Handbook of Coffee Processing By-Products

Sustainable Applications

Edited by
Charis M. Galanakis

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Preface

Coffee is one of the most consumed beverages all over the world and the second largest commodity in trading volume, being surpassed only by oil. Currently, more than 70 countries produce coffee. Global coffee production was estimated to be 145 million 60 kg bags in 2015–16, and consumption rounded the 152.1 million. On the other hand, while billions of cups of coffee are consumed worldwide each day, the bulk of the coffee plant biomass is considered to be waste. Following the several steps of production, the coffee industry generates huge amounts of residues, such as coffee silverskin, spent coffee grounds, coffee pulp, coffee husks, cut coffee stems, and wastewater. For instance, in Brazil the production of coffee in the years 2008–13 averaged 2.9 million tons, generating about 1.4 million tons of waste each year. These residues constitute a source of severe contamination of water bodies and lands around production units, and a serious environmental problem for all the producing countries. The problem is now getting even worse, taking into consideration the recent concerns that global warming will severely affect coffee cultivation if not make it disappear.

The current state-of-the-art handling of coffee processing residues includes management practices that either degrade the substrate or lead to diminution of their pollution load without advancing high-added-value ingredients like antioxidants. These practices have a negative ecologic and economic impact on the coffee industry, and cannot be continued within the sustainability and bioeconomy frame of the years to come. The urgent need for sustainability within the coffee industry has turned the interest of researchers to investigate the handling of coffee by-products with another perspective (e.g., by adapting more profitable options). Therefore, modern coffee industries are driven to develop valorization strategies that allow not only the recovery of high-added-value ingredients, but also their recycling through the generation of new products that find applications in diverse biotechnological fields, such as pharmaceutical, food, or cosmetics industries.

Following these considerations, there is a need for a new guide covering the latest developments in this particular direction. The current book aims to indicate the alternative sustainable solutions of upgrading coffee processing residues, as well as denoting their industrial potential as a source for the recovery of bioactive compounds and their reutilization in the previously noted sectors. It fills the existing gap in the current literature by providing a reference for all the involved partners active in the field trying to optimize the performance of coffee-processing industries and reduce their environmental impact. This is conducted by denoting advantages, disadvantages, and real potentiality of relevant processes, as well as highlighting success stories that are already applied in some countries. The ultimate goal is to support the scientific community, professionals, and producers that aspire to develop real high-scale commercial applications.

The book consists of 12 chapters. Chapter 1 discusses the state of the art in the field of coffee processing by-products by describing the steps involved in coffee processing from the field to the cup, the respective generation of by-products along the chain, and their characteristics. In addition, it provides an overview of the methods proposed for the sustainable management of these by-products, as well as legislative frameworks and policy recommendations. Chapter 2 explores the healthy components (e.g., caffeine, chlorogenic acids, trigonelline, and diterpenes) of coffee and coffee processing by-products, and gives some background on antioxidants (what they are and how to study them) and how these relate to health. Chapter 3 deals with the industrial valorization of relevant residues within the integrated concept of biorefinery, taking into account production scale, design, and technical and economic issues. Chapter 4 explores the extraction and formulation of bioactive compounds from coffee processing by-products using conventional extraction techniques and approaches. An overview of patented recovery methodologies and potential applications resulting from the use of the recovered bioactives is provided, too. Chapter 5 discusses the recovery of target compounds using emerging technologies (e.g., supercritical fluids, subcritical water, ultrasound, and microwave-assisted extraction).

The rest of the chapters deal with the sustainable applications of recovered ingredients in different sectors. In particular, Chapter 6 summarizes applications of coffee by-products in food products due to their biological, nutritional, and technological functions. Chapter 7 concentrates on the potential applications of bioactive compounds from coffee processing by-products as active ingredients for skin care products. Their potential UV protective action, emollient capacity, and antiwrinkle and antimicrobial activity are critically reviewed and discussed. Chapters 8 and 9 deal with the biotechnological (e.g., as a substrate for the cultivation of microorganisms) and environmental (e.g., generation of activated carbons) applications of coffee processing by-products, respectively. Chapter 10 explores the potential of utilizing exhausted coffee residues as a precursor for the production of biochar and their application for agricultural purposes. Chapter 11 describes the possibilities of using coffee processing by-products for energy applications (e.g., biofuels, biodiesel, and bioethanol). In particular, the recovery of energy from biomass through thermochemical processes (e.g., gasification, combustion, hydrothermal treatment) and biochemical processes is presented. Finally, Chapter 12 provides an overview of the main current applications of spent coffee grounds and discusses the results obtained during their processing through vermicomposting on a pilot scale.

