Mohamed Fawzy Ramadan
Editor

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Dedicated to the soul of my father, Professor Fawzy Ramadan Hassanien, and my beloved family.

Preface

Fig has been mentioned in the Holy Quran, in the form of the divine oath, in the words of God Almighty: "*By the Fig and the Olive, and by Mount Sinai*," "Surat Al-Tin: 1-2." God Almighty swore to fig in this noble verse because of its great importance.

Ficus carica L. illustrates a promising item of functional food and healthy products. There is a lack of books presenting complete information on the production, processing, chemistry, products, and medical traits of figs and the plant parts (i.e., fruit, skin, leaves, roots, latex, and by-products). This book is considered necessary since it covers all the information about fig.

This book project aims to create a multidisciplinary discussion forum on *Ficus carica* with particular emphasis on its horticulture, post-harvest, marketability, phytochemistry, extraction protocols, biochemistry, nutritional value, functionality, health-promoting traits, ethnomedicinal applications, technology, and processing. The impact of traditional and innovative processing on recovering high-added value compounds from *Ficus carica* wastes is reported. Besides, the book discusses the potential applications of *Ficus carica* in food, cosmetics, and pharmaceutical products.

Intending to provide a comprehensive contribution to the scientific community involved in clinical nutrition, food science, horticulture, phytochemistry, health, and pharmacology, this book comprehensively reviews the aspects that led to the recent advances in *Ficus carica* biochemistry, production, and functionality. The editor hopes the handbook will be a rich source for researchers and developers in related disciplines.

Book chapters have a diversity of developments in food science and horticultural research. The book contains comprehensive chapters under main sections, namely

– ***Ficus carica*: Cultivation, Species, and Cultivars**
– ***Ficus carica*: Chemistry, Functionality, and Health-Promoting Properties**
– ***Ficus carica*: Technology, Processing, and Applications**

The editor sincerely thanks all contributors for their valuable contributions and their cooperation. The Springer-Nature staff's help and support, especially Daniel Falatko and Sofia Valsendur, was essential for completing my task and is highly appreciated.

Makkah, Saudi Arabia Mohamed Fawzy Ramadan

Description

Fig (*Ficus carica* L.) is one of the oldest cultivated and consumed fruits worldwide. More than 800 varieties of the *Ficus carica* genus are cultivated in a warm climate. Fig is a seasonal fruit that could be harvested twice annually and could be consumed fresh, dried, and as a jam or juice. Fresh and dry figs are appreciated as food and for their health-promoting impacts. The syrup is used as a remedy for mild constipation. Leaves are used as fodder for animals. Fig latex is used as a curdling agent in dairy products.

The fruit is a rich source of health-enhancing phytochemicals (i.e., phenolics, organic acids, vitamin E, and carotenoids). Phytochemicals are influenced by the harvest time, variety, maturity, color, fruit part, and fruit processing. Amino acids, organic acids, fatty acids, sterols, hydrocarbons, anthocyanins, aliphatic alcohols, volatiles, and other secondary metabolites are found in fig fruit, latex, leaves, and root. In addition, figs are an essential source of minerals (i.e., potassium, iron, and calcium) and vitamins (i.e., riboflavin and thiamin).

Ficus carica fresh fruit, extracts, and isolated bioactive compounds exhibited a broad spectrum of health-promoting traits. Different nutrients and bioactive compounds, including free sugars, organic acids, tocopherols, phenolic components, and fatty acids, were detected in the *Ficus carica* peel extracts. *Ficus carica* leaves, roots, fruit, and latex are known for their biological and health traits, including antifungal, anti-helminthic, acetyl cholinesterase inhibition, and anticarcinogenic activities. Fig is used in traditional medicine for various reproductive, digestive, endocrine, and respiratory ailments. It is used in the gastrointestinal tract and urinary tract infections. Furthermore, the fig treats ailments such as diabetes, anemia, cancer, leprosy, liver diseases, skin diseases, and ulcers. Studies reported on the applications of fig extracts as functional edible ingredients, clinical trials to confirm the health effects of extracts, and the valorization of plant by-products. *Ficus carica* has been included in occidental pharmacopeias (i.e., British Pharmacopoeia and Spanish Pharmacopoeia) and therapeutic guides of herbal medicines.

The influences of processing on the *F. carica* product's quality and the amounts of individual phytochemicals in fruit were studied. Drying of *Ficus carica* has proven to be a reliable preservation method. The main factors that affect the drying process are temperature and the length of the process. Freeze-drying and microwave-drying for fig preserving are also essential technologies. Besides, the effect of post-harvest and packing methods on fruits' phytochemicals profile and biological traits were of interest.

Ficus carica is of importance due to its widespread food, industrial, and medicinal applications. Although *Ficus carica* products are already commercially available in the international market, it is hard to find in the bookstore works on the production, processing, chemistry, and properties of *Ficus carica*.

Key Features

- Explores the chemistry of *Ficus carica* phytochemicals and extracts
- Discusses *Ficus carica* active constituents and their health-enhancing traits
- Presents the applications of *Ficus carica* phytochemicals and extracts
- Authored by international scientists and industry experts
- Addresses the growing application areas, including horticulture, functional food, clinical nutrition, pharmaceuticals, and cosmetics

Readership

- Clinical nutrition, food chemistry, biochemistry, pharmacology, and horticulture researchers and students.
- Developers of nutraceuticals, novel food, and pharmaceuticals, as well as R&D researchers in different sectors, apply fruits and medicinal plants.

Contents

About the Editor

Mohamed Fawzy Ramadan is a Food Chemistry Professor at the Department of Clinical Nutrition, Faculty of Applied Medical Sciences, Umm Al-Qura University, Makkah, Saudi Arabia. Since 2014, he is Professor at Biochemistry Department, Faculty of Agriculture, Zagazig University, Egypt.Prof. Ramadan obtained his Ph.D. (*Dr. rer. nat.*) in Food Chemistry from the Berlin University of Technology (Germany, 2004). He continued his postdoctoral research at ranked universities such the University of Helsinki (Finland), Max-Rubner Institute (Germany), Berlin University of Technology (Germany), and the University of Maryland (USA). In 2012, he was appointed Visiting Professor (100% teaching) in the School of Biomedicine, Far Eastern Federal University in Vladivostok, Russian Federation.

