Handbook of Plum Fruit

Production, Postharvest Science, and Processing Technology

Edited by

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CRC Press

Taylor & Francis Group

Handbook of Plum Fruit

In the last ten years there has been an exponential increase in the adoption of high-density farming, which leads to better yield and higher-quality fruits, thus improving the economic return. *Handbook of Plum Fruit: Production, Postharvest Science, and Processing Technology* covers all the recent advances in plum production, harvesting, handling and processing.

Divided into two main parts, the first eight chapters provide insight about preharvest processing of plums, whereas the later chapters discuss the postharvest processing of plums. This book also includes vital chapters on varietal improvement and rootstock breeding, high-density planting, and pollination. After harvesting, plum quality quickly diminishes, mainly due to weight loss, total acidity, loss of firmness, and decay.

Key Features:

- In-depth information on the pre- and postharvest processing of plums
- Coverage on plum harvesting, handling, and storage practices
- Plum by-product utilization and potential health benefits

Handbook of Plum Fruit provides comprehensive information on recent advances in postharvesting technologies of plum. The health benefits of plum and its products are also addressed. This book will assist horticulturists, agriculturists, pomologists, food scientists and others working in various fruit-processing industries.

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CRC Press
Taylor & Francis Group
Boca Raton London

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

First edition published 2023
by CRC Press
6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487–2742

and by CRC Press
4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

CRC Press is an imprint of Taylor & Francis Group, LLC

Library of Congress Cataloging-in-Publication Data
Names: Gull, Amir, editor.
Title: Handbook of plum fruit : production, postharvest science, and processing technology / edited by Amir Gull, Gulzar Ahmad Nayik, Sajad Mohd Wani, Vikas Nanda.
Description: First edition. | Boca Raton, FL : CRC Press, 2023. | Includes bibliographical references and index.
Identifiers: LCCN 2022009539 (print) | LCCN 2022009540 (ebook) | ISBN 9781032062426 (hbk) | ISBN 9781032071176 (pbk) | ISBN 978100320544(ebk).
Subjects: LCSH: Plum—Handbooks, manuals, etc. | Plum—Postharvest technology—Handbooks, manuals, etc.
Classification: LCC SB377 .H36 2023 (print) | LCC SB377 (ebook) | DDC 634/.22—dc23/eng/20220625
LC record available at https://lccn.loc.gov/2022009539
LC ebook record available at https://lccn.loc.gov/2022009540

ISBN: 978-1-032-06242-6 (hbk)
ISBN: 978-1-032-07117-6 (pbk)
ISBN: 978-1-003-20544-9 (ebk)

DOI: 10.1201/9781003205449

Typeset in Times
by Apex CoVantage, LLC

Dr. Amir Gull dedicated this book to his beloved daughter, Abeeha Amir

Contents

Preface

Extensive growing technology, low yields and low-quality fruit, multitude cultivars and plum pox virus (PPV)–induced problems are main distinctions in plum production. In addition, the structure of the assortment of plums is unfavorable. About half of the total number of trees are native cultivars having small fruits, followed by poor quality. On the other hand, over 75% of the plum orchards are located in mountain areas, where a main limiting factor for plum intensive production is acidic soils, having deficiency of organic matter and inadequate availability of major nutrients. The appearance of nutrient deficiencies and responses to added nutrients indicated the prevalence of nutritional disorders of macronutrients and therefore, limited vegetative growth, low productivity and poor fruit quality.

The prunus genus (*Rosaceae* family) consists of more than 200 species, including some of the most common fruit or ornamental species that are of great economic importance. The plant is of medium height, has deciduous leaves and is ovate, dentate and glossy. White flowers with small green drupaceous fruits (3 cm), characterize the blossoming and ripening stages. It is commonly cultivated for its fruits, as a rootstock and hedge shrub. A recent study showed the potential of kernels recovered from fruit pits of this species as biodiesel feedstock. Plums are adapted to a broad range of geographic conditions, having great potential for production and consumption worldwide and therefore particularly suitable to use for selecting new cultivars.

Being rich in fibers and antioxidants, the fruits constitute an important nutritional source in the human diet. The aroma is one of the most important parameters of determining fruit quality and its perception and acceptability by consumers. The knowledge of volatiles emitted by different plant organs during different ontogenetic stages of growth evidence metabolites that are synthesized by the plant as possible intrinsic mechanisms of defense and interaction with other plants and animals, something of importance for further agronomical studies.

Plum fruits are small and oval in shape, with different skin color and flesh, which is consumed fresh, dried or used to prepare juice, jam or liquor. Plums are classified as climacteric fruits with ethylene controlling changes during ripening. However, some of them show a suppressed-climacteric pattern. Plums are appreciated by consumers due to their high-quality properties, such as sweetness and firmness, and their bioactive compound content, mainly phenolics, including anthocyanins, carotenoids, ascorbic acid and fiber. These bioactive compounds have been reported to have antioxidant properties with health benefits such as reducing the risk of cardiovascular illness.

After harvesting, plum quality quickly diminishes, mainly due to weight loss, total acidity, loss of firmness and decay. Thus, it is necessary to adopt proper postharvest technologies to maintain and extend the postharvest quality of plums for longer periods. Therefore, it is important to understand and document the modern production methods implemented in recent times for harvesting the maximum number of plums. This book will therefore bridge the gap for old and modern methods of production and will help students and researchers understand the complete pre- and

postharvest handling of plum fruit. This book will also help fruit growers understand the best possible practice for modern plum production to harvest maximum yield, which in turn will increase their returns.

The book is divided into two main parts: the first provides insights about the preharvest processing of plum, which is discussed in the first eight chapters. Chapter 1 deals with the history, distribution, production and taxonomic classification of plums. Chapter 2 highlights the orchard planning, establishment and soil management of plums, followed by Chapters 3 and 4, which discuss recent advances in rootstock breeding and plum prorogation. Chapter 5 covers the flowering, fruit set and pollination of plum, while Chapter 6 deals with orchard manuring practices of plum trees. Chapter 7 focuses on recent developments in plum harvesting and handling, and Chapter 8 deals with diseases, pests and disorders in plum.

The second part gives insights about the postharvest processing of plum. Chapter 9 discusses the emerging packaging and storage technologies of plum, while Chapters 10 and 11 focus on recent plum-processing technologies and the utilization of plum by-products. Chapter 12 deals with the health benefits of plum fruit its products, and Chapters 13 and 14 deal with the effects of pre- and postharvest technologies/factors on the quality and bioactive compounds of plum. The last chapter emphasizes the extraction of anthocyanins from plum fruit and its products.

