California Blue'), 'Valerija' (1986, 'Hall' × 'Ruth Gerstetter'), and 'Valjevka' (1986, 'd'Agen 707' × 'Stanley'). After 2000 several promising new cultivars with high commercial potential were named: 'Mildora' (2004, 'Large Sugar' × 'Čačanska Lepotica'), 'Boranka' (2004, 'California Blue' × 'Ruth Gerstetter'), 'Timočanka' (2004, 'Stanley' × 'California Blue'), 'Krina' (2005, 'Wangenheim' × 'Italian Plum'), 'Pozna Plava' (2008, 'Čačanska Najbolja'—self-pollination), 'Zlatka' (2008, 'Large Sugar' × 'Zuta Boutilcovidna'), 'Nada' (2012, 'Stanley' × 'Scolduș'), 'Petra' (2018, 'Stanley' × 'Opal'), and 'Divna' (2018, 'Stanley' × 'Čačanska Rana'). Cultivars such as 'Čačanska Lepotica,' 'Čačanska Najbolja,' and 'Čačanska Rodna' were used as parents in different breeding programs in some European countries, especially Germany, Bulgaria, the Czech Republic, and Romania [3, 69–71].

In *Germany*, plum breeding is carried out in two centers: the University of Hohenheim, Stuttgart, and Geisenheim Research Station. In the University of Hohenheim in Stuttgart, new varieties were created by Professor Walter Hartmann, valuable through resistance to plum pox virus, fruit taste, attractive appearance, and multiple uses of the fruit. These varieties are ‘Hanita’ (1991, ‘President’ × ‘Auerbacher’), ‘Katinka’ (1992, ‘Ortenauer’ × ‘Ruth Gerstetter’), ‘Elena’ (1993, ‘Italian Prune’ × ‘Stanley’), ‘Jojo’ (1993, ‘Ortenauer’ × ‘Stanley’)—the first plum cultivar immune to the plum pox virus—‘Felsina’ (1994, ‘Italian Prune’ × ‘Ersinger’), ‘Tipala’ (1995, ‘Tiroler Zuckerzwetsche’ × ‘Opal’), ‘Tegera’ (1995, ‘Ortenauer’ × ‘Ruth Gerstetter’), ‘Presenta’ (1996, ‘Ortenauer’ × ‘President’), ‘Colora’ (2003, ‘Ortenauer’ × ‘Ruth Gerstetter’), ‘Azura’ (2003, ‘Hanita’ × ‘Čačanska Lepotiča’), ‘Haganta’ (2003, ‘Čačanska Najbolja’ × ‘Valor’), ‘Haroma’ [2003, (‘Ortenauer’ × ‘Stanley 34’) × ‘Hanita’], ‘Habella’ (2003, ‘Ortenauer’ × ‘Stanley 34’), ‘Hanka’ (‘Hanita’ × ‘Katinka’), ‘Juna’ (‘Katinka’ × ‘Zwintschers’), ‘Jofela’ (2013, ‘Jojo’ × ‘Felsina’), ‘Jolina’ (2013, ‘Jojo’ × ‘Haganta’), and ‘Joganta’ (2014, ‘Jojo’ × ‘Haganta’) [3, 6, 72, 73]. At the Research Station of Fruit Growing, Geisenheim, Professor Helmut Jacob carried out an extensive breeding program for 25 years, which resulted in 12 plum varieties, of which 10 for fresh consumption and 2 for distillation [74]. The plums designated for fresh consumption are: ‘Topfive’ (1987, ‘Čačanska Najbolja’ × ‘Auerbacher’), ‘Topper’ (1988, ‘Čačanska Najbolja’ × ‘Auerbacher’), ‘Topking’ (1988, ‘Čačanska Najbolja’ × ‘Italian Prune’), ‘Tophit Plus’ (1988, ‘Čačanska Najbolja’ × ‘President’), ‘Top 2000’ (1991, ‘Stanley’ × ‘NN’), ‘Topfirst’ (1993, ‘Čačanska Najbolja’ × ‘Ruth Gerstetter’), ‘Topstar Plus’ (1993, ‘Ersinger’ × ‘Čačanska Najbolja’), ‘Toptaste’ (1994, ‘Valor’ × ‘German Prune’), ‘Topgigant Plus’ (1994, ‘Čačanska Najbolja’ × ‘President’), and ‘Topend Plus’ (1994, ‘Čačanska Najbolja’ × ‘Valor’). The two varieties destined for distillation are ‘Bellamira’ (1994, ‘Čačanska Najbolja’ × ‘Mirabelle from Nancy’) and ‘Miragrande’ (1995, ‘Mirabelle Herrenhausen’ × ‘Yellow Plum’) [75].