Prof. Ramadan published more than 300 research papers, and reviews in peer-reviewed journals. He also edited and published several books (Scopus *h*-index is 44 and more than 6500 citations). In addition, he was an invited speaker at several international conferences. Since 2003, Prof. Ramadan is a reviewer and an editor in several highly-cited international journals such as *Journal of Umm Al-Qura University for Medical Sciences*, *eFood, Journal of Medicinal Food* and *Journal of Advanced Research*.

Prof. Ramadan received several prizes, including Abdul Hamid Shoman Prize for Arab Researcher in Agricultural Sciences (2006), Egyptian State Prize for Encouragement in Agricultural Sciences (2009), European Young Lipid Scientist Award (2009), AU-TWAS Young Scientist National Awards (Egypt) in Basic Sciences, Technology and Innovation (2012), TWAS-ARO Young Arab Scientist (YAS) Prize in Scientific and Technological Achievement (2013), and Atta-ur-Rahman Prize in Chemistry (2014).

Chapter 1
Introduction to Fig (*Ficus carica*): Production, Processing, and Properties

Mohamed Fawzy Ramadan

1 Fig (*Ficus carica*): Production, Processing, and Properties

The United Nations Sustainable Development Goals (SDGs) are recognized to offer a sustainable world vision (https://sustainabledevelopment.un.org). "*Good Health and Well-Being*" goal is associated with applying health-improving plants and environmental-friendly processes in food chain sectors (Ramadan, 2021). Due to their safety, fruits and vegetables have been utilized as pharmaceuticals and nutraceuticals. Therefore, there is a great interest in fruits and vegetables as phytoconstituents-rich sources for nutraceuticals and pharmaceuticals (McClements, 2019; Ramadan, 2020).

Fig (*Ficus carica* Linn) is considered one of the oldest cultivated and consumed fruit tree worldwide. Fig has been mentioned in the Holy Quran, in the form of the divine oath, in the words of God Almighty: "**By the Fig and the Olive, and by Mount Sinai**", "**Surat Al-Tin: 1-2**". God Almighty swore to fig in this noble verse because of their great importance.

Ficus is one of 37 genera (family Moraceae). Fig species of the highest commercial value is *Ficus carica* (syn. Ficus kopetdagensis Pachom.), which consists of varieties with high genetic diversity. About 800 varieties of the *Ficus carica* genus are cultivated in a warm climate. Fresh or dry figs have been appreciated as food and for their health-promoting impacts. Besides, *Ficus carica* leaves are utilized as fodder. The syrup is utilized as a remedy for mild constipation. In addition, fig latex is used as a curdling agent in dairy products. *Ficus carica* is a seasonal fruit that could be harvested twice annually and could be consumed fresh, dried, as a jam or juice

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(Mawa et al., 2013; Barolo et al., 2014; Badgujar et al., 2014; Desa et al., 2019; Teixeira et al., 2019; Arvaniti et al., 2019; Yao et al., 2021; Salehi et al., 2021).

Ficus carica L. is a symbol of longevity and included in the human diet since ancient time. The fruit is a rich source of health-promoting phytochemicals (i.e., phenolics, organic acids, vitamin E, and carotenoids). Flavonoids and phenolic acids are the main phytochemicals in fresh and dried fruits. Chlorogenic acid, gallic acid, quercetin-3-*O*-rutinoside, rutin, and epicatechin are the main phenolic acids and flavonoids in *Ficus carica* fruit (fresh or dried). Phytochemical levels are influenced by the harvest time, variety, maturity, color, fruit part, and fruit processing. The analysis of flavonoids and phenolic acids in fresh and dried fig varieties and the distribution of these compounds between fruit pulp and skin were investigated. The antioxidant traits of fig are correlated with its content of bioactive phenolics. Amino acids, organic acids, fatty acids, sterols, hydrocarbons, anthocyanins, aliphatic alcohols, volatiles, and other secondary metabolites were found in fig fruit, latex, leave, and root. *Ficus carica* is an essential source of minerals (i.e., potassium, iron, and calcium) and vitamins (i.e., riboflavin and thiamin). In addition, fig fruits are sodium-, fat- and cholesterol-free and rich in fibers (Mawa et al., 2013; Barolo et al., 2014; Badgujar et al., 2014; Desa et al., 2019; Teixeira et al., 2019; Arvaniti et al., 2019; Yao et al., 2021; Salehi et al., 2021).

Ficus carica fresh fruit, crude extracts, and isolated bioactive compounds exhibited a broad spectrum of health-promoting traits. *Ficus carica* fruits, roots, leaves, and latex are known for their biological and health traits, including antimicrobial, anti-helminthic, acetylcholinesterase inhibition, and anticarcinogenic effects. Fig has been used for several types of disorders worldwide. Fig is used in traditional medicine for various reproductive, digestive, endocrine, and respiratory ailments. In addition, it is used for urinary tract and gastrointestinal tract infections. Furthermore, fig treats ailments such as cancer, diabetes, liver diseases, skin diseases, anemia, leprosy, and ulcers. Studies reported on the applications of fig extracts as functional edible ingredients, clinical trials to confirm the health effects of extracts, and the valorization of plant byproducts. *Ficus carica* is included in occidental pharmacopeias (i.e., British Pharmacopoeia and Spanish Pharmacopoeia) and therapeutic guides of herbal medicine. Therefore, the fig is a promising item in pharmaceutical biology for the formulations of novel drugs and clinical applications (Mawa et al., 2013; Barolo et al., 2014; Badgujar et al., 2014; Desa et al., 2019; Teixeira et al., 2019; Arvaniti et al., 2019; Yao et al., 2021; Salehi et al., 2021).

The influences of processing techniques on the *F. carica* product's quality, the phytochemicals profile, and the amounts of individual phenolics in fruit were studied. Drying of *Ficus carica* has proven to be a reliable preservation method. The main factors that affect the drying process are temperature and the length of the process. Freeze-drying and microwave-drying for fig preserving are also essential technologies. Besides, the effect of post-harvest and packing methods on fruits' phytochemicals profile and biological traits were of interest. On the other side, the impact of environmental factors on the phytochemicals content suggests the best production area and the optimum conditions for processing. On the other hand, different nutrients and bioactive compounds, including organic acids, free sugars, tocols, phenolic components, and fatty acids, were detected in the *Ficus carica* peel hydroethanolic extract. In addition, *Ficus carica* peel extract displayed promising antioxidant and antibacterial capacities (Mawa et al., 2013; Barolo et al., 2014; Badgujar et al., 2014; Desa et al., 2019; Teixeira et al., 2019; Arvaniti et al., 2019; Yao et al., 2021; Salehi et al., 2021).