Lastly, this book assists horticulturists, agriculturists, pomologists, researchers, food scientists and other members working in various fruit-processing industries. It could be used by university libraries and institutes all around the world as a handbook and/or ancillary reading for students pursuing bachelor's and master's degrees in agriculture, horticulture or fruit and vegetable processing. We would like to thank and acknowledge one by one all authors for their fruitful contribution and for their dedication to editorial guidelines and timelines. We are fortunate to have had the opportunity to collaborate with many international experts from the United States, Australia, Romania, Spain, Colombia, México, South Korea, China and Pakistan. We would like to thank colleagues from the production team at Taylor & Francis for their constant help during the editing and production process. Finally, we as editors have a message to all readers that this book may contain minor errors or gaps. Suggestions, criticism and comments are always welcome, so please do not hesitate to contact us for any relevant issue.

Dr. Amir Gull,
Dr. Sajad Mohd Wani,
Dr. Gulzar Ahmad Nayik,
Dr. Vikas Nanda

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Dr. Amir Gull completed his master's degree in Food Technology from Islamic University of Science & Technology, Awantipora, Jammu and Kashmir, India, and his PhD from Sant Longowal Institute of Engineering & Technology, Longowal, Sangrur, Punjab, India. Dr. Gull has published more than 35 peer-reviewed research and review papers in reputable journals. He has also published two books in Springer, more than ten book chapters and delivered a number of presentations at many national and international conferences. Dr. Gull's main research activities include developing functional food products from millets. He also serves as an editorial board member and reviewer of several journals. He is also an active member of the Association of Food Scientists and Technologists India and is a recipient of the Maulana Azad National Fellowship from the University Grants Commission of India.

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Prof. Vikas Nanda completed his master's degree and PhD in food technology from Punjab Agricultural University, Ludhiana, Punjab, India. He is currently working as Professor in the Department of Food Engineering & Technology, Sant Longowal Institute of Engineering & Technology, Sangrur, Punjab, India. Prof. Nanda has published more than 80 peer-reviewed research and review papers and many book chapters, has authored two books and has delivered a number of presentations at various national and international conferences, seminars, workshops, and webinars. Prof. Nanda has supervised 5 PhD scholars and 24 M.Tech students. Prof. Nanda has visited Israel, the Czech Republic, France, Greece, Argentina, the Netherlands, Thailand and the United Arab Emirates to attend international conferences. Prof. Nanda is also working as Co-Chairman for the International Honey Commission and Co-chairman/Mentor council formed by the Ministry of Labour and Employment, Government of India.

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1 History, Distribution, Production and Taxonomic Classification of Plum

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DOI: 10.1201/9781003205449-1

1.1 INTRODUCTION OF PLUM

Plums rank third after apples and pears as far as their job in natural product creation in the cooler and calmer portions of the world (Zohary et al. 2012). Plums are a highly commercialized stone fruit and are consumed fresh, in jams or dried, known as prunes. Despite its agricultural importance and long history of cultivation, there are still many mysteries concerning the species' origins and connections. One of most cultivated is the European plum (*Prunus domestica*), a hexaploid (2 n = 6x = 48 chromosomes) fruit tree that is grown all over the world (Zhebentyayeva et al. 2019; Zohary et al. 2012).

Plums and prunes are among the fruits in the Rosaceae family, which also includes cherries, apples, nectarines, peaches, pears, and various berry harvests. The genus *Prunus*, which includes all real plums, is a prominent part of the Rosaceae family. Approximately 200 *Prunus* species are thought to exist. Principally, they are located in northern temperate areas. There are a variety of plums, the most significant of which are European plums (*Prunus domestica* L.) and Japanese plums (*Prunus salicina* Lindl). There are also American plums, damsons, Mirabelle plums, and more varieties. Recently, a few 'interspecific hybrids' have been developed by crossing plums with apricots or sweet cherries (Jayasankar et al. 2015). Figure 1.1 shows some different varieties of most cultivated plums from Europe.

Luna-Vázquez et al. (2017) compile studies of principal phytochemicals in stone fruits. Plums are low in calories, with simple sugars, vitamins, minerals, proteins and lipids. Some phytochemicals are recognized as polyphenols, carotenoids, triterpenes and unstable mixtures. Phenolic compounds are incompletely credited to their cancer prevention agent: polyphenols. Different health properties have been revealed with the consumption of plums, such as increased antioxidants, antiallergenic properties, better cognitive function and lower cardiovascular risk (Igwe and Charlton 2016). Particularly, prunes or dried plums have an exclusive nutritional bioactive profile and are suggested to be beneficial for bone health (Wallace 2017).

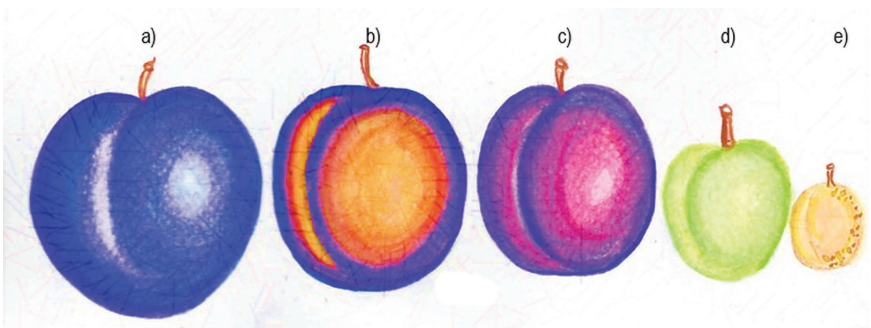

FIGURE 1.1 Types of plums *Prunus domestica*: a) prune monsieur native, b) damson, c) prune royale tours, d) greengage and e) Mirabelle plum. Illustrated by Laura Natali Afanador-Barajas.

The European plum likely began in a district near the Caspian and Caucasus Seas and is no less than 2,000 years old. The species of plum localized in the Old World, beginning in Europe or Asia, is the damson plum (*Prunus insititia*); antiquated works interface early development of those plums with the district around Damascus. The Japanese plum was first tamed in China millennia prior, yet it was broadly evolved in Japan; from that point, it was acquainted with the remainder of the world. Japanese plums have a more extended time span of usability than most European assortments and are in this way the most well-known plum sold economically. Plum production is developed all through the world, and numerous assortments are adjusted to a scope of soils and climatic conditions (Milošević and Milošević 2018; Okie and Hancock 2008; Faust and Surányi 1999; Siddiq 2006).

1.1.2 History of Plums

1.1.2.1 Origin of Plums

Different species of plums evolved in Europe, Asia, and North America and were domesticated independently. Historical evidence proposes *Prunus domestica* originated in Europe as *P. cerasifera* and *Prunus spinosa* originated in western and central Asia. *P. salicina* originated in China, and the *Prunocerasus* species, such as *P. americana* (Marshall plum), originated in North America (Topp et al. 2012; Milošević and Milošević 2018). The highest diversity of plums among different *Prunus* species and have been tamed around three continents (Faust and Surányi 1999). Figure 1.2 shows the places of origin, the expansion and the dispersion of plums around the world.

