CHAPTER

31

An Overview of the Potential Uses for Coffee Husks

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List of Abbreviations

ACs Activated carbons
BC Bacterial cellulose
CHs Coffee husks
C:N Carbon-to-nitrogen ratio
CP Coffee pulp
db Dry basis
^{13}C-NMR Carbon 13 nuclear magnetic resonance
^{1}H-NMR Hydrogen 1 nuclear magnetic resonance
pH_{PZC} Point of zero charge
RBO3R Remazol Brilliant Orange 3R
SSF Solid state fermentation

31.1 INTRODUCTION

Coffee, a commodity ranking second only to petroleum in terms of currency traded worldwide, is quite relevant to the economy of its major producing countries such as Brazil, Vietnam, Indonesia, Colombia, Ethiopia, India, and Mexico. Brazil is the largest coffee producer and exporter in the world and the second largest consumer. Coffee processing generates significant amounts of agricultural waste, ranging from 30% to 50% of the weight of the total coffee produced, depending on the type of processing.[1] The production of coffee in Brazil from 2008 to 2013 averaged 2.9 million tons, with an amount in the range of 0.9–1.45 million tons of agricultural waste being generated each year. Coffee husks (CHs) and coffee pulp (CP) are the solid residues obtained after dehulling the coffee cherries during dry or wet processing, respectively. They are probably the major residues from the processing of coffee, for which there are no profitable uses, and their adequate disposal constitutes a major environmental problem. Furthermore, in compliance with the concept of sustainable development, innovative techniques and products for the valorization, reuse, and recycle of this type of residue should be sought. Several research works presenting proposals for such endeavors have been published in the literature and are reviewed in the following sections.

31.2 COFFEE PROCESSING

A brief description of the types of coffee processing is necessary to understand the different proposals for adequate exploitation of CHs available in the literature. A schematic view of a coffee cherry is displayed in Figure 31.1. The cherry usually bears two coffee beans inside, with their flat sides facing each other, and each bean is covered with a tightly fitting tegument, termed silver skin. A second yellowish skin, the parchment, loosely covers each bean. The parchment-covered beans are encased in a mucilaginous pulp, the flesh of the cherry, which, in turn, is covered by the outer skin or peel. The green coffee bean constitutes only 50–55% of the dry matter of the ripe cherry.[2] The remaining material is diverted to various types of waste, depending on the processing technique used.

The general steps involved in the processing of coffee cherries are displayed in Figure 31.2. Two methods are usually used: dry and wet processing. Dry processing is the simplest technique for handling coffee cherries. After harvesting, the cherries are dried to about 10–11% moisture content. Then the coffee beans are separated by removing the material covering the beans (outer skin, pulp, and parchment) in a de-hulling machine. The solid residues generated by de-hulling are called CHs. This processing method is commonly used for the majority of the Arabica and Robusta coffees harvested in Brazil. Drying can be accomplished by either natural or artificial methods. Natural drying, or sun-drying,

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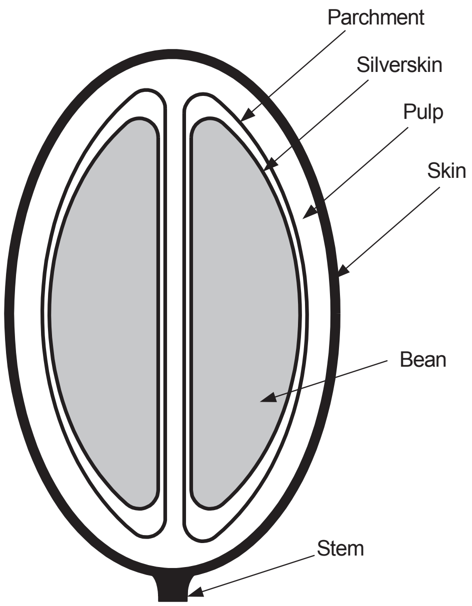

FIGURE 31.1 Schematic of a coffee cherry.

is the method commonly used in large farms because it requires no equipment investments or energy costs. However, it requires large drying areas (usually concrete surfaces). The process is slow, ranging from 3 to 4 weeks; the berries are usually spread out in a thin layer to avoid fermentation. Frequent raking is required to avoid mold proliferation and provide homogeneous drying conditions. Artificial drying can be used either as substitute or as a complement to natural drying.[2]

Wet processing does not require drying of the cherries themselves. In this type of processing, first the outer skin and pulp are mechanically removed, generating the solid residue denominated CP (see Figures 31.3 and 31.4). The beans can be fermented to remove a layer of remaining pulp material—after which the processed coffee is called pulped coffee—or can be dried directly, after which the final product is called de-hulled coffee. In both cases, after drying to approximately 12% moisture content, the beans are de-hulled again to remove the parchment.