2 Fig (*Ficus carica*) Market

Recent FAOSTAT (2022) statistics reported that the global harvested area of *Ficus carica* is 281,522 ha, global yield is 44,932 hg/ha, and production is 1,264,943 tonnes. Figure 1.1 presents the world's top producing countries of *Ficus carica* and

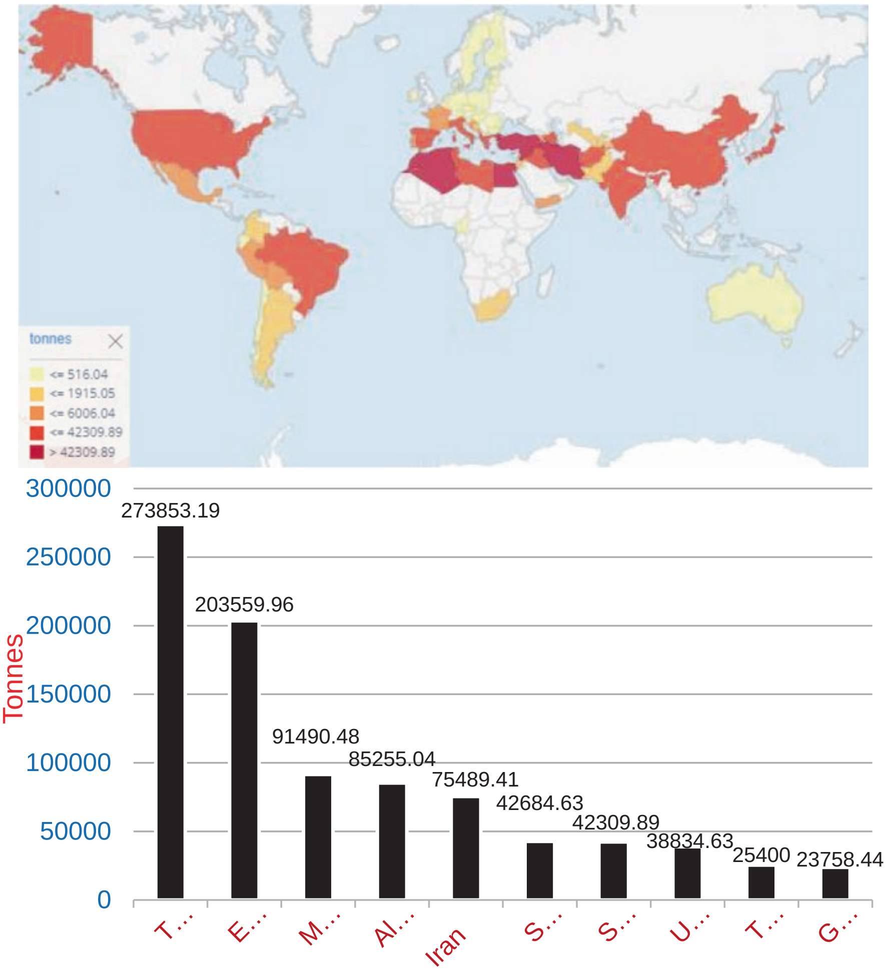

Fig. 1.1 Top producer countries and production quantities (tonnes) of fig. (FAOSTAT, 2022)

the production quantities (tonnes). *Ficus carica* tree is one of the oldest fruits cultivated in the Mediterranean area and presents an essential nutritional and economic value because of its high consumption worldwide (Melgarejo et al., 2003; Crisosto et al., 2011; Badgujar et al., 2014; Núñez-Gómez et al., 2021). Turkey, Egypt, Greece, Algeria, Italy, and Spain are among the Mediterranean producers, from which *ca*. 90% of fig yield is produced (Sadder & Ateyyeh, 2006; Melgarejo, 2017; Núñez-Gómez et al., 2021). Europe, Spain is the top fig-producing country in Europe, with about 56,600 tonnes in 2019, representing *ca.* 4% of the world's production and *ca*. 44% of European production (Núñez-Gómez et al., 2021).

3 Fig (*Ficus carica*) in the Scientific Literature

As a part of this work, a survey in the literature (Scopus and PubMed) has been performed. Fig (*Ficus carica* L.) highly attracts international scientific research. A survey and scientific literature search with the keyword "(Fig and *Ficus carica* L.)" in the PubMed database (June 2022) revealed 288 documents belonging to fig (*Ficus carica* L.) bioactivity, phyto-extracts, oils, bioactive constituents, and applications.

A careful search on fig (*Ficus carica* L.) in Scopus (www.scopus.com) showed that the number of documents is high (*approx.* 1500 till June 2022). Figure 1.2 presents the document counts on fig (*Ficus carica* L.) from 2001 to 2021. The annual documents published in fig (Ficus carica L.) significantly increased from 13 documents in 2001 to 187 documents s in 2021. These numbers reflect the current

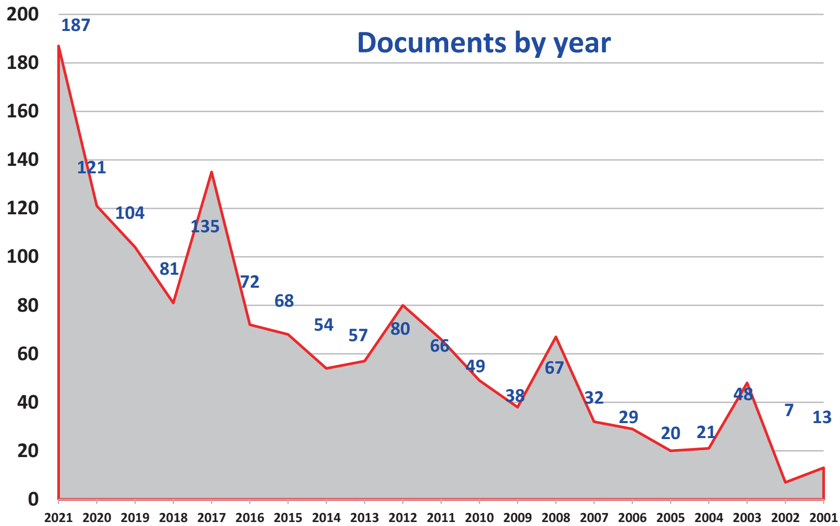

Fig. 1.2 Scholarly output on *Ficus carica* from 2001 to 2021. (www.scopus.com)