Plums are distributed throughout Europe, North America and Asia (Okie and Hancock 2008). The origin of these fruit trees of the genus *Prunus* is located in the central (the Caucasus area) and eastern (China) regions of Asia (Figure 1.2). Its

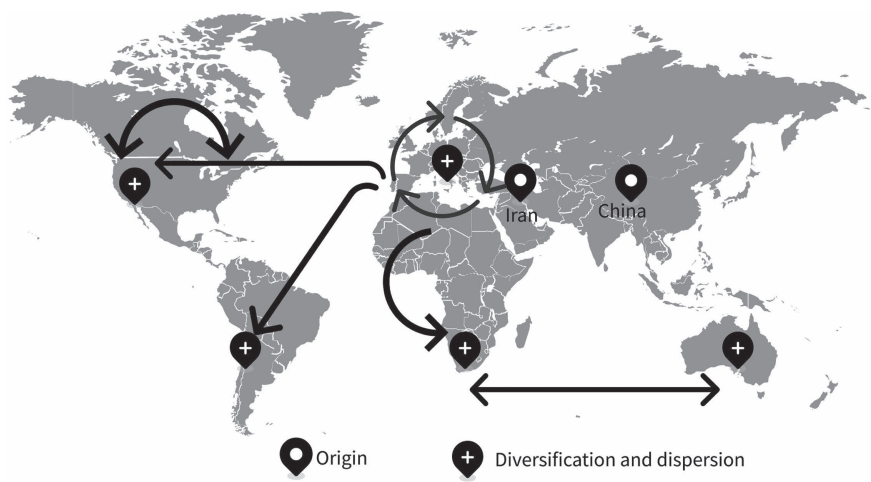

FIGURE 1.2 Places of origin, expansion and dispersion of plums around the world.

expansion toward the Near East and the Mediterranean went in parallel with trade routes and historical events that put the Persian Empire in contact with Europe in the 4th century BCE. This first arrival in Europe would occur through Armenia or Iran to Greece and Italy. The species also arrived through the southern Mediterranean to Spain through the Arabs in the second half of the 7th century CE. Finally, the expansion of these fruit trees to North America, Mexico and South Africa would be produced from Europe (mainly from Spain) in the 16th and 17th centuries. It was not until the 18th century that they arrived in Australia (Martínez-Gómez 2017).

P. domestica L. was utilized by humans at least 6,000 years ago, according to stone remains, and it was commonly grown in Roman times. Because of the lengthy history of domestication, there is a wide range of morphology (Urrestarazu et al. 2018; Topp et al. 2012). *Prunus salicina* was initiated in the Yangtze River and spread across eastern China. The cultivar known as 'Zhui Li' has a history of more than two eras ago. The species labeled as *P. consociiflora*, *P. gymnodonta*, *P. ussuriensis* and *P. thibetica* are all *P. salicina* plums with minor differences and are not currently considered differentiated species (Faust and Surányi 1999).

Watkins (1976) investigates the split of the *Prunocerasus* and *Euprunus* species. He claims that if they had separated earlier, the parallels between them would not be as strong. Most diploid species have a high degree of interspecific compatibility, and they have been hybridized during the last two centuries to increase adaptability, fruit quality, and yield. *Prunus* research has largely focused on crop species and their relatives. The geographic origin of *Prunus* has unavoidably been assumed to be Eurasia, given that the genus's core of crop diversity is in that region. A complex interaction of geologic tectonic processes and climatic oscillations from the early Eocene period determined *Prunus*'s worldwide spread from its place of origin, which either favored or impeded migration into both the Old and New Worlds at various episodic periods of geologic time. Furthermore, we have given evidence to support the notion that the primary evolved from a hybrid (Chin et al. 2014).

1.1.2.2 Polyploidy of Plums

Polyploidy is a common occurrence that plays an important role related to the expansion of new species or forms. Polyploidy is also significant from a practical standpoint because plants with this trait are frequently highly robust and may be more resistant to cold and parasitic (OECD 2002). In *Prunus*, the indispensable number of chromosomes in vegetative cells is eight. Polyploidy, because of interspecific hybridization, occurred during the phylogeny of the variety and is liable for self-sterility and intersterility (OECD 2006).

The *Prunus* species of European plums are hexaploid, despite the fact that some of them are genuine diploids. Specifically, *Prunus domestica* is a polymorphic allopolyploid (2n =6x= 48) (Faust and Surányi 1999). Two additional ancient wild plums, the diploid cherry plum *Prunus cerasifera* and the tetraploid blackthorn *Prunus spinosa* L., gave rise to the tetraploid species (Jayasankar et al. 2015). The European plum may be an amphidiploid derived from *Prunus cerasifera* (2n=16) and *Prunus spinosa* (2n=32) (Hartmann and Neumüller 2009).

Table 1.1 shows many species of plum, the principal ones being *P. domestica*, commonly called the European plum, 2n=48, hexaploid, from Europe; *Prunus*

TABLE 1.1
Types of Plums and Different Origins and Genetic Compositions

Plums	Native	Chromosome number
P. domestica (European plum)	Europe	2n=48 (hexaploid)
P. domestica ssp. P. insititia (damson plum)	Europe	2n=48 (hexaploid)
P. cerasifera (cherry plum)	Europe	2n=16 (diploid)
P. spinosa (sloe)		2n=32 (tetraploid)
P. simonii	Asia	2n=16 (diploid)
P. salicina (Japanese plum)	China	2n=16 (diploid)
P. nigra		2n=16 (diploid)
P. americana (American plum)	North America	2n=16 (diploid)
P. hortulana	North America	2n=16 (diploid)
P. angustifolia	North America	2n=16 (diploid)
P. mexicana	North America	2n=16 (diploid)
P. munsoniaca	North America	2n=16 (diploid)

domestica ssp. P. insititia, or damson plum, 2n=48, hexaploid, from Europe; *Prunus salicina* with a 2n=16, diploid, from China; and *Prunus americana*, known as the American plum, 2n=16, diploid, from North America. The present plum industry is based on *Prunus domestica* and *Prunus salicina*. Neither of these species takes wild ancestors, and both entered into human use highly developed. The garden plum and the Japanese plum emerged as important fruit crops around 300 BCE (Zohary et al. 2012).

1.1.2.3 Archaeological Evidence

Stones of all European species of plum (*P. domestica*, *P. cerasifera* and *P. spinosa*) have been uncovered dating back to 4000–6000 BCE in Ukraine and Germany. These archeological discoveries of European plums matches more specifically in Neolithic times (Faust and Surányi 1999). *Prunus domestica* appears to have begun in southern Europe or western Asia between the Caucasus Mountains and the Caspian Sea, covering the beginning of *P. cerasifera* and moving into western Europe. The most punctual archeological remaining parts of *P. domestica* in Europe are inferable from the Roman period (Sarigu et al. 2017; Browicz and Zohary 1996; Okie and Ramming 1999; Zohary et al. 2012). Plum stones had appeared in different locations in Europe from the Neolithic and Bronze Ages, such as Italy, Germany, Austria, and Switzerland. The stones are variable in shape, but they decrease within the morphological range compared to actual plums, such as *cerasifera* and *insititia* (Zohary et al. 2012).