FIGURE 31.2 Simplified diagram of coffee processing. *Adapted from the literature.*[2]

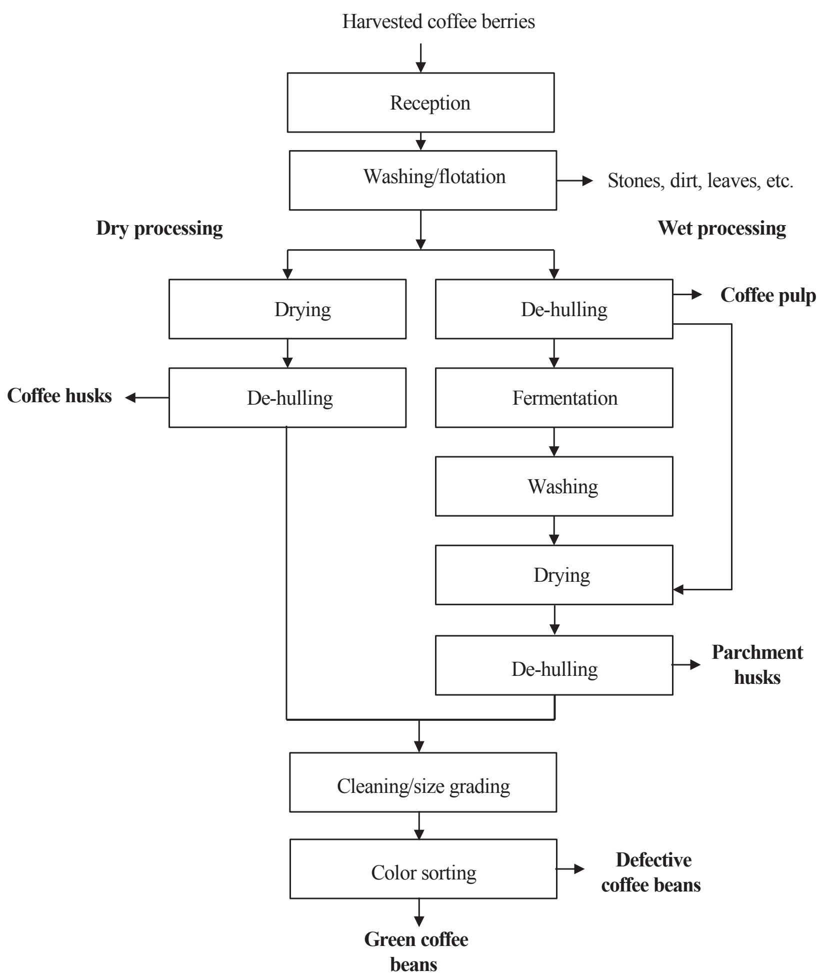

FIGURE 31.3 Photograph of coffee pulp and remaining coffee beans after separation.