Conclusively, the book provides a handbook for agricultural, chemical, and environmental engineers, as well as food scientists and technologists who work in the coffee-processing industry and are seeking to improve their by-products management by actively utilizing them in effective applications. It addresses professionals, researchers, specialists, and new product developers working at the edge of the food and environmental sectors. It could be used as a textbook for ancillary reading at the graduate and postgraduate levels, and in multidisciplinary courses dealing with agricultural science, food technology, and environmental, bioresource, and chemical engineering. Along these lines, it could become a target reference for libraries and institutes dealing with coffee production all around the world (e.g., Brazil, Vietnam, Colombia, Indonesia, USA).

I would like to take this opportunity to thank all the contributors of this book for their fruitful collaboration and high-quality work in bringing together different topics and sustainable applications in an integral and comprehensive text. Their acceptance of my invitation to participate in this book, as well as their dedication to editorial guidelines and the book's concept is highly appreciated. In addition, I would also like to thank the acquisitions editor, Megan Ball, and the book manager, Jackie Truesdell, for their assistance during editing, as well as Lisa Jones and all the team of Elsevier during the production process. I would also like to acknowledge the support and expertise of the Food Waste Recovery Group of the ISEKI Food Association that provided us with tools and insights in the field. The ability of the group to support the food and beverage industries in order to recover food waste and improve sustainability is remarkable.

Last but not least, a message for the readers: in such big collaborative project, it is impossible to avoid minor errors or gaps. Therefore, if you find any mistakes or have any objections regarding the content of the book, please do not hesitate to contact me. Instructive comments are and always will be welcome.

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CHAPTER

1

State of the art in coffee processing by-products

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ABSTRACT

This chapter describes the steps involved in coffee processing from the field to the cup and the respective generation of by-products along the chain. The chemical composition of coffee husks, pulp, immature, and defective beans, coffee silverskin, and spent coffee grounds is detailed and methods for the sustainable management of these by-products are addressed, as well as legislative frameworks and policy recommendations. Although coffee by-products have a high potential of application in different fields, more integrated strategies with the involvement of coffee producers, industries, academic institutions, governmental and nongovernmental organizations are still needed to convert coffee by-products into really profitable substrates.

Keywords: coffee production; processing; waste; by-products; valorization; innovation; frameworks

1.1 INTRODUCTION

Coffee is one of the most popular beverages all over the world. Behind each hot and tasteful cup of coffee, which can be presented by so many different ways, a real journey is hidden. The genus *Coffea*, which belongs to the Rubiaceae family, embraces two of the more important plant species of the international coffee trade: *Coffea arabica* L. and *Coffea canephora* Pierre, widely known as Arabica and Robusta. *C. arabica* L., considering the different varieties and cultivated forms, originates about 65%–70% of the world coffee production. Its origin remounts to the mountains of Ethiopia (Yemen, AD 850) and it is an autogamic plant (self-fertile) (Alves et al., 2011; Ferrão, 2009). Its cultivation is carried out in regions of moderate temperature from tropical and subtropical areas. Some of the *C. arabica* varieties with higher commercial interest are the *typica* Cramer, the *bourbon* (B. Rodr.) Choussy, the *caturra* K.M.C., the *culumnaris* Ottotandr. ex Cramer, the *mokka* Hort. ex Cramer, and the *xanthocarpa* (Caminhoá) Froehner (Ferrão, 2009).

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Over the years, as the coffee market achieved great importance, an outstanding scientific and technical investment was performed. The preparation of new cultivars, ecologically well adapted, more productive, resistant to pests and diseases, giving origin to a commercial product of high quality, has been one of the fields in which success has been achieved. The selection and improvement of coffee have been fundamental tools in this process, which implied the use of hybridizations and crossings to assemble as many desirable characteristics as possible. Along this process, coffee plants that were not originally interesting due to the quality of the produced beverage were used to induce advantageous characteristics. Thus, besides the natural *C. arabica* varieties with their typical chromossomal and genetic composition, several others also have been emerging as a result of the genetic improvement (e.g., cultivar Catimor, cultivar Sarchimor) or, even, by natural and spontaneous crossing along the time (e.g., cultivar Mundo Novo, cultivar Bourbon-amarelo). Although not pure, their behavior in culture and their final product presents characteristics similar to those of natural Arabicas (Ferrão, 2009).