Based on archeological findings, confined stones of *Prunus spinosa* and *Prunus insititia*. were found in resident disinterring near to lake at Switzerland. From the Caspian Sea and the Caucasus Mountains, the plum was spread to antiquated Egypt, Syria, Mesopotamia and Crete around 6000 BCE (Faust and Surányi 1999). A lot later, because of wars, relocation and exchange developments, plums were known

in Rome and Greece. The previous account of the history of plums comes from the Greek verse writer Archilochus (680–645 BCE) and the versifying artist Hipponax (541–487 BCE), whereas the old Greek thinker Theophrastus (370–287 BCE) depicted three plum cultivars. The Romans brought homegrown plums from Syria after they vanquished the region in 65 BCE (Zohari 1986).

1.2 DISTRIBUTION OF PLUMS

1.2.1 Generalities about Plum Distribution

Diversity in plants is driven by many factors related to climate, geography, soil and nutrient content (Lompo et al. 2021). Recently, improvement in predicting species distribution attempts to contribute to understanding the ecological and evolutive patterns of diversity that will be an important tool in making proper decisions in reforestation plans, conservation and predicting the suitability of a habitat for many species (Elith et al. 2006). Undoubtedly, climate change will cause fast alterations in these patterns, causing problems for people who cultivate these important fruits for their subsistence. Particularly, plums are native in temperate regions (Okie and Ramming 1999), and many of the native plums have been improved with better flavor, shape, color and nutritional content.

Ten countries lead plum production, China being the most important. The other countries are Chile, Spain, India, Iran, Italy, Romania, Serbia, Turkey and the United States (Milošević and Milošević 2018). According to FAOstat data, plums are widely distributed around the world. but it is important to distinguish between botanically recognized species and varieties, although this classification may vary in some articles. For Faust and Surányi (1999), *Prunus spinose* and *Prunus cocomilia*, *Prunus spinose* L., were the two former species. Both were well distributed and originated in Europe, North Africa and Northern Turkey; specifically, *P. cocomilia* is described in Italy. *Prunus spinossa macrocarpa* can also be considered an early species, but its exact origin and history are very controversial (Milošević and Milošević 2018), even today.

1.2.2 Principal Groups

1.2.2.1 Cherry Plum (*Prunus cerasifera*)

The well-distributed *Prunus cerasifera* (cherry plum) originated in west Asia, is native to southeast Europe, and is well known as a common plum; however, the exact origin of this species is not clear. It is considered the diploid European plum's progenitor and is cross-fertile with American species and Asiatic species, which constitutes it as a basic species because it can reproduce with many other species.

The cherry plum is also known as the Myrobalan plum (derived from the Greek words *Myron*, which means juice of plant, and *balanos*, which means nut). In Europe, it is possible to find it in the United Kingdom, and it is naturalized in the northeast and far west United States as the Stanley prune. Some common varieties are: 'Thundercloud', 'Krauter Vesuvius', and 'Newport'. Some authors consider it a cultivated form of *P. cerasifera* macrocarpa and a wild form named *P. divaricate*, more common in the Caucasian region but native from Macedonia to northern Persia (Faust and Surányi 1999).

Some species derived from *P. cerasifera* are spp ursine (Turkey and Syria); and varieties and forms of *P. cerasifera* based on local adaptations have been described as var.iranica in Iran, var nairica in Armenia and caspica in Caucasia. There are many hybrids of cherry plums, including the Mariana plum, the Methley plum, and *P. ferganica*, and ornamental forms, such as *planteriensis* Hort, *pendula* Hort, *acutifolia* Hort and *pisardiii,* distributed in France.

Garden plums, derived from *cerasifera*, may include common *P. domestica* and *P. insititia*. The first one well cultivated may be a cross between *cerasifera* and *spinosa*; found in Turkey, northwestern Xinjiang (China), Serbia, Hungary and Bulgaria, with possible origin in Iran (Faust and Surányi 1999).

1.2.2.2 *Prunus domestica*—The Most Important Plum Industry

Prunus domestica is one of the two most important bases of the plum industry and commerce; the other is *Prunus salicina* (Faust and Surányi 1999). This species was described by Linnaeus in 1753, and his description was published in *Species Plantarum* 1:475 (Méndez 2015). Actually, *Prunus salicina* are the most important species in the plum industry and are widely cultivated (Faust and Surányi 1999). This variety is known as the Italian or European plum, but the first cultivars were in Syria and probably distributed in Rome and then to the rest of Europe, especially in the west countries (Okie and Ramming 1999).

During the Crusades, the Romans introduced European plums to the western part of Europe (Okie and Ramming 1999). It is still not clear for breeders where they can find its wild form, but is possibly near the Caspian Sea (Milošević and Milošević 2018). It is the most economically important fruit tree, particularly in Europe and southwest Asia, where it is vastly cultivated and is considered a younger species resulting from the natural cross between *Prunus cerasifera* and *Prunus spinose*, but it is necessary to use other types of analysis to determine this idea.

The trees are well adapted to cooler regions and may be eaten in a variety of ways. In the United States, California is the main producer, but it can also be found in Idaho, Washington, Oregon, Michigan and New York (Okie and Ramming 1999). A subspecies, *P. insititia*, is cultivated in Connecticut, Maine, Massachusetts, New Hampshire and Vermont.

1.2.2.3 Yellow Egg Plums—*Prunus institia*

This group comprises *P. insititia* L., with all its derived varieties. It originated in Turkey and is derived from *Prunus domestica* (*Prunus domestica* subsp institia) and has divisions as *P. pomarium*, *P. insititia glaberrima*, alpine-orientalis y var leopodiensis, *Prunus insititia syriaca* and var Juliana (Faust and Surányi 1999).