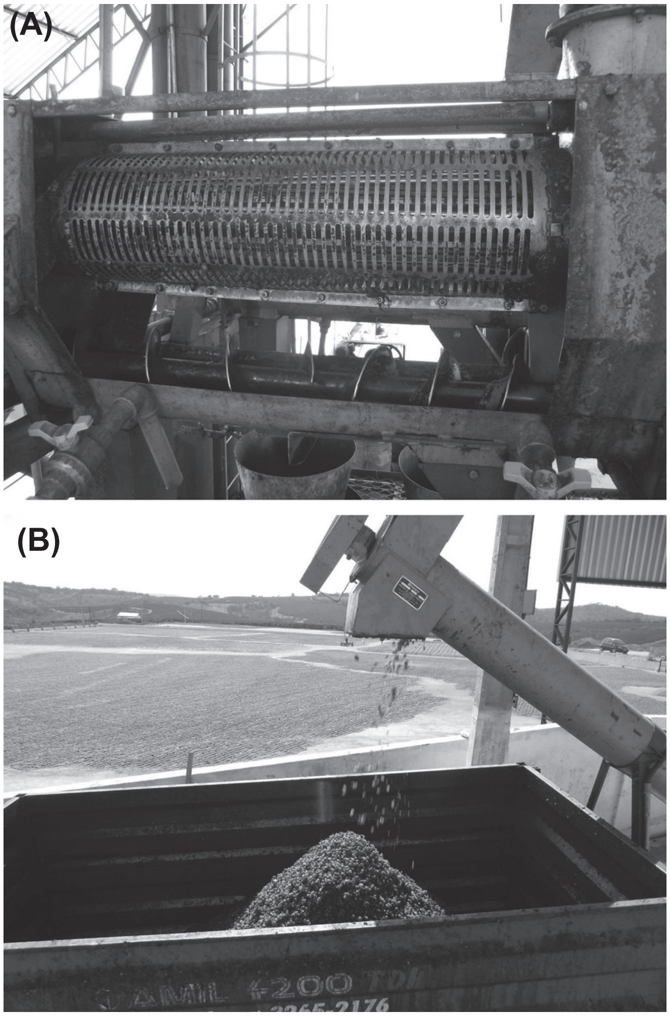

FIGURE 31.4 Photographs of equipment used for the mechanical separation of coffee pulp (CP) (A) and CP after separation (B).

31.3 CHEMICAL COMPOSITION OF CHs AND CP

Dry processed CHs have moisture contents ranging from 7% to 18%; such an extensive range is attributed to variations in processing and storage conditions.[3] Wet-processed CHs (CP) contain approximately 75% moisture and are usually left to dry to approximately 13% moisture.[4] Average values for the chemical composition of CHs and CP are displayed in Table 31.1. The high contents of carbohydrates are expected, given the origin of such solid residue. Some authors also make reference to a specific type of CHs known as sticky CHs.[5] Attributes that differentiate this specific type of CHs from the regular ones include its higher density and protein content, and lower fiber contents. However, the major difference relies on its sugar content (dry basis (db)): 29% total sugars, 24% reducing sugars, and 4% sucrose for sticky CHs[5] and 12% total sugars, 14% reducing sugars, and 2% sucrose for CP and CHs.[6] These significant differences have encouraged research studies of sticky CHs in association with specific applications such as animal feed and fermentation studies.

CHs and CP are rich in organic matter and nutrients and contain compounds such as caffeine, tannins, and polyphenols. Because of the presence of the latter compounds, these residues have a toxic nature that not only adds to the problem of environmental pollution but also restricts its use as animal feed. Caffeine, one of nature's most powerful stimulants, is present in CHs at approximately 1.3% concentration (db).[5] Tannins are generally thought to be an antinutritional factor and to prevent CHs from being used in animal feed at percentages >10%. Such compounds are found in CHs at approximate levels of 1% and 2.3% for Arabica and Robusta species, respectively.[7] Barcelos et al.[4] evaluated the levels of caffeine, tannins, lignin, and silica in dry- and wet-processed CHs from Brazilian Arabica coffees. After 1 year of storage, there was a 12% increase in caffeine levels,

TABLE 31.1 Chemical Composition of Coffee Husks and Pulp (g/100 g Dry Basis)[a]

	Coffee Husks (Dry Processed)	Coffee Pulp (Wet Processed)
Protein	8–11	4–12
Lipids	0.5–3	1–2
Minerals	3–7	6–10
Carbohydrates	58–85	45–89
Caffeine	~1	~1
Tannins	~5	1–9

[a] *Compilation of data presented in the literature.*[3,5–7]

a 39% reduction in tannin levels, and a slight decrease in lignin content. It was concluded that 12-month storage improved the quality of CHs. However, the increase in caffeine levels was considered a limiting factor for using this residue for animal feed.