C. canephora Pierre, in turn, is indigenous from Equatorial African lowland forests from Guinea to Uganda and its cultivation was extended to Asia and South America. It is an allogamic species (self-sterile) that represents about 10%–25% of the worldwide coffee production. The organoleptic characteristics of these coffees are considered inferior to those of Arabica, but they contain higher levels of caffeine and total soluble solids. Besides, they present higher resistance to diseases, particularly to the coffee leaf rust (*Helimeia vastatrix*) and coffee berry disease (*Colletotrichum kahawae*). Also, their roasted seeds produce a "neutral" brew that easily accept the Arabica flavor, and because it is cheaper, *C. canephora* sp. have been assuming increased interest in international markets. Their applications are essentially to increase the body of the beverages (e.g., espresso coffee) and to produce instant coffee (Alves et al., 2011; Ferrão, 2009; Illy and Viani, 2005). We can cite as examples of varieties of this coffee species the *laurentii* De Wild, the *kouillensis* Pierre ex De Wild, the *ugandae* Cramer, and the *welwitschii* Chev (Ferrão, 2009). A summary of the main differences between Arabica and Robusta coffees is depicted in Table 1.1.

Besides the referenced main species—*C. arabica* L. and *C. canephora* Pierre—others can be listed, as *C. liberica* or *C. stenophyla*, but they present low economical importance compared to the first two, since from all the commercial coffees that

Table 1.1 Characteristics of Arabica and Robusta Coffees

Arabica Coffee	Robusta Coffee
• Superior cup quality • More appreciated organoleptic characteristics • Lower total soluble solids content • More vulnerable to pests and diseases	• Smaller bean size • Usually cheaper • Double caffeine content • Higher yield of extractable solids • More resistant to pests and diseases

currently circulate in the international market, about 98% correspond to Arabica and Robusta coffees (Ferrão, 2009).

Currently, more than 70 countries produce coffee. In 2015–16, the global coffee production was about 145 million of 60 kg bags, while the consumption rounded the 152.1 million. Brazil is the world's largest producer of coffee (~43 million 60 kg bags in 2015), followed by Vietnam (27.5 million 60 kg bags). Colombia and Indonesia are in third and fourth place, respectively (International Coffee Organization, 2016).

Along the several steps of coffee production (from the small producers to the big companies of coffee processing and roasting) a huge amount of residues is generated. For instance, in Brazil the production of coffee from 2008 to 2013 averaged 2.9 million tons, being generated about 1.4 million tons of wastes each year (Oliveira and Franca, 2015). Considering all the producing countries, coffee wastes and by-products constitute a source of severe contamination and a serious environmental problem. It is very important that coffee industries make an effort to valorize the by-products that result from coffee processing in order to increase the sustainability of the process. Simultaneously to an environmentally friendly approach, this can be seen as an opportunity to increase economical incomes and create new jobs. In fact, the different types of by-products are rich in valuable chemical compounds with potential applications in diverse biotechnological fields, such as pharmaceutical, food, or cosmetic ones.

The next subsections of this chapter detail the different steps of coffee beans processing (from the field to the fork) in order to show the variety of by-products generated in each phase and, subsequently, to highlight the suggested strategies to recover and use those by-products for innovative and useful applications.

1.2 COFFEE PROCESSING

1.2.1 THE POSTHARVESTING PROCESSING

The postharvesting processing aims to separate the seed from the remaining parts of the coffee fruit and guarantee a good preservation of the final product. Moreover, the technique has to be adequate in order to protect coffee from the acquisition of undesirable characteristics during all this process (Ferrão, 2009).

The coffee fruit has five layers of protective material that need to be removed in order to reveal the bean inside. From outside to inside, it is composed by:

1. the skin (epicarp or exocarp), a monocellular layer covered with a waxy substance; when ripe it can be red, yellow, or pink, according to the coffee variety;
2. the pulp (mesocarp), composed by a fleshy pulp and, in ripe fruits, a slimy pectinaceous layer of mucilage;
3. the parchment (endocarp), a thin polysaccharide covering;
4. the silverskin (or chaff), a thin tegument that directly coats the seed; and
5. two seeds with elliptical form (Farah and Santos, 2015; Instaurator, 2008).