1.2.3 Worldwide Distribution

The two major types of plum are the Asiatic and European species. The first ones include two species, *Prunus salicina* (formerly *P. triflora* Roxb.) and *Prunus simonii*, also known as the Simon or apricot plum found in China, Japan, and Central Asia; *Prunus simonii* was used as a parental species in Californian cultivars. *P. salicina*, the Japanese plum, has its origin in the Yangtze River in China, according to Yoshida (1987), and then spread to the east lands. Small, sun-loving deciduous trees found in

TABLE 1.2
Major Distribution of Principal Species Cultivated over the World

Country	World plum distribution	Source
Argentina	*Prunus domestica* (var Agen, President and Reineclaudes) *Prunus salicina* (Black Amber, Santa Rosa and Red Beaut)	(Colamarino 2010)
Bulgaria	*Prunus domestica*	(Faust and Surányi 1999)
Brazil	*Prunus salicina* (Carmesin, Rosa Paulista, Gran Cuore, Gema de Ouro, Golden Talisma, Rosa Mineira, Januaria and Kelsey-31)	(Milošević and Milošević 2018)
Chile	*Prunus domestica* (var DÁgen, President and Imperial Epineuse)	(Colamarino 2010)
China	*Prunus domestica* *Prunus salicina*	(Faust and Surányi 1999)
Colombia	*Prunus salicina* Lindl. Horvin	(Orjuela, Camacho, and Parra-Coronado 2016)
Costa Rica	*Prunus domestica*	(Calvo 2009)
France	*Prunus cerasifera*	(Faust and Surányi 1999)
United Kingdom	*Prunus cerasifera* (Myrobalan)	(Faust and Surányi 1999)
Hungary	*Prunus domestica*	(Faust and Surányi 1999)
Iran	*Prunus cerasifera*	(Faust and Surányi 1999)
Italy	*Prunus domestica*	(Okie and Ramming 1999)
Japan	*Prunus salicina*	(Yoshida 1987)
South Korea	*Prunus salicina*	(Yoshida 1987)
Mexico	*Prunus domestica* *Prunus sativa*	(Méndez 2015)
Syria	*Prunus cerasifera*	(Milošević and Milošević 2018)
Uruguay	*Prunus domestica* (Stanley and Reineclaudes) *Prunus salicina* (var Santa Rosa, Obil´naja, Leticia and Rosa Nativa)	(Mercado 2016)
United States	*Prunus angustifolia* *Prunus nigra* *Prunus hortulana* Bailey *Prunus munsoniana*	(Faust and Surányi 1999)
Vietnam	*Prunus salicina*	

Japan, Korea, Vietnam and Australia produce Japanese plums. However, these round and smooth or wrinkled fruits are actually native to China. In the United States, especially in California, the plum cultivars now include all the fresh-market plums developed by intercrossing various diploid species with the original species. Japanese plums are well distributed in Australia, Vietnam, Japan and Korea. In California, this species is usually found at supermarkets. A wide variety of fruits resulted from several genetic crosses between the original species and the diploid species (Okie and Ramming 1999).

1.2.3.1 Species and Varieties in the United States

The original five American species of plums are *Prunus americana*, or wild plum, *Prunus angustifolia*, *Prunus nigra*, *Prunus hortulana* Bailey and *P*runus *munsoniana*. *P. americana* is well distributed in the United States, especially in the northern and eastern regions; it is probably native to Missouri and is well cultivated in Utah and at the Gulf of Mexico, as well as other states, such as Georgia and Massachusetts. *Prunus angustifolia* is well distributed alongside the Missouri River. It comes from a small deciduous tree and is also called a Chickasaw plum. It can be found in Delaware, Florida and Texas because it grows well in sandy soils. *Prunus nigra* is also known as the Canada plum, but its range includes New England, Michigan, New York, northern Ohio and Wisconsin. *Prunus hortulana* Bailey has been cultivated in many regions, including central Kentucky, Tennessee, Iowa and Oklahoma. This variety is a hybrid between *P. americana* and *P. angustifolia*. Finally, *Prunus munsoniana*, or the wild goose plum, is cultivated in Kentucky, Tennessee, Mississippi, Texas, Minnesota and Kansas (Faust and Surányi 1999). Numerous American plum species resulted from crosses of commercial varieties.

Prunus avium's (wild cherry) origin is in Europe, northern Africa and southwestern Asia, but it has been well distributed in the United States since colonial times. It's not as sweet as other species that have been derived from this type of plum. Their seeds are dispersed by birds and small mammals, such as squirrels. Varieties include Lapin Starkrimson and Stella, 'Thomas' Stark gold.

Prunus armeniaca (dwarf apricot) has two types. The 'Homedale' Stark Sweetheart is native to northern China, and its name is derived from Armenia (western Asia). It was introduced by Stark Bro's of Louisiana, Missouri, but it's not as well developed as other types of plums because of its low tolerance to freezing temperatures and because it's extremely susceptible to insects and other pests. The Wilson is a small-dwarf apricot native to northern China and is considered a cultivar that adapts well in small spaces.

Prunus carolinianus (cherry laurel) is widely distributed to North Carolina and Florida at the southeast of the United States and to Louisiana, Texas and Arkansas in the central part of the country. It is characterized as being well adapted to drought places.

Prunus cistena (purple-leaf sand cherry) resulted from controlled reproduction between *P. pumila* and *P. cerasifera*, resulting in a hybrid. It has red leaves is a small shrub, is tolerant to sun exposure and is more abundant in Canada but is also found in the United States. *Prunus glandulosa* 'Sinensis', or commonly called the dwarf flowering almond, has adapted to urban areas but requires well drained soils.

1.2.3.2 Species and Varieties in Latin America

Chile is one of the most important plum cultivators in Latin America; "Sweet Pekeetah" was the first variety produced at Universidad de Chile for genetic improvement and fruit quality (Bravo 2010). This plum's culture comprises 32° to 36° south latitude, at the central valley from the V to VII regions that comprise Maipo Valley, Curicó and Maule Valley. The varieties used to pulp dehydration are D'Agen, President and Imperial Épineuse, all derived from *Prunus domestica*; D´Agen concentrates 95% of the planted area, and due to its high sugar level it is particularly suitable for dehydration, allowing for a high-quality product.

Argentina is the leading producer of plums in the Southern Hemisphere and is among one of the three largest exporters of the same group. Varieties of both *Prunus domestica* and *Prunus salicina* can be found in Mendoza and Rio Negro. Japanese plum varieties (*P. salicina*) include Black Amber, Red Beauty and Santa Rosa. The European plum varieties (*P. domestica*) Agen, President and Reineclaudes are the most cultivated (Colamarino 2010). Uruguay produces fresh fruit based in the two principal species (*Prunus domestica* and *Prunus salicina* Lind.) and some varieties include Stanley and Reineclaudes. Uruguay also produces Santa Rosa, Obil'naja, Methley, Leticia and Rosa Nativa varieties with high juicy content and Golden Japan and Crystal, with particularly yellow and white pulp (Mercado 2016). Colombia reports *Prunus salicina* Lindl. Horvin in 16 small towns at Nuevo Colón, principally Aposentos, Potreros 5º 21' 11" North, 73 º 27' 24" West in the Boyaca region, where 63% of the country's plums are produced (Orjuela et al. 2016). Brazil cultivates the improved Japanese plum varieties Carmesin, Rosa Paulista, Gran Cuore, Gema de Ouro, Golden Talisma, Rosa Mineira, Januaria and Kelsey-31 (Milošević and Milošević 2018).