31.4 REVIEW OF PROPOSALS FOR THE PROFITABLE EXPLOITATION OF CHs AND CP

31.4.1 Livestock Feed

Agricultural residues are commonly reused as livestock feed but, in the case of CHs, its low digestible protein content, in addition to the fact that the starch equivalent is comparable to low-quality hay, has prevented its use as animal feed.[6] Given the high amounts generated, however, coupled to their low-cost availability throughout the harvesting and processing season, several studies evaluated their use as a dietary supplement for cattle, swine, fish, sheep, chicken, and horses.[8] All of the aforementioned attempts were partially successful in their proposal in the sense that the addition of CHs and CP to animal feed formulations presented serious limitations in terms of the quantity allowed in the mixture without depreciating the quality of the feed. The use of CHs as a supplement in animal feed was reviewed by Franca and Oliveira[8]; their major conclusions are that CHs as a supplement in cow diets was considered feasible, with the upper limits for feed substitution varying from 30% to 40%; in the case of pigs, use of CH was deemed to be technically and economically feasible at inclusion levels ranging from 5% to 10% for CHs and up to 16% in the case of sticky coffee. For sheep, CHs could be used as a corn substitute up to 25%, and in the case of fish, conclusions varied depending on the fish and on the way in which the husks were incorporated into the fish feed was done. Neither fresh nor ensiled CP was considered a suitable foodstuff for Nile tilapia, but CP showed potential as a feed ingredient in fish diets if fish are reared in earthen ponds or pens instead of concrete tanks or raceways.

31.4.2 Detoxification Studies

The precise nature of the antiphysiological effects of CHs and CP is still unknown, but they are mostly attributed to the combined effect of compounds such as caffeine, which has stimulatory and diuretic effects, and tannins, which decrease protein availability and inhibit digestive enzymes.[6] In that regard, some studies of the detoxification of CHs and CP by physical, chemical, or biological methods are available and were reviewed by Franca and Oliveira,[8] Gokulakrishnan et al.[9] and Mazzafera.[10]

31.4.3 Silage

CHs and CP are rich in potassium and other mineral nutrients, which has resulted in studies of their application as organic fertilizers without any treatment or after composting.[1] The use of CHs directly as soil coverage is deemed a good option for potassium-depleted soils and can be used for different types of crops, including coffee. They favor erosion control, decrease temperature fluctuations, and decrease water loss by evaporation.[1] Couto Filho et al.[11] prepared a residue silage based on a mixture of mango husks and pulp with CHs at three levels of addition. It was concluded that CHs could be added up to 30%, improving the fermentative standard for silages of good quality. The same research group also evaluated silage based on a mixture of passion fruit husks and seeds, with CHs added up to 25%, and observed an increase in protein content.[12]

31.4.4 Composting and Vermicomposting

Composting can be defined as a solid-waste management system that accelerates the process of decomposition of biomass. Decomposition occurs spontaneously for CP and, if not controlled, can result in severe problems, including the proliferation of flies and foul odors, soil infiltration, and others.[6] Controlled composting, however, provides a product that can be easily handled, stored, and applied to the land without the abovementioned adverse effects. Composting of CP was described in early studies.[6] Matos[1] reported that CHs have low values for the carbon-to-nitrogen ratio (C:N), indicating that residues with high C:N should be mixed with CHs to guarantee a good-quality product. The compost produced using either CHs or CP should be viewed more as a soil conditioner rather than as a fertilizer. Furthermore, it has the physical effect of increasing soil's water retention and should improve the long-term quality of the soil.[6]

Raphael and Velmourougane[13] evaluated the efficiency of an exotic and a native earthworm from a coffee farm in the decomposition of CP into valuable vermicompost. Exotic earthworms were found to degrade the CP faster than the native worms, but both vermicomposting efficiency and yield were found to be significantly higher with native worms. Rezende and coworkers[14] addressed the production of organic compost through the association of wastes, CHs, and cow manure. The addition of manure to the CH provided a decrease in the C:N. Composts from the mix of CH and manure provided better results for fresh and dry biomass. A study of vermicomposting was conducted in Ethiopia[15] to evaluate the performance of epigeic earthworms in altering and changing CHs into a high-quality vermicompost. Results indicated that vermicomposting could be an adequate option for improving solid-waste management performance.