The high quality of a commercial coffee can only be achieved when all (or almost all) the fruits are harvested in a perfect stage of maturation. However, this highly increases the costs of the process so, in a normal harvest, perfectly mature fruits (that should be the great majority) are usually mixed with some fruits that are excessively mature or, instead, immature (Ferrão, 2009). According to local conditions of the producer country, coffee processing can be performed by different methods (Alves et al., 2011). Each one has its own advantages and disadvantages; therefore it is not possible to select one as the best. It is possible to obtain commercial coffees of good quality using all the processes, if well conducted, and the technique selection depends a lot on the local possibilities (e.g., water availability) (Ferrão, 2009).

In the dry processing method, the cherries are dried and then mechanically dehusked. This process is used for most Brazilian, Ethiopian, and Haitian Arabica coffees, and for Robusta coffee in most parts of the world (Alves et al., 2011). In general, in this technique, excessively mature and immature beans are not usually separated from those perfectly mature and, thus, they will all compose the final batch. The fruits are harvested, and disposed in thin layers (5–10 cm) as quickly as possible. This, together with an adequate mixing along the process, should avoid pulp decomposition (due to its high content in water and sugars) that could originate the much-unappreciated "fermented beans" or "black beans." The drying process can be performed under the sun in yards (natural drying) or in mechanical dryers. The latest are recommended in regions where rain is frequent during the fruit-drying period or to finish the natural drying. During this process, the coffee beans detach from the parchment (endocarp) and after 3–4 weeks, depending on the drying conditions, the fruits are ready to be dehusked (moisture $<12\%$). Nevertheless, if the dried fruits could rest (e.g., in silos) for some months before dehusking, the quality of the final product can be improved. During dehusking, the pericarp (skin, pulp, and parchment) is removed from the beans (Ferrão, 2009).

The wet method is a more sophisticated procedure compared to the previous one. It is based on depulp of the fruits, followed by fermentation. Although this process demands water in abundance and specific technical equipment, it generally allows the obtention of higher quality coffees with higher economical value. It is mainly used for Arabica coffees and coffees of higher quality (Alves et al., 2011; Ferrão, 2009). In order to be wet-processed, the fruits should be in a perfect state of maturation; therefore a careful selection of the cherries is needed, often with manual harvesting or with machinery that allows the separation of the mature beans. In this case, selection and washing tanks in which the coffee will be processed are unevenly disposed in a way that the materials can be separated by gravity. The well-mature beans present a slightly higher density than water and tend to deposit. The green and excessively mature fruits usually float. Therefore, it is possible to separate them and only the mature ones will proceed to the subsequent step: the depulping phase. This operation intends to remove the epicarp and the mesocarp of the fruit. At the end of depulping, the seed is still involved in the endocarp (Fig. 1.1). The gelatinous layer