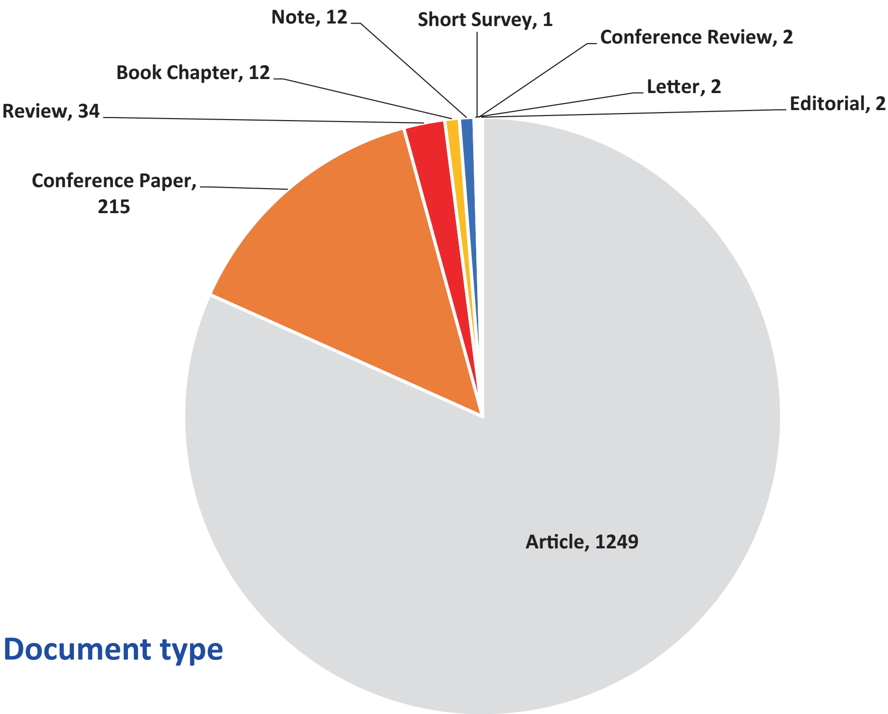

Fig. 1.3 Distribution by types of the document on *Ficus carica*. (www.scopus.com)

interest in fig (*Ficus carica* L.) as a topic in the scientific community. Figure 1.3 presents the distribution of the types of documents in fig (*Ficus carica* L.), which includes research articles (1249), conference papers (215), reviews (34), and book chapters (12). The contributions related to the subject fields (Fig. 1.4) of Agricultural and Biological Science (47%), Biochemistry, Genetics, and Molecular Biology (12%), Medicine (6%), Pharmacology, Toxicology, and Pharmaceutics (6%), Environmental Science (5%), and Chemistry (4%). Scientists from Turkey, Italy, Brazil, USA, Iran, Spain, Tunisia, China, India, Japan, France, Egypt, and Saudi Arabia emerged as principal authors (Fig. 1.5). Acta Horticulturae, Scientia Horticulturae, Revista Brasileira De Fruticultura, Journal Of The Japanese Society For Horticultural Science, Plant Disease, Journal Of Plant Pathology, International Journal Of Fruit Science, Hortscience, Food Chemistry, Frontiers In Plant Science, Fruits and South African Journal of Botany are the leading journals that published scientific research on the fig (*Ficus carica* L.).

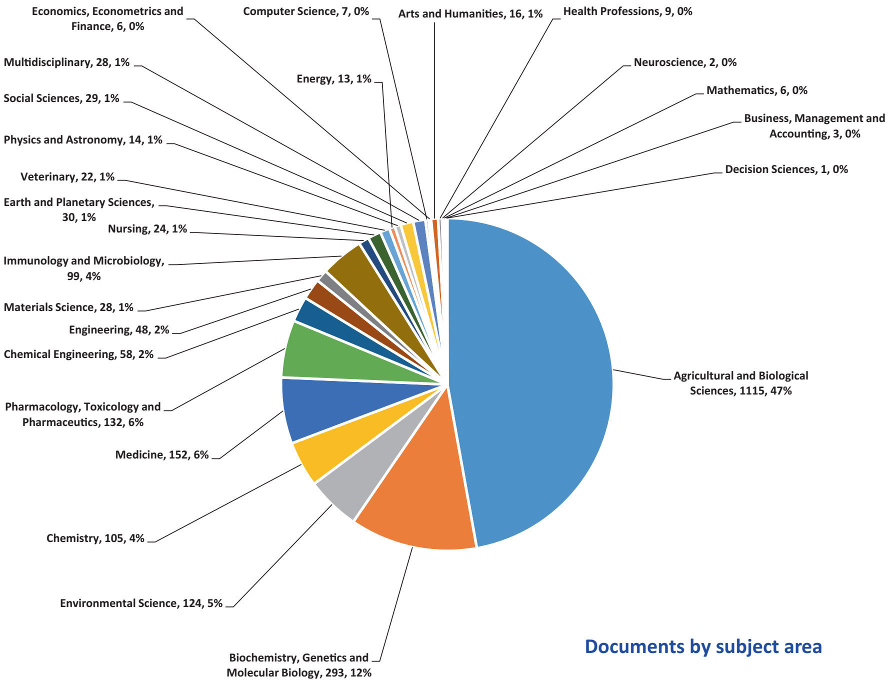

Fig. 1.4 Distribution by subject area of documents on *Ficus carica.* (www.scopus.com)