Mexico cultivates many subspecies derived from *Prunus domestica* in Puebla, Veracruz, Chiapas, Jalisco, Nayarit and Sinaloa, among others, and also *Prunus sativa* (Méndez 2015). Costa Rica has plum cultivars in high zones at Los Santos, in La Pastora in San Marcos de Tarrazý and Copey de Dota. In Copey de Dota, some growers are replacing their apple plantations with plum, as the production is less expensive. However, its production and commercialization is recent, in small quantities within the national economy; in addition, it is a product little rooted in the national economy (Calvo 2009).

The European-type plums (*Prunus domestica*) are elongated, have a dark skin color and the stone is easily separable from the pulp. They are the most appropriate for industrial processing. Within this group are the Stanley and Reineclaudes varieties, both with skin tones ranging from purple to blue. Japanese plums (*Prunus salicina* Lind.) are medium to large spherical fruits, with a sweet aroma that is accentuated with ripening, as well as abundant juice, which is why they are preferred for fresh consumption (Sottile et al. 2010).

1.3 PLUM PRODUCTION

1.3.1 Background

The status of the plum production, market and trade around the world is reviewed. China is the most important producer of plum and sloes, with seven million tons and with revenue amounted to USD 10 billion (Wood 2019), followed by Romania, Serbia, Chile and the United States (FAOSTAT 2021).

1.3.2 International Production

Plums usually need a subtropical and temperate climate, such as those in Europe, Asia and America. Of the nearly 40 existing species, the most important species commercially around the world are *Prunus domestica* and *Prunus salicin*a (Okie and Ramming 1999; Topp et al. 2012).

World plum production increased from 10.8 million tons in 2009 to 12.6 million tons in 2019, as per the estimated data from the Food and Agriculture Organization of the United Nations (FAOSTAT 2021). The world's major plum producers are China (11%), Romania (1%) and Serbia (1%) (Figure 1.3). The United States contributes 0.5% (FAOSTAT 2021). Most plums are produced in Asia (58%), followed by Europe (29%), America (10%), Africa (2%) and Oceania (1%) (Figure 1.3).

China has established itself as one of the main plum producers and has been increasing its harvest due to national economic reform (Liu et al. 2007). In the 1980s the production reached 1 million tons, during the 1990s it reached approximately 4 million tons and finally in the last decade it reached approximately 7 tons (FAOSTAT 2021). GuangDong Food and Drug Vocational College is one of the companies that preserved plum production lines in GuangDong Province, an area in China that supplies more than 65% of preserved plums in the global market (Wang et al. 2017).

In cooler areas European plums are produced and usually are more acclimatized than Japanese plums that are produced in hotter areas (Topp et al. 2012; Wangchu et al. 2021). One of the limitations Japanese plums present are frosts in the winter

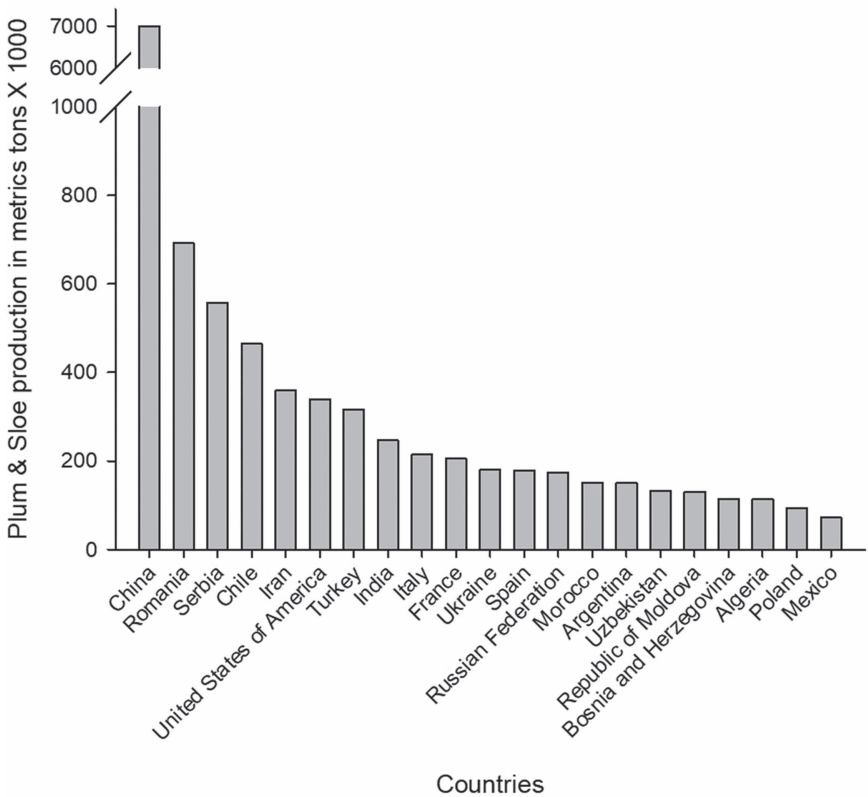

FIGURE 1.3 Principal countries associated with plum and sloe world production.

and early spring, and some physical and chemical characteristics of the soil (Okie and Hancock 2008). The European market sells more European plums, about 90% of plum production, while Asian markets sell more Japanese plums, about 82%. They are sold as separate crops and marketed as distinct commodities (Topp et al. 2012).

Europe plum production in 2019 was 2,895,801 tons (FAOSTAT 2021). The principal countries in Europe with the highest production of *Prunus domestica* are Romania, Bulgaria, Hungary and Germany (Dalla and Baric 2012). However, since 2010 the plum yielding in countries such as Bulgaria and Romania has decreased due to early fruit drop from sharka disease, a viral disease caused by the plum pox virus (PPV) (Wangchu et al. 2021). In 1997 Bulgaria produced 112,589 tons of plum fruit, which decreased by 50% in 2019. In Romania from 2018 to 2019 the production of plums decreased by 17%. During the 1960s Germany produced approximately 1 million tons and in 2019 only 52,140 tons (FAOSTAT 2021), making it sixth in plum production within the European Union (Dalla and Baric 2012). Even so, cultivars often self-fertilize with better resistance to PPV and with high yielding (Mónika Molnár et al. 2016). Contrary to these countries and despite the fruit production in Serbia showing signs of reduction, plum production has increased from 459,712 tons in the period 1981–2011 (Lukac Bulatovic et al. 2013) to 558,930 in 2019 (FAOSTAT 2021).

Plum production in the Americas in 2019 was 1,075,914 tons. South America contributed 66% of production, and North America contributed 34%. Chile, with 465,000 tons, and Argentina, with 150,000 tons, are two of the most important countries in Latin America when it comes to plum production. The production is located in cold areas as the states of Rio Grande do Sul that produces about 50% of the national harvest and the upper mountains of states such as Minas Gerais, Santa Catarina and São Paulo (Eidam et al. 2012).