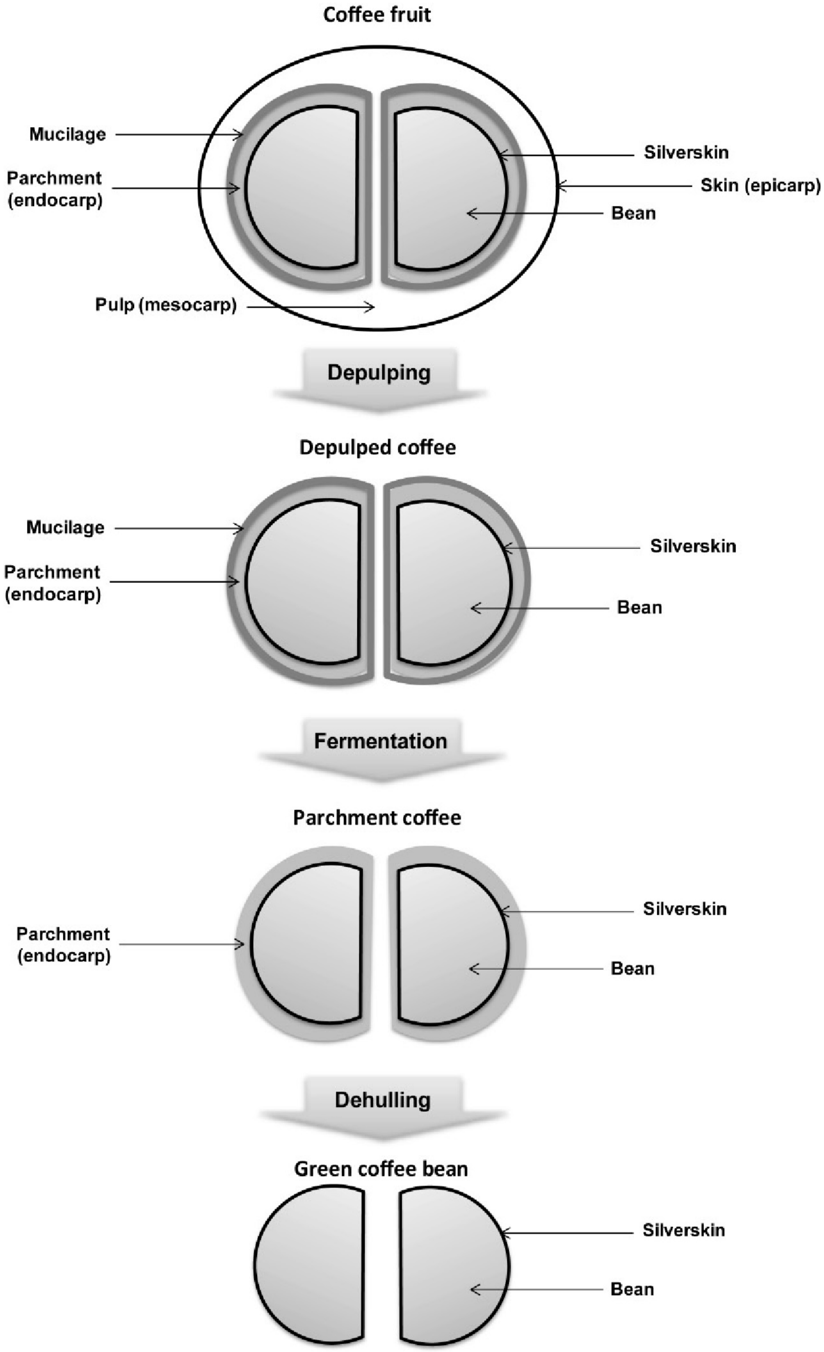

FIGURE 1.1 Coffee Processing Steps in the Wet Postharvesting Method

(mucilage) that coats the endocarp facilitates depulping by reducing the number of broken seeds and the strength to be applied. However, its tendency to retain water and slippery characteristics can impair the following phases. This mucilage, composed mainly by pectins, can be eliminated by fermentation, a process that involves a complex group of chemical and biological reactions. In this phase, the coffee stays in rest to allow the enzymatic and other processes to occur naturally, causing the degradation of mucilage. During this process, the temperature often increases, due to the alcoholic fermentation of the pulp sugar remaining, which is favorable to the enzymatic action of pectinases. The ideal time of fermentation is between 24 and 72 h. Otherwise, the color of the beans can be affected (fermented beans). Besides the natural action of pectinases, commercial enzymes or chemical agents can be also added to increase the efficiency of the process. However, it is still not a very common procedure (Ferrão, 2009).

In a third process, called “semidry” or “semiwashed,” concepts of both dry and wet methods are combined. This method consists of washing and selecting the fruits in flotation tanks, followed by depulping, but excluding the fermentation step (Farah and Santos, 2015). Then, the depulped coffee, which contains the mucilage remains, can be directly dried. This process has been used in Central Africa and Brazil, producing the “natural depulped coffee”. Both, wet- and semiwashed methods require an additional step for parchment removal, an inner membrane that stays adherent to the beans (Alves et al., 2011).

In addition, in the last years, the mucilage elimination by friction (mechanical action), instead of water, has been gaining supporters. Machines and equipments based on this principle have been appearing in the market, allowing the use of a method that simultaneously saves costs and water. In several regions where the dry-method was a tradition due to the water scarcity, these equipments were, indeed, very well accepted. These machines receive directly the fruits from the washing and calibration and, in sequence, remove the pulp, the mucilage, and wash the parchment coffee that is then ready to be dried and processed (Ferrão, 2009).

As previously referenced, along all of these types of processing, several by-products are generated. Just as an example, values described for washed Colombia coffee show that each 100 kg of mature fruits are constituted by 39 kg of pulp, 22 kg of mucilage, and 39 kg of parchment coffee (Ferrão, 2009). Therefore, considering the millions of bags produced in just 1 year, it can be highlighted that the amount of generated residues is extremely high. Fig. 1.2 summarizes the described postharvesting techniques and the main by-products generated in each one.

1.2.2 THE COFFEE ROAST

The roasting of raw beans is usually carried out in the consumer countries due to the friability and flavor characteristics of roasted beans, which would not resist the necessary movements of international circulation (Ferrão, 2009).