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REVIEW PAPER

Production, Composition, and Application of Coffee and Its Industrial Residues

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Abstract Coffee is one of the most consumed beverages in the world and is the second largest traded commodity after petroleum. Due to the great demand of this product, large amounts of residues are generated in the coffee industry, which are toxic and represent serious environmental problems. Coffee silverskin and spent coffee grounds are the main coffee industry residues, obtained during the beans roasting, and the process to prepare "instant coffee", respectively. Recently, some attempts have been made to use these residues for energy or value-added compounds production, as strategies to reduce their toxicity levels, while adding value to them. The present article provides an overview regarding coffee and its main industrial residues. In a first part, the composition of beans and their processing, as well as data about the coffee world production and exportation, are presented. In the sequence, the characteristics, chemical composition, and application of the main coffee industry residues are reviewed. Based on these data, it was concluded that coffee may be considered as one of the most valuable primary products in world trade, crucial to the economies and politics of many developing countries since its cultivation, processing, trading, transportation, and marketing provide employment for millions of people. As a consequence of this big market, the reuse of the main coffee industry residues is of large importance from environmental and economical viewpoints.

Keywords Coffee · Silverskin · Spent grounds · Cellulose · Hemicellulose

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Introduction: The Coffee History

Coffee has been consumed for over 1,000 years and today it is the most consumed drink in the world (more than 400 billion cups yearly) (Sobésa Café 2008). Arabia was responsible for the coffee culture propagation. The most ancient manuscripts mentioning the culture of coffee date from 575 in Yemen, but only in the century XVI in Persia, the first coffee beans were toasted to be turned into the drink that we know today (Neves 1974).

Coffee began to be savored in Europe in 1615, brought by travelers. Germans, Frenchmen, and Italians were looking for a way of developing the plantation of coffee in their colonies. But it was the Dutchmen who got the first seedlings and who cultivated them in the stoves of the botanical garden of Amsterdam, a fact that made the drink one of the most consumed in the old continent and becoming a definitive part of the habits of the Europeans. Next, the Frenchmen were given a plant of coffee by the major of Amsterdam, and they began to cultivate in the islands of Sandwich and Bourbon (Neves 1974). With the Dutch and French experiences, the coffee cultivation was taken to other European colonies. The European market growth favored the expansion of the plantation of coffee in African countries and was also through the European colonists that coffee reached Puerto Rico, Cuba, Suriname, São Domingos, and Guianas. Through the Guianas, coffee arrived to the north of Brazil. Then, the secret of the Arabs was spread by the entire world (Taunay 1939).

The coffee tree or shrub belongs to the family *Rubiaceae*. Coffee beans are produced from the plant *Coffea* L., of which there are more than 70 species. However, only two of these species are commercially explored worldwide: *Coffea arabica* (Arabica), considered as the noblest of all coffee plants and providing 75% of world's production; and *Coffea canephora* (Robusta), considered to be more acid but more resistant to plagues, and provides 25% of world's production (Belitz et al. 2009; Etienne 2005). *C. arabica* is a bush originally from Ethiopia and develops well in high altitudes (600–2,000 m), while *C. canephora* plantations adapt well in altitudes below 600 m (Comité Français du Café 1997).

Coffee Beans Processing

Coffee cherries are the raw fruit of the coffee plant, which are composed of two coffee beans covered by a thin parchment like hull and further surrounded by pulp (Fig. 1). These cherries are usually harvested after 5 years of coffee trees plantation and when the bear fruit turns red (Arya and Rao 2007). The processing of coffee initiates with the conversion of coffee cherries into green coffee beans, and starts with the removal of both the pulp and hull using either a wet or dry method. Depending on the method of coffee cherries processing, i.e., wet or dry process, the solid residues obtained have different terminologies: pulp or husk, respectively (Pandey et al. 2000). The dry method, commonly used for Robusta, is technologically simpler comparing with the wet method, which is generally used for Arabica coffee beans. In wet coffee process, the pulp and hull are removed while the cherry is still fresh. This process involves several stages that comprise considerable amounts of water and also includes a microbial fermentation step in order to remove any mucilage still attached to the beans. The production of microbial volatile compounds during fermentation results in coffee with richer aroma quality (Gonzalez-Rios et al. 2007a, b). The quality evaluation of green coffee is based on odor and taste tests, as well as on the size, shape, color, hardness, and presence of defects (Feria-Morales 2002).