In the United States close to 53% of the plum yield are European plums, 38% are Japanese plums and 9% are a mixture of *Prunus americana* and others species (Surányi and Erdős 2004). California during the 2000s was the principal US producer, with close to 300,000 tons in annual yield (Jayasankar et al. 2015). However, since 2011 production has decreased to close to 67%. The last register for 2019 was approximately 100,000 tons (USDA 2006).

1.3.3 Marketing and Trade

The world market revenue for plums and sloes came to USD 15.7 billion in 2018, a 12% increase from 2017. In the last decade the market value of plums has increased by about 5%, with some years seeing a decreases in value. By the end of the past decade market value totaled USD 16.3 billion. China, with USD 10 billion, is the principal marketer, followed by the United States, with USD 757 million (Wood 2019).

California is the major marketer of plums used for drying. The value of plum production in California State in 2020 was USD 122,233,000 (Ross et al. 2020). The United States is the most important plum seller internationally, with 30% of the worldwide average. Canada and Taiwan were the main importers of US plums in 2020, followed by Mexico and Hong Kong (Boriss et al. 2006). In 2019 the leading importers were Canada (37%), Mexico (22%), Hong Kong (20%) and, finally, Taiwan (11%) (FAOSTAT 2021).

Following the United States, Chile increased its sales from USD 35 million to USD 100 million between 2001 and 2008 in the exportation of plums (Bravo 2010). The main Chilean market for plums is the United States. For the years 2016 and 2017, the United States imported about USD 54 million in fresh plums and USD 40 million in dried plums (USDA 2017). In 2019 Chile exported 76,305 tons of plum and sloes to China and 23,860 to the United States, with transactions of USD 121 million and USD 35 million, respectively. The United States imported USD 52 million in plum and sloes from Chile (FAOSTAT 2021).

In Germany about 50,000 tons of European plums are sold by producer markets annually. In total about 300,000 tons of plums are harvested, including fruits produced for direct marketing, liquor production and for homegrown trees. In Germany half of the plum production is used in bakeries, 30% for fresh consumption, and the rest for alcohol production as brandy (Wangchu et al. 2021).

1.4 TAXONOMY

1.4.1 Botanical Characteristics of Plums

The study of taxonomy involves studying an organism's morphological characters in detail and classifying; plums are part of the genus *Prunus*. The botany defines plums, especially *P. domestica*, as trees characterized to be deciduous, small and branched (Figure 1.4). The plums are approximately 4–15 m in height, the branches are rosy or brown and glabrous, with a few spines that change from reddish brown to grayish green. *P. domestica*'s leaves have a deep green color and are alternated; the form can be obovate or elliptic, the margins are serrulate, and it has parallel veins. The flowers are solitary or in fascicles of three, with spreading white or pink petals and approximately 15–30 stamens, diverse with filiform strings. The flower stigma is

FIGURE 1.4 Illustration of *Prunus domestica*, characteristics of leaves, fruit, seed and flower. Illustrated by Laura Natali Afanador-Barajas.

usually truncated. The fruit mostly has a fleshy exterior and is edible. The mesocarp is fleshy, the endocarp is generally ellipsoid and horizontally compacted, containing a hard seed known as a stone with a bony pit. Drupes can be purple, purpleblack, red, green, yellow or golden yellow, are usually globose to oblong and are rarely subglobose (see Figure 1.4) (Lim 2012; Waugh 1901).

1.4.2 Principal Taxonomy of *Prunus* Classification

Prunus is the principal genus in most significant species of plum (Table 1.3), in the family Rosaceae and subfamily Amygdaloideae. The European plum is *Prunus domestica*, which is hexaploidy. Japanese plum (*Prunus salicina*) and sloe (*Prunus spinosa*) have diploidy, and *Prunus simonii* shows tetraploidy (Hussain et al. 2021). Waugh (1901) pronounced the genus *Prunus* as trees. Flowers have spreading white or pink petals, with approximately 15–30 stamens, are diverse with filiform strings. The flower stigma is usually truncated. The fruit is mostly with carnosus with a fleshy exterior and edible. Also, fruit contains hard seeds known as stones with a bony pit. An example of these characteristics in *Prunus domestica* is shown in Figure 1.4.

The NCBI database (Schoch et al. 2020) includes two subspecies for *Prunus domestica* (*P. domestica* subsp. insititia and *P. domestica* subsp. syriaca), and only one variety (*P. domestica* var. Juliana). For *Prunus salicina* only one variety is included in the database (*Prunus salicina var. cordata*). Similarly, *P. japonica* has the variety *P. japonica var. nakaii*. Different varieties of *Prunus cerasifera* (cherry plum) include var. *cerasifera*, f. atropurpurea, var. divaricate and var. Pissardii. There are also different hybrids with other species of *Prunus* genus, such as *Prunus*

TABLE 1.3
Taxonomic Classification in the Different Species of Plums. According to the Taxonomy of the NCBI Database (Schoch et al. 2020)

Classification	European plum	Asian plum	American plum
Kingdom	Viridioplantae	Viridioplantae	Viridioplantae
Phylum	Streptophyta	Streptophyta	Streptophyta
Class	Magnoliopsida	Magnoliopsida	Magnoliopsida
Superorder	Rosanae	Rosanae	Rosanae
Order	Rosales	Rosales	Rosales
Family	Rosaceae	Rosaceae	Rosaceae
Genus	*Prunus*	*Prunus*	*Prunus*
Species	*Prunus domestica* (damsons and domestica plums) *Prunus spinosa* *Prunus cerasifera* (Myrobalan or cherry plum)	*Prunus salicina* *Prunus simonii* (Simon plums) *Prunus triflora* (Japanese plums)	*Prunus americana* *Prunus nigra* *Prunus angustifolia* *Prunus hortulana* *Prunus munsoniana* *Prunus subcordata* *Prunus maritima* *Prunus pumila*

cerasifera x *Prunus dulcis*; *Prunus cerasifera* x *Prunus munsoniana*; *Prunus cerasifera* x *Prunus persica*; *Prunus cerasifera* x (*Prunus persica* x *Prunus dulcis*); *Prunus cerasifera* x *Prunus salicina*; and (*Prunus cerasifera* x *Prunus salicina*) x (*Prunus cerasifera* x *Prunus persica*).