31.4.5 Biofuels

31.4.5.1 Solid Biofuel

CHs have been deemed a source of cheap fuel, with an approximate calorific value of 16 MJ/kg.[6] A study by Saenger et al.[16] investigated the combustion of CHs and observed that combustion products contained a large amount of volatile matter, had small amounts of fixed carbon and ash, and devolatilized easily upon heating, therefore requiring water cooling or short residence times in the feeder to avoid pyrolysis in the feeding system. High values for NO_x emissions were measured, indicating the need for NO_x emission reduction techniques. In addition, it was observed that the low melting temperature of ash, because of high content of potassium oxide, may lead to agglomeration, fouling, slagging, and corrosion. The authors suggested the need for further research on the use of additives, proper furnace design, and cofiring with coal for the direct use of CHs as fuel to become viable. Other studies of the pyrolysis of CHs[17,18] indicated that the pyrolysis of this residue gives rise to the yield of a larger gas fraction compared to other fractions, even at relatively low temperatures. The gas fraction increased with an increase in pyrolysis temperature. A comparison of microwave-assisted pyrolysis and conventional pyrolysis showed that microwave treatment produced more gas and less oil than conventional pyrolysis. In addition, the gas from the microwave had much larger amounts of hydrogen and syngas than those obtained by conventional pyrolysis in an electrical furnace, of which carbon dioxide (CO_2) is the main product.

Wilson et al.[19] studied the high-temperature air/steam gasification of CHs to harness the potential of this biomass energy in a sustainable way. High temperatures enhanced the gasification process. Furthermore, increased gasification temperatures led to a linear increment of carbon monoxide concentration in the syngas. When gasification temperature was increased from 700 to 900 °C, the carbon monoxide yield for the 2% oxygen concentration increased six times.

31.4.5.2 Ethanol Production

Bioethanol is a biofuel regarded as a promising substitute for gasoline in the transportation sector. To make it competitive with fossil fuels, however, it is necessary to reduce production costs by using alternative biomass feedstock. Current industrial processes for bioethanol production use either sugarcane or cereal grains as feedstock, directly competing with the food sector. Also, projected fuel demands indicate that alternative, low-priced feedstocks are needed to reduce ethanol production costs. Furthermore, it is estimated that ethanol production from agricultural residues could increase to 16 times the current production.[20] Given the high concentration of carbohydrates in CHs, this residue can be viewed as potential raw material for bioethanol production. Furthermore, the produced ethanol could be used for biodiesel production based on coffee oil obtained from defective coffee beans, thus further contributing to the implementation of sustainable development in the coffee production chain.[8,20] However, the production of ethanol from CHs has not yet been adopted on a practical scale.

Early studies indicated that biofuel fermented just from CP contained only 2.5–3.0% ethanol (w/v), which would require high energy costs during the distillation stage.[6] A preliminary feasibility study by Gouvea et al.[5] however, demonstrated that fermentation of sticky CHs led to a product containing 14% ethanol (w/v). Ethanol production was comparable to other agricultural residues that were being studied for bioethanol production,[5] and most of the residues were either supplemented with sugar or underwent hydrolysis.

Kefale et al.[21] studied a suitable condition for bioethanol production from CP using commercial baker's yeast; the pulp was hydrolyzed using dilute sulfuric acid and distilled water at boiling temperature. A 90% maximum total sugar concentration was obtained at 4 h acid-free hydrolysis. Based on the hydrolysis results, fermentation was performed, and it was observed that ethanol concentration decreased with increases in acid concentration, hydrolysis time, and fermentation time. The maximum ethanol concentration of 7.4 g/l was obtained with distilled water hydrolysis for 4 and 24 h of fermentation. Results indicated that CP could be a potential feedstock for bioethanol production in Ethiopia. The production of ethanol by fermentation of CP extracts was studied by Menezes et al.[22] The effects of heat treatment and comminution on the yield and composition of CP extracts were evaluated, and the extraction process deemed most efficient was that using grinding followed by pressing at room temperature. Five different fermentation media were tested for ethanol production: sugarcane juice or molasses diluted with water or with CP extract and a medium with only CP extract. The addition of CP extract to sugarcane juice or molasses did not influence the fermentation or yeast viability, and thus it was concluded that the mixture can be used for the production of bioethanol, with a yield of approximately 70 g/l.