In *Bulgaria*, during the 60-year period of the breeding program, 29 plum cultivars were created in centers such as Dryanovo, Troyan, Kyustendil, and Plovdiv. By improving the old Kjustendilska cultivar, breeders like Marinov, Vitanov, Balev, Minev, Enev, Videnov, Georgiev, and Velkov obtained the following varieties: ‘Dryanovska,’ ‘Sinya Yubileyna,’ ‘Gulyaeva,’ ‘Gabrovska,’ ‘Pop Hariton,’ ‘Burya,’ ‘Strinava,’ ‘Nevena,’ ‘Vitanova,’ ‘Edra trankosliva,’ ‘Baleva sliva,’ ‘Strumska sinja,’ ‘Kyustendilska ranna,’ ‘Izobilie,’ ‘Kyustendilska krasavitsa,’ and ‘Plovdivska.’ After 2000, breeders Zhivondov and Bozhkova created our plum varieties with tolerance to plum pox virus and resistance to late frost and drought: ‘Plovdivska renkloda’ and ‘Sineva’ (‘Stanley’—open pollination), ‘Ulpia’ (‘President’—open pollination), and ‘Ostromila’ (‘Pacific’ × ‘Serdika 2’) [76].

In *France*, the plum breeding program started in 1947 at INRA Bordeaux, and eight plum varieties (6 varieties for drying (prunes) and 2 varieties for fresh consumption (plums)) were registered: ‘Primacotes®Coten’ (1982, ‘d’Ente’ × ‘d’Ente 629’), ‘Tardicotes®Enduke’ (1982, ‘d’Ente’ × ‘Grand Duke’), ‘Lorida®Enspa’ (1985, ‘d’Ente’ × ‘Anna Späth’), ‘Lemburn’ and ‘Double Robe’ (1985, ‘d’Ente’ mutagenesis), ‘Spurdente®Ferco’ (1986, ‘d’Ente 707’ mutagenesis), ‘Fermareine®Bellina’ (1993, ‘Reine Claude Verte’ × ‘Reine Claude de Bavay’), and ‘Ferbleue®’ (1985, ‘Reine Claude Verte’ × ‘California Blue’) [3, 6, 77, 78]. French plum breeding program has stopped.

In *England*, many of the varieties created by Thomas Rivers are widespread today in culture: ‘Czar,’ ‘Victoria,’ ‘Early Prolific,’ ‘Early Transparent,’ ‘Golden Transparent,’ ‘Heron,’ ‘Monarh,’ ‘President,’ ‘Early Rivers,’ and ‘Blue Tit.’ ‘President’ and ‘Early Rivers’ cultivars are used as parents in breeding work from some

European countries. Thomas Laxton has created varieties such as ‘Laxton Beautiful’ and ‘Laxton Cropper.’ At the East Malling Research Station, ‘Cox’s Emperor’ and ‘Yellow Egg’ varieties were obtained but also other more recent varieties: ‘Avalon’ (1990, ‘Reeves’—open pollination), ‘Excalibur’ (1990, ‘Cox’s Emperor’—open pollination), and ‘Guinevere’ (obtained in 2000)—these three varieties being created to replace the old ‘Victoria’ cultivar. England plum breeding program has stopped [3, 6].

In *Italy*, there are plum breeding programs both in public (at Universities Bologna, Firenze and Forli) and in private, and the following varieties have been obtained: ‘Parlantina’ (1987), ‘Grossa di Felisio’ (1988), ‘Big Egg’ (1989), ‘Firenze 90’ (1990), ‘Grossa di Solarolo,’ ‘Empress,’ ‘Sugar Top’ (2000, ‘Susino II’ × ‘Stanley’), ‘Prugna 29’ (2000, ‘French improved’ × ‘Stanley’), ‘Liablu’ (2000, ‘Empress’ × ‘Ruth Gerstetter’), and ‘Maria Novella’ (2000) [6, 10, 79].