Waugh (1901) found some contradictions in the taxonomy of some members of the *Prunus* genus. Consequently, Bortiri et al. (2001) made a summary of the principal inconsistencies. First, the classification of *Prunus* into four different genera (*Prunus*, *Padus*, *Cerasus* and *Amygdalus*), and later changed to two genera (*Prunus* and *Amygdalus*). Second, a division of five genera formed by *Prunus*, *Armeniaca*, *Persica*, *Amygdalus* and *Cerasus* (with *Padus* and *Laurocerasus*). Third, *Prunus* as a single genus divided into seven units (*Amygdalopsis*, *Amygdalus*, *Armeniaca*, *Cerasus*, *Ceraseidos*, *Laurocerasus* and *Prunus*). Fourth, *Prunus* with the previous seven parts as subgenera; and fifth, *Prunus* were classified into five subgenera as *Amygdalus*, *Cerasus*, *Laurocerasus*, *Prunophora* and *Padus* and *Prunus* distributed in *Euprunus*, *Prunocerasus* and *Armeniaca*. Finally, sixth, *Prunus* was separated into three genera conformed by *Prunus*, *Laurocerasus* and *Padus* (Chavez and Chaparro 2020).

1.4.3 *Prunus* Phylogenetic Classification

Plant classification has been difficult due to intergenic hybridization, which has changed the configuration of taxa. As a result, the definition of species is broadened to include apomixis and hybridization. Mowrey and Werner (1990) reported a phylogeny and systematics in *Prunus* using isozymes to focus on the phylogenetic connections in *Prunus*. *Prunocerasus* was observed to be polyphyletic, with a clade formed by *Prunus americana*, *Prunus angustifolia*, *Prunus hortulana*, *Prunus munsoniana* and *Prunus subcordata*. Other clade were formed by *Prunus maritima* and *Prunus umbellata*. Also, Bortiri et al. (2006) demonstrated the utility of morphological characters in phylogenetic analysis of *Prunus*. While Bortiri et al. (2001) used a combination of ITS sequences, cpDNA, and morphological features to support several nodes that had previously been discovered in *Prunus*. Large groups were supported by several synapomorphies, which provided extra resolution for several clades.

Hodel et al. (2021) studied nuclear and chloroplast phylogenies of *Prunus* species using nuclear markers of DNA. They found that various species of *Prunus* had histories consistent with hybridization and allopolyploidy. Also, they observed that the *Prunus* group is monophyletic, but there is some conflict in the gene tree with a substantial disharmony at several nodes, including the node of the racemose group. They suggest that a different form of tree topologies that conflicted with the species tree were consistent with a paraphyletic racemose group. In the case of European plums, they found a monophyletic clade between *Prunus salicina* and *Prunus domestica*.

Chin et al. (2014) found the importance of studying phylogenetic analysis in *Prunus* to understand the geographic beginning and ancestral genes of cladogenesis using the Bayes-DIVA method. Their outcomes showed that contemporary genus appeared almost ~61 Myr in eastern Asia and enhancement of all significant heredities might have been set off by a worldwide temperature boost of the early Eocene epoch.

We constructed a phylogeny using the 18S marker with some of the most representative species of plum. Figure 1.5 shows three principal clades of species

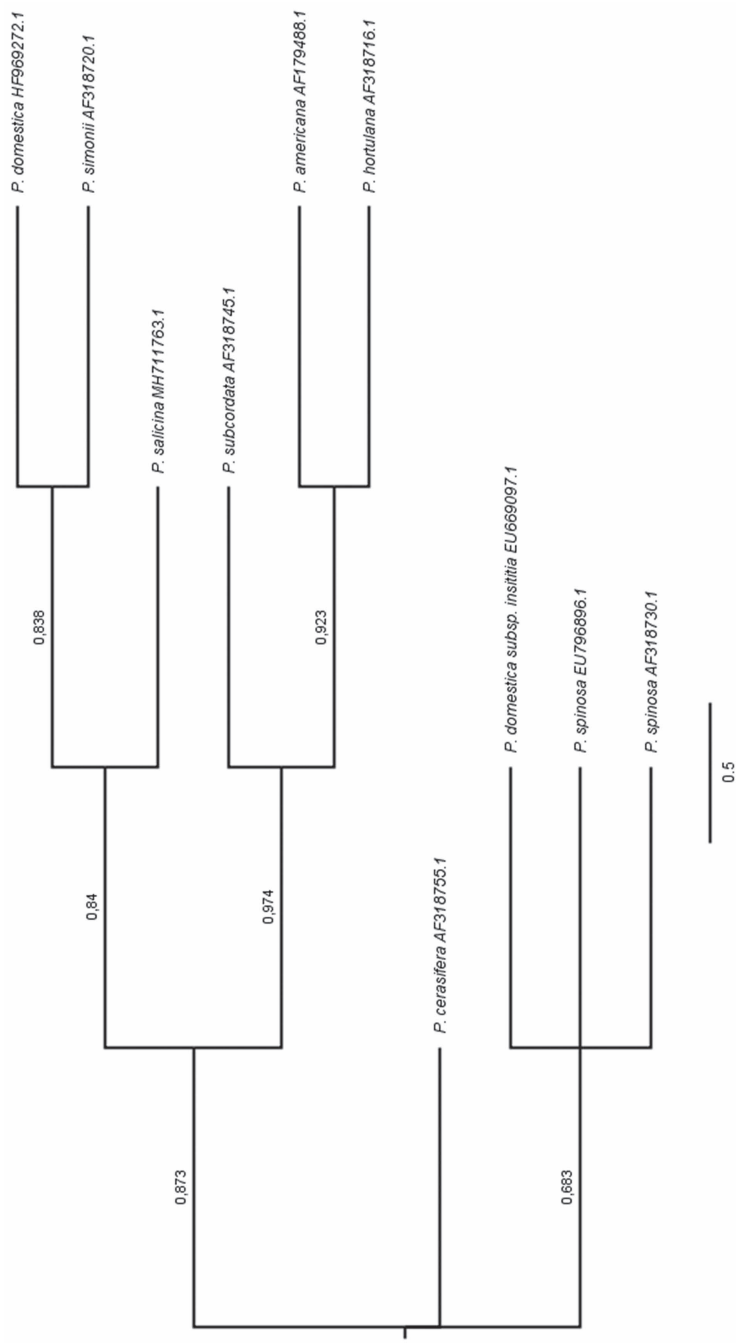

FIGURE 1.5 Maximum likelihood phylogeny of gene 18S rRNA with some of most representative species of plums.

plums more related with the geographical distribution. The first clade is formed by Asian plums (*P. salicina* and *P. simonii*), the second clade are formed by American plums (*P. subcordata*, *P. americana* and *P. hortulana*) and third clade is formed by European plums *(P. domestica*, *P. spinosa* and *P. cerasifera*).

1.5 CONCLUSION

Plums are an edible plant with diverse origins, dissemination and geographical distribution (mainly in Europe, the Americas and Asia) that constitutes important resources of the diversity of fruits. These species of *Prunus* have great potential to increase the world production and commercialization of other types of plums in the future. The classification of plums using taxonomy and phylogenetic analysis offers a geat form to appreciate the species of plant relationships. In summary, the study of the history, distribution and production of plums can help maintain the germplasm of plum species.

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