31.4.5.3 Production of Biogas (Biomethanation)

The potential of using biogas as a viable alternative source of energy has been widely recognized.[23] Biogas is the name of a mixture of CO_2 and methane produced by bacterial conversion of organic matter, mostly manure and organic waste, under anaerobic conditions. Even though there are biogas plants currently being used, both economic and technical data available indicate that the profitability of many anaerobic digesters is still borderline, although current techniques to upgrade quality and to enhance energy use are being developed.[23] Early studies of the use of CHs and pulp for biogas production in anaerobic digestion have been developed.[6] CHs, known to resist biomethanation because of their acidic pH and the presence of polyphenols, were treated with a thermophilic fungus by Jayachandra and coworkers[24] to enable biomethanation. The fungus lowered the acidity of the husk and increased methane production. Cow dung was used as the control. In 2 months, the amount of gas produced by the treated husks was significantly higher than that produced by control.

31.4.6 Fermentation Studies

Several applications of CP and husks in fermentation studies have been reported, including the production of enzymes, citric acid, gibberellic acid, gallic acid, flavoring substances, and bacterial cellulose (BC). The majority of these works have already been reviewed by Franca and Oliveira,[8] and only the more recent work is discussed here.

Murthy and Naidu[25] evaluated lignocellulosic coffee byproducts such as pulp, husk, silver skin, and spent coffee for their efficacy as sole carbon sources for the production of xylanase in solid state fermentation (SSF) using *Penicillium* sp. CFR 303. Among the residues, CH was observed to produce maximum xylanase activity. Rani and Appaiah[26] investigated the suitability of coffee cherry husks for the production of BC by *Gluconacetobacter hansenii* UAC09. Various concentrations of CH extracts were used as carbon sources along with other nutritional components such as nitrogen and additives. Under optimized conditions, CHs allowed the production of more than threefold yield of BC than control medium. The extract of CHs was used by Rani and Appaiah[27] as a substrate for the production of endo- and exopolygalacturonase, polyphenol oxidase, and tannase during fermentation by *Gluconacetobacter*. The feasibility of using CHs for the production of β-glucosidase by *Rhizopus stolonifer* in SSF was evaluated by Navya et al.[28] Results indicated that CH as the sole carbon source provided the necessary nutrients for cell growth and for β-glucosidase synthesis. Bhoite and coworkers[29] studied the production of gallic acid through the transformation of CP tannins by *Penicillium verrucosum*. Among the fungi isolated from coffee byproducts, *P. verrucosum* produced 35.23 μg/g of gallic acid with CP as the sole carbon source in SSF.

31.4.7 Production of Mushrooms

A few studies have focused on the use of CHs and pulp as substrates for mushroom growth and were reviewed by Franca and Oliveira.[8] Silva and collaborators[30] recently grew *Pleurotus ostreatus* in CHs enriched with various concentrations of sodium selenite. The biological efficiency of *P. ostreatus* was affected by the addition of high concentrations of selenium (Se); the mushrooms from the first flush contained more Se than the subsequent flushes. The results demonstrated the potential of CHs in the production of Se-enriched mushrooms, showing the ability of the fungus to absorb and biomagnify Se.

31.4.8 Production of Adsorbents

The association between CHs and the production of charcoal has been considered first in terms of fuel, given that the calorific value is practically doubled after carbonization.[6] Given the significant amount of published information and increasing research interest on the use of agrifood residues in the preparation of activated carbons (ACs),[31] however, recent studies have dealt with the application of CHs as either biosorbents or as raw materials for the production of adsorbents.

ACs were prepared by pyrolysis of CHs in the presence of phosphoric acid as an activating agent.[32] The phosphoric acid impregnation ratio had a strong influence on the pore structure of the prepared ACs. Low impregnation ratios led to essentially microporous ACs, whereas at intermediate impregnation ratios, ACs with wider pore size distribution (from micropores to mesopores) were obtained. High impregnation ratios yielded essentially mesoporous carbons with a large surface area and pore volume. Untreated CHs were used as potential biosorbents for the treatment of dye-contaminated water.[33] Methylene blue was the model dye used in batch adsorption studies. The pH of the biosorption system did not have significant effects on the adsorption capacity for values above the determined point of zero charge (pH_{PZC}), indicating that mechanisms other than ion exchange might be taking place. CHs had an excellent adsorption capacity, and it was concluded that husks had great potential as inexpensive and easily available alternative adsorbents for the removal of cationic dyes in wastewater treatments.