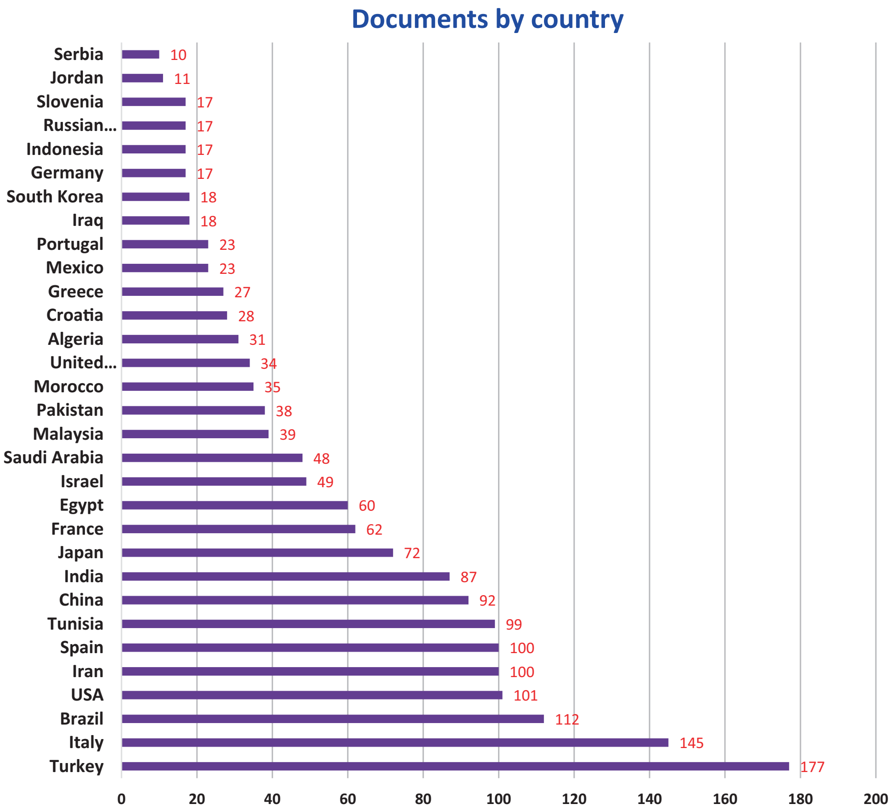

Fig. 1.5 Distribution by country of documents on *Ficus carica.* (www.scopus.com)

4 Aims and Features of This Book

Fig (*Ficus carica* L.) illustrates an excellent functional food and healthy product item. To the best of knowledge, there is a lack of books discussing complete information on the production, processing, chemistry, products, and medical properties of figs and the plant parts (i.e., fruit, skin, leaves, roots, latex, and byproducts). Therefore, this book is considered necessary since it will cover all the information about fig (*Ficus carica* L.). In addition, to the best of knowledge, this book presents and collects available scientific information mentioned above in one work.

Fig (Ficus carica): Production, Processing, and Properties create a multidisciplinary discussion forum on *Ficus carica* with particular emphasis on its horticulture, post-harvest, marketability, phytochemistry, extraction protocols, biochemistry, functionality, nutritional value, health-promoting traits, ethnomedicinal applications, technology, and processing. The impact of processing (traditional and innovative) on recovering value-added compounds from *Ficus carica* byproducts is reported. Also, the book discusses the novel applications of *Ficus carica* in foodstuffs, cosmetics, and pharmaceutical products.

The tentative manuscripts have a diversity of developments in nutrition, food science, and horticulture research. The book contains comprehensive chapters under main sections, namely

Part I: *Ficus carica*: Cultivation, Species, and Cultivars
Part II: *Ficus carica*: Chemistry, Functionality, and Health-Promoting Properties
Part III: *Ficus carica*: Technology, Processing, and Applications

References

Arvaniti, O. S., Samaras, Y., Gatidou, G., Thomaidis, N. S., & Stasinakis, A. S. (2019). Review on fresh and dried figs: Chemical analysis and occurrence of phytochemical compounds, antioxidant capacity and health effects. *Food Research International, 119*, 244–267. https://doi.org/10.1016/j.foodres.2019.01.055

Badgujar, S. B., Patel, V. V., Bandivdekar, A. H., & Mahajan, R. T. (2014). Traditional uses, phytochemistry and pharmacology of *Ficus carica*: A review. *Pharmaceutical Biology, 52*(11), 1487–1503. https://doi.org/10.3109/13880209.2014.892515

Barolo, M. I., Ruiz Mostacero, N., & López, S. N. (2014). *Ficus carica* L. (Moraceae): An ancient source of food and health. *Food Chemistry, 164*, 119–127. https://doi.org/10.1016/j.foodchem.2014.04.112

Crisosto, H., Ferguson, L., Bremer, V., Stover, E., & Colelli, G. (2011). Fig (*Ficus carica* L.). In *Postharvest biology and technology of tropical and subtropical fruits* (pp. 134e–160e). Elsevier.

Desa, W. N. M., Mohammad, M., & Fudholi, A. (2019). Review of drying technology of fig. *Trends in Food Science & Technology, 88*, 93–103. https://doi.org/10.1016/j.tifs.2019.03.018

FAOSTAT. (2022). Food and Agriculture Organization of the United Nations. Available online https://www.fao.org/faostat/en/#home. Accessed 10 June 2022.

Mawa, S., Husain, K., & Jantan, I. (2013). *Ficus carica* L. (Moraceae): Phytochemistry, traditional uses and biological activities. *Evidence-based Complementary and Alternative Medicine*, 974256. https://doi.org/10.1155/2013/974256

McClements, D. J. (2019). The science of foods: Designing our edible future. In D. J. McClements (Ed.), *Future foods: How modern science is transforming the way we eat*. Springer.

Melgarejo, P. (2017). El cultivo de la higuera (*Ficus carica* L.). In *Frutales de Zonas Áridas* (p. 118). A. Madrid Vicente, Ediciones. ISBN 84-89922-37-3.

Melgarejo, P., Sánchez, M., Hernández, F., & Martínez, J. (2003). Chemical and morphological characterization of four fig tree cultivars (*Ficus carica* L.) grown under similar culture conditions. *International Society for Horticultural Science, 605*, 33–36.

Núñez-Gómez, D., Legua, P., Martínez-Nicolás, J. J., & Melgarejo, P. (2021). Breba fruits characterization from four varieties (*Ficus carica* L.) with important commercial interest in Spain. *Food, 10*(12), 3138. https://doi.org/10.3390/foods10123138

Ramadan, M. F. (2020). Chapter 1 – Introduction to cold pressed oils: Green technology, bioactive compounds, functionality, and applications. In M. F. Ramadan (Ed.), *Cold pressed oils* (pp. 1–5). Academic. https://doi.org/10.1016/B978-0-12-818188-1.00001-3

Ramadan, M. F. (2021). Introduction to black cumin (*Nigella sativa*): Chemistry, technology, functionality and applications. In M. F. Ramadan (Ed.), *Black cumin (Nigella sativa) seeds: Chemistry, technology, functionality, and applications* (Food bioactive ingredients). Springer. https://doi.org/10.1007/978-3-030-48798-0_1

Sadder, M. T., & Ateyyeh, A. F. (2006). Molecular assessment of polymorphism among local Jordanian genotypes of the common fig (*Ficus carica* L.). *Scientia Horticulturae, 107*, 347–351.