In the present, in *Russia*, there are 12 plum breeding programs. After 2000, 44 new plum varieties were released: ‘Aleksiy,’ ‘Bolhovcanka,’ ‘Kantemyrovka’ (at the All Russian Research Institute of Fruit Crop Breeding, Orel), ‘Ballada,’ ‘Osenniy Suvenir,’ ‘Prikubanskaya,’ ‘Debjut,’ ‘Golubaja Mechta,’ ‘Milena,’ ‘Podruga,’ ‘Gertsog,’ ‘Krasotka,’ ‘Charodeyka,’ ‘Osenniyaya,’ ‘Krasnodarskaya,’ ‘Beglyanka’ (at the North Caucasian Zonal Research Institute of Horticulture and Viticulture Krasnodar), ‘Vengerka Korneevska,’ ‘Nižegorodskaya,’ ‘Renklod Scherbinskiy’ (at Nizhny-Volzhsky Research Institute of Agriculture, Moscow), ‘Vecherniy Zvon,’ ‘Viola,’ ‘Galateya,’ ‘Pamyat Finayeva’ (at the Samara Zonal Experimental Station of Horticulture, Samara), ‘Volžanka,’ ‘Kazanskaya,’ ‘Pamyat Hasanova,’ ‘Rakitovaya,’ ‘Teknovskaya Golubka’ (at Tatar Scientific Research Institute of Agriculture, Kazan), ‘Zanyatnaya,’ ‘Syniy Dar,’ ‘Suhanovskaya,’ ‘Utro,’ ‘Yahontovaya,’ ‘Kantemirovka’ (at the All Russian Horticultural Institute of Breeding, Agrotechnology and Nursery, Moscow), ‘Indira’ (at the Kuibyshev Experimental Station for Horticulture Samara), ‘Predgornaya,’ ‘Sverhrannyaya’ (at the Dagestan Breeding Experimental Station of fruit and Berry Crops, Buynaksk), ‘Antonina’ (at the Maritime Fruit and Berry Experimental Station of the Maritime Research Institute of Agriculture in Vladivostok), ‘Startovaya,’ ‘Zarecnaya Rannaya,’ ‘Renklod Kursakova,’ ‘Nochka’ (at the All Russian Research Institute of Genetics and Breeding of Fruit Plants in Michurinsk), ‘Viktorina,’ and ‘Baykalskaya’ (at the Nikitsky Botanical Garden—National Science Center Yalta and the Scientific Research Institute of Horticulture of Siberia, Barnaul) [3, 80–83].

In *Belarus*, at the Institute for Fruit Growing, Minsk, the following varieties were created: ‘Dalikatnaya’ (2005, ‘Evrasia 21’ × ‘d’Agen’), ‘Kroman’ (2005, ‘Perdigron’ × ‘d’Agen’), ‘Charadejka’ (‘Doneckaya rannayaya’ × ‘Victor’), ‘Narach’ (2008, ‘d’Agen’ × ‘Renclod Althan’), ‘Venera’ (2009, ‘Narach’ × ‘Wangenheim Fruhwetsche’), ‘Ranaya Losickaya,’ ‘Vengerka Belorusskaya’ (2010, ‘Stanley’ × ‘Dalikatnaya’), ‘Volat,’ and ‘Nagrada Nemanskaya’ [10, 84, 85].

Important achievements in the plum breeding are also in the *Republic of Moldova*, the work being started by Hramov in 1946 and continued by Condratiev, Juraveli, and Levițaia at the Research Institute for Horticulture and Alimentary Technologies, Chisinau. Of these we mention ‘Chisinovskaia Raniaia,’ ‘Vengherka Krupnaia Sladkaia,’ ‘Vengherka Jubileinaia,’ ‘Sopernița,’ ‘Raniaia Hramova,’ ‘Udlinioniaia,’ ‘Pamiati Kostinoi,’ ‘Pozdniaia Hramova,’ ‘Pamiati Vavilova’ (2010, ‘Reine Claude Verte’ × ‘Vanat Italy’), ‘Crasa Oseni’ (2010, ‘Reine Claude Verte’ × ‘Ispolinscaia’), ‘Superpresident,’ ‘Ajur 1,’ ‘Naiboleco,’ and ‘Cabardinca’ [3, 6, 10].

Plum breeding in *Estonia*, started in 1945 by Julius Eslon at the Polli Horticultural Institute, has had four stages so far, the varieties registered being the following: ‘Karski,’ ‘Polli Munaploom,’ ‘Suhkruploom,’ and ‘Polli Varane,’ created in the first

stage; 'Julius,' 'Esloni Varane,' and 'Polli Viljakas,' obtained in the second stage; 'Amitar,' 'Ave,' 'Kadri,' 'Liisu Norgen,' 'Sargen,' 'Vilkana,' 'Vilmitar,' and 'Vilnor,' created in the third stage, from 1964 to 1985); and 'Kaidi,' a variety created in the last stage starting in 1986 [86, 87].