Oliveira and collaborators[34] evaluated the performance of CHs as adsorbents for the removal of heavy-metal ions from aqueous solutions. The adsorption studies were conducted with a batch system using divalent copper, cadmium, zinc, and hexavalent chromium as adsorbates. CHs had better sorption performance for low concentrations of all metal ions studied. The maximum adsorption capacity of CHs was shown to be higher in comparison to other untreated residues such as sugarcane bagasse, cocoa shell, banana peel, and peanut hulls. Ferric chloride was used as an activating agent to obtain ACs from CHs.[35] This material was compared with two samples from the same raw material: one activated using zinc chloride, and the other activated with a mixture of ferric and zinc chloride in the same mass proportion. The AC obtained after the activation process showed large specific surface areas (>900 m^2/g). The activation with $FeCl_3$ produced smaller pores compared to the activation with $ZnCl_2$, with the activation temperature (280 °C) below the temperature commonly used for chemical or physical activation. The potential to remove chromium(VI) from aqueous solutions through biosorption using CHs was investigated by Ahalya et al.[36] The effects of pH, contact time, initial concentration, and adsorbent dosage on the adsorption of Cr(VI) were studied. The Langmuir adsorption capacity was found to be 44.95 mg/g. Infrared spectral studies revealed the presence of functional groups, such as hydroxyl and carboxyl groups, on the surface of the biomass, which facilitates biosorption of Cr(VI).

Ahmad and Rahman[37] prepared CH-based AC by physicochemical activation and used it to remove Remazol Brilliant Orange 3R (RBO3R) dye from an aqueous solution. Results showed that the adsorption of RBO3R was favorable at acidic pH. Adsorption uptake was found to increase with an increase in the initial RBO3R concentration, contact time, and solution temperature. The adsorption process was endothermic, and the reaction mechanism followed a physisorption process. ACs with highly developed porosity were prepared from CHs.[38] Characterization results showed these materials exhibited a large number of oxygen groups and large specific surface area with micro- and mesopores. The ACs obtained from CHs were deemed promising adsorbent materials, and the adsorption capacity for methylene blue was higher than that of commercial ACs.

31.4.9 Extraction and Recovery of Bioactive Compounds

Prata and Oliveira[39] investigated the potential of fresh CHs as sources of anthocyanins for applications as natural food colorants. Pigments were extracted in successive steps using an acidified methanol solution as the extractant. Cyanidin 3-rutinoside was characterized as the dominant anthocyanin in fresh CHs, and its quantification indicated that fresh CHs can be considered an abundant source of this colorant. Tello et al.[40] evaluated the technical feasibility of supercritical CO_2 extraction of caffeine from CHs. Different pretreatments and operational conditions were studied in a CO_2 continuous flow unit. The use of higher flow rates and/or longer operational times resulted in higher extraction rates. The process was favored by increased operational pressure and temperature because of higher solubility. The maximum extraction yield was 84% and, after washing with water, the caffeine was at least 94% pure. Comparing world production data, the initial caffeine content, and the global extraction yield data of other natural sources, this process was deemed very advantageous for its technological application.

Characterization of anthocyanins, polyphenols, and the biological properties of coffee skin/pulp were recently investigated.[41,42] Anthocyanins were analyzed by high-performance liquid chromatography with photodiode array detection and electrospray ionization mass spectrometry. The anthocyanins from CP yielded 25 mg of monomeric anthocyanins per 100 g of fresh pulp on a dry weight basis. The purified anthocyanin was identified as cyanindin-3-rutinoside and cyanidin-3-glucoside. The red color of coffee peels was attributed to the presence of cyanidin 3-rutinoside, which was confirmed by hydrogen 1 nuclear magnetic resonance (^{1}H-NMR) and carbon 13 nuclear magnetic resonance (^{13}C-NMR). CP had 22 mg GAE/g of polyphenols and free radical scavenging-linked antioxidant activity was observed. Coffee anthocyanins have shown multiple biological effects resulting in effective α-glucosidase and α-amylase inhibitory activities. It was concluded that coffee skin/pulp are potential sources of colorants and bioactive ingredients to be used in formulated foods.