Salehi, B., Prakash Mishra, A., Nigam, M., et al. (2021). Ficus plants: State of the art from a phytochemical, pharmacological, and toxicological perspective. *Phytotherapy Research, 35*, 1187–1217. https://doi.org/10.1002/ptr.6884

Teixeira, N., Melo, J. C. S., Batista, L. F., Paula-Souza, J., Fronza, P., & Brandão, M. G. L. (2019). Edible fruits from Brazilian biodiversity: A review on their sensorial characteristics versus bioactivity as tool to select research. *Food Research International, 119*, 325–348. https://doi.org/10.1016/j.foodres.2019.01.058

Yao, L., Mo, Y., Chen, D., Feng, T., Song, S., Wang, H., & Sun, M. (2021). Characterization of key aroma compounds in Xinjiang dried figs (*Ficus carica* L.) by GC-MS, GC-olfactometry, odor activity values, and sensory analyses. *LWT, 150*, 111982. https://doi.org/10.1016/j.lwt.2021.111982

Part I
Fig (*Ficus carica*): Cultivation, Species, and Cultivars

Chapter 2
Figs in Morocco: Diversity Patterns, Valorization Pathways and Value Chain Resilience

Lahcen Hssaini, Rachid Razouk, Aziz Fadlaoui, and Karim Houmanat

Abbreviations

ABTS	Ethylbenzothiazoline-6-sulfonic acid
CE	Catechin equivalent
cy-3 rutinoside	Cyanindin-3- rutinoside
DPPH	2,2-diphenyl1-picrylhydrazyl
dw	dry weight
FRSA	Free radical scavenging activity
GAE	Gallic acid equivalent
IC_{50}	Half maximum inhibitory concentration
ISSR	Inter-simple sequence repeat
mM	Millimole
PCA	Principal components (PC) analysis
RAPD	Random amplified polymorphic DNA
RFLP	Restriction fragment length polymorphism
SSC	Soluble sugars content
SSR	Simple sequence repeat
TA	Titratable acidity
TAC	Total anthocyanins
TFC	Total flavonoids content
TPAC	Total pro-anthocyanidins
TPC	Total phenolic content
TSS	otal soluble solids
β-Car	β-carotene

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1 Introduction

Morocco hosts large biodiversity and considerable within-species genetic diversity (Achtak et al., 2010). Located in the northwest of Africa, between the Strait of Gibraltar and the Mediterranean Sea to the north, the Sahara Desert to the south, with a long coastline in the west overlooking the Atlantic Ocean and crossed diagonally by the Atlas Mountains moving eastwards from the Atlantic, Morocco shelters an exciting diversity of both climates and agroecosystems hosting the second most diverse flora in the Mediterranean basin, after Turkey. The country domesticates around 4200 species, of which over 20% are endemic (Rankou et al., 2013). The fig (*Ficus carica* L., 2n = 26) tree is undoubtedly one of the most emblematic species of the Mediterranean landscape (Khadari et al., 2008; Hssaini et al., 2020b). Being the earliest domesticated fruit species of the Neolithic Revolution (7000–8000 B.P), the fig tree belongs to the *Moraceae* family, which is one of the most populous of all plant genera with over 800 species (Schmitzer et al., 2011; Pourghayoumi et al., 2017; Boudchicha et al., 2018). *Ficus carica* L. is thought to be native to the Middle East and has been cultivated for millennia in close association with grapevine and olive (Barolo et al., 2014; Pérez-Sánchez et al., 2016; Vitelli et al., 2017). In Morocco, the fig cultivation is ancestral and is mainly planted in mountains and family gardens (Hssaini et al., 2019b). The fig landscape is characterized by four cultivation systems based on applied agricultural practices and varietal associations. The first system, described as extensive, concerns plantations where no cultivation operations other than picking are practiced. These are generally small-sized farms located on steep slopes. The second system is semi-extensive, characterized by maintaining several agricultural practices, including tillage, pruning, impluviums, and caprification. These practices are generally applied for both fig trees and the intercropping system. The third system, semi-intensive, is represented by plantations that benefit, in addition to the cultivation practices adopted in the semi-extensive system, from manual weeding, maintenance pruning, and/or contribution of mineral or organic manure. These last two systems are the most common and are also distinguished from the extensive system by the very high number of varieties used.

The country ranks the third-largest producer of figs globally after Turkey and Egypt, with an annual production of more than 153,472 tons, representing about 11% of the worldwide production (FAOSTAT, 2019). This production is concentrated mainly in the Rif region (Northern Morocco), the main fig growing area (Hssaini et al., 2019b). Traditionally, local fig resources are defined based on qualitative criteria or the proper names associated with pruning, pollination, and protection practices that make them similar regardless of being genetically far from each other.

In the Moroccan diet, figs are consumed either fresh or dried during the whole year but abundantly during religious occasions (Hssaini et al., 2019b). This growing interest in fig consumption is related to the fruit's nutritional values, as they constitute an essential source of fiber, minerals (potassium, magnesium, calcium, iron, etc.), vitamins (vitamin E, vitamin C, thiamine, and riboflavin), carotenoids (lycopene as the most abundant, zeaxanthin, α-carotene, lutein, cryptoxanthin, and β-carotene) and antioxidant polyphenols which are more abundant in a fig than red wine and tea and concentrated mainly in the peel (chlorogenic acid, gallic acid, and syringic acid). In addition, figs are also rich in flavonoids (anthocyanins, catechin, and epicatechin), sugars (glucose and fructose, with minor traces of sucrose), organic acids, amino acids (aspartic acid and glutamine), and volatile molecules (Solomon & Golubowicz, 2006; Oliveira et al., 2009; Veberic & Mikulic-Petkovsek, 2015; Hernández, 2016; Hssaini et al., 2019a). Those compounds are responsible for the fig's pleasant taste, color, astringent flavors, and aroma (Veberic et al., 2008; Muji et al., 2012). They are also associated with preventing coronary diseases due to their numerous biological effects, such as scavenging unstable free radicals from anticarcinogenic and anti-inflammatory activities (Makris et al., 2007; Çalişkan & Polat, 2012; Palmeira et al., 2019). The aforementioned bioactive compounds' amounts strongly depend on the genetic, geographic, and growing factors (Solana et al., 2018; Hssaini et al., 2020b; Mirheidari et al., 2020). Figs are classified as highly perishable commodities because their high moisture content reaches up to 80% (Saki et al., 2019; Hssaini et al., 2020c). Therefore, maintaining their freshness has always been the adequate approach to keeping their health-promoting attributes. However, this decision implies sophisticated storage techniques and chain distribution with considerable energy consumption.