In *Latvia*, the breeding program carried out at the Latvia State Institute of Fruit Growing, Dobeles, based on a large germplasm fund (184 plum accessions, of which 25 are indigenous varieties), contributed to the completion of the plum assortment with 12 new varieties: 'Agra Dzeltēna' (now is growing only as pollinator), 'Inese,' 'Minjona,' 'Zemgale,' 'Lase,' 'Ance' (2010, 'Jubileum' × 'Opal'), 'Adele' (sin. 'Adelyn'; 2010, 'Laxton's Early' × 'Ruth Gerstetter'), 'Lotte' (2010 ['Jubileum' × 'BPr 5613' ('R.C. Reforma' × 'Ruth Gerstetter')], 'Sonora' (2010, 'La Crescent' × 'Jefferson'), 'Zane,' 'Laine,' and 'Lienite' [10, 88, 89].

In *Poland*, plum breeding program started at the Research Institute of Pomology and Floriculture at Skierniewice in the 1960s, and seven new cultivars were registered: 'Kalipso,' 'Emper,' and 'Polinka' (obtained by control hybridization); 'Dabrowice Prune' (seedling of the common plum—'Wegierka Zwyczajna'—from open pollination); 'Nectavit,' 'Tolerant'; and 'Promis' (clones of the common plum—'Wegierka Zwyczajna') [90].

In the *Czech Republic*, at the Research Breeding Institute of Pomology, Holovousy, 13 new plum cultivars were released: 'Amátka' (2011, 'Čačanska Lepotica' × 'Gabrovska'), 'Dwarf' (2011, 'Asatan' × 'Čačanska Najbolja'), 'Staňa' (2011, 'Stanley' × 'Gabrovska'), 'Kamir,' 'Hololepa,' 'Simona,' 'Samera,' 'Lipniská,' 'Malenovická,' 'Paní Háje,' 'Těchobuzická,' 'Valentýnka,' and 'Vítek' [91].

In *Sweden* and *Norway*, countries with a climate less favorable to plum culture, the results of the breeding programs were 'Edda' (1980, 'Czar' × 'Pêche') in Norway and 'Opal' (1925, 'Oullins Gage' × 'Early favorites'), 'Herman' (1983, 'Czar' × 'Ruth Gerstetter'), 'Ariel' (1983, 'd'Autumn Compot' × 'R.C. Althan'), 'Jubileum' (1985), 'Madeleine' (1987, 'Hackmann' × 'Victoria'), 'Emil' (1989), and 'Violetta' (1991, 'Grand Duke' × 'Herman') in Sweden [6].

In *Canada*, at present, the plum breeding program has been suspended. However, from the old breeding program, starting in 1913 at the Horticultural Research Institute of Ontario in Vineland, 10 European plum cultivars were named: 'Valor' and 'Verity' (1967, 'Imperial Epineuse' × 'Grand Duke'), 'Vision' (1967, 'Pacific' × 'Albion'), 'Veeblue' (1984, 'Imperial Epineuse' × 'President'), 'Voyageur' (1987, 'Ruth Gerstetter'—open pollination), 'Victory' (1992, 'Vision' × 'Valor'), 'Valerie' ('Valor' × 'California Blue'), 'Vanette' ('Early Rivers' × 'Stanley'), 'Vibrant' ('Valor' × 'California Blue'), and 'Violette' ('Verity' × 'Bluebell') [92, 93].

In the *USA*, at the New York Agricultural Experiment Station, Geneva, several cultivars have been released: 'Hall' (1923), 'American Mirabelle' (1925), 'Stanley' (1926, 'd'Agen' × 'Grand Duke'), 'Albion' (1929), 'Iroquois' (1966, 'Prugna di Italy' × 'Hall'), 'Mohawk' (1966), 'Oneida' (1966), 'Seneca' (1972), 'Moyer Prune' (1984), 'Castleton' ('Valor' × 'Iroquois'), 'Longjohn' ('Iroquois' × 'CA4A33L'), 'Polly' ('Oneida'—self-pollination), 'Kenmore' ('Standard' × 'Stanley'), and 'Amers' ('Stanley' × 'Standard'); the last five cultivars are registered after 2000. Among them, 'Stanley' cv. is the most widely grown cultivar worldwide [6]. At the Missouri State Fruit Experiment Station, in 1947, three European plum cultivars were released: 'Radiance,' 'Bluebell,' and 'Bluefree' ('Stanley' × 'President'). At the University of California at Davis, cultivars for dessert use were released ('Emperor' cv.), but also cultivars suitable for drying ('Sutter,' 'Tulare Giant' in 2000, and 'Muir Beauty' in 2005) [9, 94]. Other European plums released in the USA at Oregon Agricultural Experiment Station are 'Gardner' (1923) and 'Hildreth' (1982) [9].

Recently, at the USDA Kearneysville WV, the researchers are focused on creating plum varieties with resistance to PPV using gene manipulation methods, and the first transgenic cultivar—‘Honey Sweet’—was registered, which included a gene from the virus coat protein [39].

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