The process of recovering phenolic compounds from CP, husk, silver skin, and spent coffee, and their respective antioxidant activities, were investigated by Murthy and Naidu.[43] The phenolic conserves were extracted using a solvent mixture of isopropanol and water. The conserved yield was highest in the case of silver skin (25%), followed by spent waste (19%) and husk (17%), when pretreated with viscozyme. Chlorogenic acid was the major component recovered. The bioactive conserves prepared from coffee byproducts possessed 65–70% antioxidant activity and contained total dietary fibers in the range of 40–80%. The soluble and insoluble fiber proportions of the coffee byproduct ranged between 16–35% and 18–64%, respectively. The antioxidant activity of coffee byproduct fiber was analogous to that of widespread fruits and fresh vegetables. Andrade et al.[44] presented a study describing the chemical composition and the antioxidant activity of spent coffee grounds and CH extracts obtained by supercritical fluid extraction with CO_2 and with CO_2 and a cosolvent (high-pressure methods). Low-pressure methods, such as ultrasound and soxhlet with different organic solvents, also were applied to obtain the extracts. The extracts obtained by low-pressure extraction with ethanol showed the best results for the global extraction yield when compared to supercritical fluid extraction results. The highest antioxidant activity was presented by CH extracts obtained by low-pressure extraction. The main compounds in the supercritical extracts from CHs were caffeine and chlorogenic acid, as identified by high-performance liquid chromatography.

31.4.10 Materials

Bekalo and Reinhardt[45] studied the use of CHs for partial replacement of wood (up to 50%) in the production of particleboards. Depending on the type and amount of resin used, the laboratory-made particleboards fulfilled the requirements of European standards with respect to general use in dry conditions and partly in humid conditions. The CH-wood board showed great promise for use in structural and nonstructural panel products based on superior flexural and internal bond properties. The study indicated that there is a potential for substituting up to 50% of wood with CH in the production of particleboard products. Acchar and Dultra[46] researched the thermal characterization and X-ray diffraction of coffees husk ash reject and its possible use in the ceramic industry. CHs were characterized and added to a commercial clay mixture. The addition of CHs had a positive effect on the strength of clay material and its use in a clay-based material was deemed feasible.

31.5 CONCLUDING REMARKS

Studies evaluating the sustainable and profitable use of CHs and CP as animal feed, solid biofuel, a component for structural materials, a source of bioactive compounds, and raw material for the production of liquid and gaseous biofuels, mushrooms, low-cost adsorbents, and fermentation products such as enzymes, flavor, and aroma ingredients for food products and others have been conducted. The overall conclusion of the studies with applications in animal feed is that using CHs as a diet supplement is significantly restricted by the presence of antinutritional compounds such as caffeine, tannins, and others. Some studies with the purpose of removing these antinutritional substances from CHs have been successful, but they all involve processing steps that will add to the costs of producing a material that has no significant value added to it. Production of compost and vermicompost, although deemed a feasible solution for the adequate disposal of CHs and CP, present problems: the market demand is not able to keep up with the voluminous supply of husks and pulp, and the composting processes currently used do not guarantee the destruction of the coffee borer that may be infecting some of the CP. Although using CHs as solid fuels on the coffee-producing farms has become a common practice in major coffee-producing countries, it has been demonstrated to present several problems; the major issue is the excessive emission of pollutants during combustion. Even though solid coffee residues have been reported to perform better in terms of biogas production in comparison to other agricultural residues, recent studies related to biomethanation of coffee processing residues indicated that this alternative use still does not seem to be viable because of either technical or economic setbacks. The production of bioethanol by fermentation of CHs constitutes a promising alternative for their adequate use, but there still is a need for significant research to make it both technically and economically viable. The production of fermentation products is also a promising alternative, but studies dealing with proper scale-up of the laboratory processes and with their respective economic feasibility are necessary for its implementation on a large scale. Significant research also is needed to produce adsorbents from CHs that can be implemented as a value-added alternative for their adequate use.

31.6 SUMMARY POINTS

- CHs and CP are generated in large amounts during coffee production.
- No adequate methods are available for the disposal of CHs and CP.
- CHs and CP constitute a rich source of bioactive compounds.
- Proposals for adequate exploitation of CHs and CP are plenty, but the majority are not yet suitable for implementation.
- There is still need for research in alternative and profitable uses of CHs and CP.

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