Nevertheless, figs cannot be stored for an extended period without a significant loss of nutritional value (Mat Desa et al., 2019). Therefore, processing remains the best way to extend a fig's shelf-life and preserve the nutritional quality of the end products. Traditionally, salting, dehydration, and fermentation, however, new processing techniques are acquiring popularity worldwide since they offer key advantages such as shelf-life extension, nutritional and sensory quality preservation, and food safety (Martins et al., 2019). In Morocco, the fig processing is an increasing challenge because of the low interest given to this sector and the low investment in existing infrastructure, which significantly impacts the fruits and their end products' marketability. So far, the fig processing is limited to drying, juice, and jam, even though the fruit has many other potentials to be exploited with a high value-added such as seeds (Hssaini et al., 2020a). The latter has been the less valorized part of the fruit, although some recent studies reported a satisfactory oil yield with high unsaturation level and antioxidant potency (Icyer et al., 2016; Hssaini et al., 2020a, b). On the other hand, improving the fig value chain resilience to changing environments and different chocks is a challenging endeavor nowadays since the sector is poorly organized and requires a holistic approach and coordinated policies to evade undesired chocks that may occur during specific supply chain steps or in other related sections.

This chapter focuses on the fig diversity in Morocco, highlights its valorization pathways, and examines the fig value chain vulnerability to shocks and the exploration of solutions aiming at improving the system's ability to adapt and to be resilient when single or multiple shocks by mapping the fig value chain weaknesses alongside potential consequences of various chocks that may occur taking into account the opportunities that can be captured during the fig value chain examination.

2 Genetic Diversity Patterns

2.1 Overview of Available Fig Germplasm

The fig tree is one of Morocco's most diversified fruit species, with over 130 morphotypes, mostly seedlings clones propagated by cuttings and exotic varieties introduced from neighboring Mediterranean countries (Achtak et al., 2010). The Moroccan fig genetic resources also include various unknown types and spontaneous forms in coexistence with cultivated types, which are few subjected to intensive breeding programs and therefore continue to exhibit a large genetic diversity (Hmimsa et al., 2012). This outstanding genetic diversity results from a series of domestication events, gene flow between wild and cultivated compartments, effects of natural adaptive selection, human selection, and large diffusion dynamics over long periods (Khadari et al., 2005a). The impact of these processes on diversity depends not only on the species' biology but also on social context, human practices, and local dietary preferences (Ater et al., 2008; Perez-Jimenez et al., 2010). Since 2008, the local fig diversity has been enriched by some exotic varieties, which were confirmed to be suitable for drying, particularly 'Sarilope' from Turkey, 'Kadota' from Italy, and 'Col de Dame Blanche' from France. These varieties were efficient under local conditions through behavioral studies undertaken by the National Agricultural Research Institute (INRA) in 1995 (Oukabli et al., 2003a).

Two types of edible figs are growing in Morocco: biferous (breba and main crop) and uniferous (main crop). The local biferous types are mainly represented by eleven cultivars, 'Ghouddane', 'Ournaksi', 'El Khal', 'Ember El Khal', 'Fassi', 'Messari', 'Filalia', 'Jeblia', 'Hamra', 'Ounq El Hmam' and 'Beida'. The uniferous types mainly concern 'Nabout', 'El Quoti Labied', 'Embar Labied', 'Hafer El Brhel', 'Chaari', 'Ferquouch Jmel', and 'Ferzaoui' (El Hajjam et al., 2018). Denominations of the aforementioned cultivars and others refer mainly to leaf shape and fruit morphometric traits (color, shape, or taste) and geographic origin or the production locality (Table 2.1). In addition, the exchange of plant material, which was accompanied by the flows of human populations, caused varietal confusion. This problem has led to the attribution of the same denomination to various genotypes, although they have different pomological characteristics (homonymy), or rather naming differently some genetically identical individuals (synonymy). The most remarkable case is that of 'Ghouddane' cultivar, known as polyclones (Achtak et al., 2009). The cases of polyclonality have also been revealed in the cultivars 'Nabout', 'Chaari', 'Ournaksi', 'Hamra', and 'Bioudi' (Khadari & Oukabli, 2005). This list of polyclonal cultivars is not exhaustive due to the lack of intra-varietal molecular authentication studies within other local fig ecotypes. Due to the

Table 2.1 Denomination meaning of some fig cultivars in Morocco

Cultivar	Denominations meaning
Nabout[a]	Generic Arabic word meaning a seedling plant
Gouddane[b]	Dark skin color
Zerqui[b]	Blue skin color
Sebti[b]	Originating from Sebta in northern Morocco
Messari[b]	Originating from Beni Messara in northern Morocco
Jaadi[b]	fruit with ribs over the skin
Ounq El Hmam[b]	Refers to the pigeon neck shape
Ferquouch Jmel[b]	Refers to the camel foot in Moroccan dialect, which describes a typical fruit shape

[a]Hmimsa et al. (2017)
[b]Hssaini et al. (2019b)

environmental effect, this confusion in the cultivar denomination is linked to the fruit phenotypic variation. In particular, the human factor's modest technicality during the exchange and reproduction of the plant material may also explain the observed varietal confusions (El Khaloui, 2010; Achtak et al., 2010). The morphological similarities and the inter-connections characterizing these species have influenced the human selection pressure exerted on the individuals, mainly resulting from seedlings, distinguished by the local term 'Nabout' (Hmimsa et al., 2017). The problems of homonymy and synonymy constitute a severe challenge in the management, use, study, and conservation of genetic resources of fig. In addition to Morocco, this problem has been reported in several other Mediterranean countries such as Tunisia (Chatti et al., 2003; Saddoud et al., 2011), France (Khadari, 2005b), Spain (Sanchez et al., 2016), Turkey (Caliskan & Polat, 2012) and Italy (Ciarmiello et al., 2015).

The Moroccan agroecosystems also include an important diversity within the caprifigs (male fig trees), which remains less documented. This diversity is dominated by spontaneous forms resulting from seedlings growing alongside water sources and frequently encountered near the riversides, streams, irrigation canals, and wells (Oukabli et al., 2003b; Hmimsa et al., 2012). The named types, multiplied by cuttings, remain less diversified. Hmimsa et al. (2017) counted less than 10 well-known denominations of caprifig in Rif areas in northern Morocco, of which the most popular are 'Ḥlu', 'Marr', 'Lwizi', 'Ahurri', 'Aharchiw', 'Ahfriw' and 'Azundri'. The later remains thus far less domesticated and still growing naturally in the wild, even though few can be found near houses and family gardens. Farmers give little importance to caprifig cultivation, although they know its role as a pollen source.