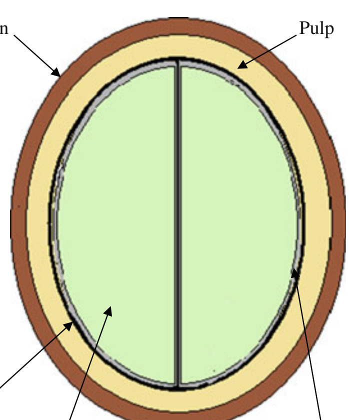

Fig. 1 Longitudinal cross-section of the coffee cherry

The roasting of coffee beans is another very important step in coffee processing, since specific organoleptic properties (flavors, aromas, and color) are developed and affect the quality of the coffee and the excellence of the coffee beverage, as a consequence (Hernández et al. 2008; Franca et al. 2005; Fujioka and Shibamoto 2008). This process is time–temperature dependent and leads to several changes in the chemical composition and biological activities of coffee as a result of the transformation of naturally occurring polyphenolic constituents into a complex mixture of Maillard reaction products (Czerny et al. 1999; Sacchetti et al. 2009), as well as the formation of organic compounds resulting from pyrolysis (Daglia et al. 2000). Sulfur compounds are also changed by oxidation, thermal degradation, and/or hydrolysis (Kumazawa and Masuda 2003), and the vanillin content increases considerably during the roasting process (Czerny and Grosch 2000). Besides the chemical reactions during coffee roasting, moisture loss and other major changes (color, volume, mass, form, pH, density, and volatile components) occur, while CO_2 is generated (Hernández et al. 2008). Therefore, coffee roasting is a quite complex process considering the importance of the heat transferred to the bean (Franca et al. 2009a). After the roasting process, coffee beans should be rapidly cooled in order to stop exothermic reactions and to prevent excessive roast, which might jeopardize the product quality (Baggenstoss et al. 2007; Dutra et al. 2001). Subsequently, the roasted beans are ground, usually by multi-stage grinders. Some roasted beans are packaged and shipped as whole beans. Finally, the ground coffee is vacuum sealed and shipped.

If the objective is producing instant coffee, an additional step of extraction follows the roasting and grinding operations. The soluble solids and volatile compounds that provide aroma and flavor are extracted from the coffee beans using water. Water heated to about 175 °C under pressurized conditions (to maintain the water as liquid) is used to extract all of the necessary solubles from the coffee beans. Manufacturers use both batch and continuous extractors. Following extraction, evaporation or freeze concentration is used to increase the solubles concentration of the extract (EPA 2010). The concentrated extracts are then dried; freeze drying and spray drying being the most frequently used methods to produce instant coffee. In the freeze-drying method, the concentrated coffee extract is initially frozen and then milled. Next, the frozen granules are sifted before drying to ensure uniform sizes. In this process, few changes in aroma are caused by heating and oxidation since the moisture is sublimed in a vacuum chamber. When spray-drying method is used, concentrated coffee extract is atomized in a drying chamber from which the water is removed due to the contact with air at temperatures between 200 and 300 °C. This technique allows large-scale production and provides products with low density and good flowability. Sensory evaluations of different commercial instant coffee revealed that the quality attribute is associated with the beans, storage time, fermentation process, roasting, extraction of the soluble solids, and the packaging material (Oliveira et al. 2009).

Chemical Composition of Coffee Beans

Caffeine is the most known component of coffee beans. In raw Arabica coffee, caffeine can be found in values varying between 0.8% and 1.4% (w/w), while for the Robusta variety these values vary between 1.7% and 4.0% (w/w) (Belitz et al. 2009). However, coffee bean is constituted by several other components, including cellulose, minerals, sugars, lipids, tannin, and polyphenols. Minerals include potassium, magnesium, calcium, sodium, iron, manganese, rubidium, zinc, copper, strontium, chromium, vanadium, barium, nickel, cobalt, lead, molybdenum, titanium, and cadmium. Among the sugars, sucrose, glucose, fructose, arabinose, galactose, and mannose are present. Several amino acids such as alanine, arginine, asparagine, cysteine, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tyrosine, and valine can also be found in these beans (Belitz et al. 2009; Grembecka et al. 2007; Santos and Oliveira 2001). Additionally, coffee beans contain vitamin of complex B, the niacin (vitamin B3 and PP), and chlorogenic acid in proportions that may vary from 7% to 12%, three to five times more than the caffeine (Belitz et al. 2009; Lima 2003; Trugo 2003; Trugo and Macrae 1984). Table 1 shows the chemical composition of coffee beans from Arabica and Robusta varieties.

Among the substances present in the chemical composition of coffee, only caffeine is thermostable, i.e., it is not destroyed by excessive roasting. Other substances such as

Table 1 Chemical composition of green coffee

Component	Arabica[a]	Robusta[a]	Constituents
Soluble carbohydrates	9–12.5	6–11.5	
Monosaccharides	0.2–0.5		Fructose, glucose, galactose, arabinose (traces)
Oligosaccharides	6–9	3–7	Sucrose (>90%), raffinose (0–0.9%), stachyose (0–0.13%)
Polysaccharides	3–4		Polymers of galactose (55–65%), mannose (10–20%), arabinose (20–35%), glucose (0–2%)
Insoluble polysaccharides	46–53	34–44	
Hemicelluloses	5–10	3–4	Polymers of galactose (65–75%), arabinose (25–30%), mannose (0–10%)
Cellulose, β(1–4)mannan	41–43	32–40	
Acids and phenols			
Volatile acids	0.1		
Nonvolatile aliphatic acids	2–2.9	1.3–2.2	Citric acid, malic acid, quinic acid
Chlorogenic acid	6.7–9.2	7.1–12.1	Mono-, dicaffeoyl-, and feruloylquinic acid
Lignin	1–3		
Lipids	15–18	8–12	
Wax	0.2–0.3		
Oil	7.7–17.7		Main fatty acids: 16:0 and 18:2 (9,12)
N compounds	11–15		
Free amino acids	0.2–0.8		Main amino acids: Glu, Asp, Asp-NH_2
Proteins	8.5–12		
Caffeine	0.8–1.4	1.7–4.0	Traces of theobromine and theophylline
Trigonelline	0.6–1.2	0.3–0.9	
Minerals	3–5.4		

From Belitz et al. (2009)

[a] Values in percent dry-weight basis

proteins, sugars, chlorogenic acid, trigonelline, and fat may be preserved or even destroyed and transformed into reactive products during the coffee roasting process (Ginz et al. 2000; Lima 2003; Rawel and Kulling 2007; Trugo 2003; Trugo and Macrae 1984).

Coffee Beans Brewing

"Coffee" is the designation of the drink prepared by extraction, in boiling water, of the soluble material from roasted coffee grounds. There are many different coffee brewing methods in the world. Coffee beverage can be prepared, for example, by filtration–percolation method, where ground coffee is placed on a specific support grid (filter paper, muslin, perforated plastic filter, sintered glass, etc.) and the coffee is extracted by dripping or spraying with hot water, i.e., by slow gravity percolation. This procedure is generally used in most coffee machines. In an Espresso machine, used to produce the traditional Italian coffee beverage called Espresso, coffee is extracted using superheated water (90±5 °C), and filtration is accelerated by steam at a pressure of 7–9 bar for a short time (30±5 s) (Petracco 2001). An exceptionally strong beverage is usually turbid, and is prepared with freshly ground and darkly roasted coffee. In this process, the water should not exceed 90–95 °C so that the volatile substances are retained in the coffee beverage (Belitz et al. 2009; Navarini and Rivetti 2010).