Morocco set up the first national ex-situ collection in 1995 at the National Institute for Agricultural Research (INRA) experimental station in north-central Morocco to conserve this genetic diversity while avoiding varietal confusion. This collection comprises 160 local clones prospected with 60 exotic varieties over the kingdom. Lately, it has been enriched by around sixty hybrids within a program of intraparietal diversification and around thirty caprifig trees. Thus far, a large part of this important fig germplasm has been screened for its morphometric, physio-biochemical, and molecular traits, of which the superior results are briefly reported throughout the following sections of this chapter.

2.2 Fruit Morphometric Diversity

The international guide for fig tree description includes 192 morphometric traits for the female type, among which 40 are specific for fresh fruit, while 14 are considered highly discriminating descriptors. The latter concerns fruit shape (width/length index and fruit shape according to the location of the maximum width), apex shape, fruit weight, skin ground color, internal pulp color, ease of peeling, skin cracks, ostiole width, resistance to ostiole-end cracks, fruit flesh thickness, pulp juiciness, fruit cavity and total soluble solids (IPGRI and CIHEAM, 2003). However, the use of morphometric descriptors to characterize the fig diversity faces two significant problems, firstly, the subjectivity in qualitative traits description (Khadari et al., 1995), and on the other hand, the influence of environmental conditions that induce fluctuations in the expressions of traits as well as uncertainties in identifying synonymies and homonymies, which are widespread within the local fig populations (Giraldo et al., 2010). Despite these inaccuracies, morphometric characterization continues to be widely used as a practical approach in fig germplasm screening in several Mediterranean countries (Essid et al., 2017; Khadivi et al., 2018). According to these studies, the fruit geometry, skin color, and total soluble solids were the most discriminant morphometric traits for fig screening. Such studies were also carried out in Morocco, *in-situ*, and *ex-situ*, which concerned the local fig germplasm. Regarding studies carried out in-situ, the available literature illustrates that several surveys were performed within local fig populations in some main producing areas to highlight the extent of existing diversity. However, it is essential to emphasize that these studies remain questionable as the environment and agricultural management practices are highly variable and significantly affect the phenotypic expression.

In the most recent screening studies carried out by Hssaini et al. (2020a, b, c, d) on the fig *ex-situ* collection previously mentioned, the large variability revealed was attributed to the genetic factor as the edaphoclimatic conditions alongside the orchard management practices were the same for all genotypes. This made it possible to fix the 'genotype x environment' interaction impact on the expression of the morphometric and physico-biochemical trait and thus compare the genetic potentialities among 135 fig accessions (Table 2.2). It is noteworthy to mention that the abovementioned collection was planted in 2003 following a completely random design.

The descriptive analysis highlighted a wide variability among genotypes for the observed traits, except for the drop at the ostiole, lenticels color, seed size, and ostiole width (Tables 2.3 and 2.4). Visually, 9 skin colors were distinguished within the collection, where yellow-green and light-green were the dominant ones (Fig. 2.1).

Table 2.2 List of local clones and exotic cultivars of fig in *ex-situ* collection screened for fruit morphometric and biochemical traits

Local clones		Exotic cultivars
1. Ahra 2870	48. Arguil_PS8	95. Abgaiti 2111
2. Aicha Moussa 2208	49. Chaari_PS15	96. Abiarous 3015
3. Amellal	50. ELQuoti Lbied_PS11	97. Bellone
4. Assel 2890	51. ELQuoti Lbied_PS20	98. Bougie
5. Ben_T1	52. ElQuoti Lbied_PS3	99. Breval Blanca 2736
6. Ben_T2	53. ElQuoti Lbied_PS6	100. Brown Turkey
7. Bioudi 2218	54. Ghani_PS2	101. Burjasot Blanca 3037
8. Bioudi 2878	55. Ghoudan_PS1	102. Cuello Dama Blanco 2233
9. Bioudie 2255	56. Ghoudan_PS17	103. Cuello Dama Blanco
10. Bousbati 2880	57. Ghoudan_PS4	104. Colle de dame blanc
11. Btitarbi	58. Jaadi_PS16	105. Conadria (Porquert)
12. Chaari 2881	59. Lamtal_PS9	106. Conidria
13. Chaari 2881	60. Mssari_PS13	107. Diamna
14. Chabaa Ourgoud	61. Nabout_PS12	108. Dottato Perguerolles
15. El Ghani	62. Nabout_PS7	109. Figue de Marseille
16. EL Hmiri 2224	63. Ounq Hmam_PS14	110. Grise St. Jean
17. EL Khal 2283	64. Sebti_PS10	111. Grosse dama Blanca
18. EL Qoti Lezreq 2883	65. Tabli _PS19	112. Grosse Dame Blanche 2953
19. EMBAR EL KHAL 2247	66. Tabli_PS18	113. Gulgium
20. EMBAR LEBIED 2240	67. Zerqui_PS5	114. Herida
21. Fassi	68. INRA 1301	115. III 31 Roger
22. Fassi 2267	69. INRA 1302	116. Khelema 3148
23. Filalia 2211	70. INRA 1303	117. Kodata
24. Hafer El Brhel	71. INRA 1304	118. MELISSOSYKI 3074
25. Hafer Jmel 2253	72. INRA 1305	119. Nardine
26. Hamra	73. INRA 1306	120. Palmeras
27. Hamra 2252	74. INRA 1308	121. Pingo de Mel
28. Hamra 2588	75. INRA 1314	122. Princesse
29. Hmidi 2250	76. INRA 1502	123. Rey Blanche
30. Kahoulta 2251	77. INRA 1503	124. Royal Blanck
31. Lamandar Noir	78. INRA 1506	125. Snowden
32. Lmandar Bied	79. INRA 1606	126. Sucre vert
33. Mendar 2891	80. INRA 2101	127. Sucre vert
34. Nabout 2893	81. INRA 2103	128. Tena
35. Noukali 2254	82. INRA 2105	129. Trojana
36. Noukalli	83. INRA 2201	130. VCR 153/17
37. Rhoudane 2227	84. INRA 2201	131. VII 1 Roger 3
38. Taranimt 2399	85. INRA 2204	132. Violette d'Agenteruil
39. V12	86. INRA 2205	133. White Adriatic_102
40. V2 (b)	87. INRA 2206	134. White Adriatic_13
41. V33(b)	88. INRA 2304	135. Palmares

(continued)