The most popular coffee brew preparation is by filter, but during the past few decades the consumption of espresso coffee has increased. Moreover, in southern European countries such as Italy and Spain, the use of the mocha coffeemaker is much extended at the domestic level, and the plunger coffeemaker is being used more often for coffee aroma lovers (Pérez-Martínez et al. 2010). In each case, the technical conditions applied, such as the coffee/water ratio, water temperature and pressure, the volume of coffee prepared, and the home and store grinding, contribute to the different chemical compositions of coffee brews (Andueza et al. 2002, 2003, 2007; Bell et al. 1996; Franková et al. 2009; Navarini et al. 2009; Parras et al. 2007; Ratnayake et al. 1993). For example, the mocha coffeemaker was found to present the highest yield in coffee antioxidant extraction per gram of ground roasted coffee when compared with coffee brews prepared by filter, plunger, or espresso, but espresso coffee was the richest in terms of antioxidant intake (per milliliter of coffee brew) followed by mocha, plunger, and filter (Pérez-Martínez et al. 2010). Filtered coffee brews were reported as containing less than 7 mg of lipids, whereas those prepared by boiling without filtering and espresso coffee may reach up to 160 mg of lipids per cup (Ratnayake et al. 1993). The caffeine content in the coffee drink also vary according to the used brewing procedure, being observed a considerable increase on caffeine yields when higher amounts of coffee grounds and volumes of coffee prepared are used. Depending on the length of coffee boiling time, similar or higher caffeine contents can be found when comparing with filtered coffee (Bell et al. 1996).

The water quality plays also a crucial role in coffee brewing, being considered as the second most important ingredient for coffee brewing. Water with an altered composition, such as some mineral spring waters, excessively hard water, and chlorinated water, might reduce the quality of the coffee brews (Belitz et al. 2009; Navarini and Rivetti 2010). Besides water, the pH of brewed coffee is another factor with great influence on the flavor characteristics of the coffee beverage. For pH value lower than 4.9, coffee brews presents a sour taste, and higher than 5.2 it is flat and bitter. Therefore, the pH value using mild roasted coffee (42.5 g/l) should be 4.9–5.2. Coffees of different origins provide extracts with different pHs, and, generally, the pHs of Robusta varieties are higher than those of Arabica varieties. The difference between the aroma qualities of the coffee beverage is due to more intensive phenolic, buttery, caramel-like, and weaker roasty notes, which are caused by shifts in the concentrations of the aroma substances during brewing (Bell et al. 1996).

Coffee World Production and Exportation

World coffee production has grown more than 100% from 1950 to 1960, and there was a prediction to grow more 0.5–1.9% by 2010 (Fujioka and Shibamoto 2008). Coffee is nowadays produced in a large number of countries worldwide. Nevertheless, the ten largest coffee-producing countries are responsible for approximately 80% of the world production. Of this percentage, South America participates with around 43%, Asia with 24%, Central America 18%, and Africa with 16%. Brazil, Vietnam, Colombia, and Indonesia are respectively the first, second, and third largest world producers, responsible for more than half of the world supply of coffee (Table 2). According to the International Coffee Organization (ICO 2010), in 2009 Brazil produced approximately 40 million bags of coffee (Table 2).

The world consumption of coffee in 2007, estimated by the International Coffee Organization, has been around 124,636 million bags of 60 kg, representing an increase of 2.88% regarding the 121,150 million sacks consumed in 2006 (ICO 2010). Despite the financial crisis, the world consumption of coffee in 2008 was

Table 2 Annual worldwide coffee production (million bags of 60 kg)

Countries	Production					
	2004	2005	2006	2007	2008	2009
Brazil	39.272	32.944	42.512	36.070	45.992	39.470
Vietnam	14.370	13.842	19.340	16.467	18.500	18.000
Colombia	11.573	12.564	12.541	12.504	8.664	9.500
Indonesia	7.536	9.159	7.483	7.777	9.350	9.500
Ethiopia	4.568	4.003	4.636	4.906	4.350	4.850
India	4.592	4.396	5.159	4.460	4.372	4.827
Mexico	3.867	4.225	4.200	4.150	4.651	4.500
Guatemala	3.703	3.676	3.950	4.100	3.785	4.100
Peru	3.425	2.489	4.319	3.063	3.872	4.000
Honduras	2.575	3.204	3.461	3.842	3.450	3.750
Côte d'Ivoire	2.301	1.962	2.847	2.598	2.353	1.850
Nicaragua	1.130	1.718	1.300	1.700	1.615	1.700
El Salvador	1.437	1.502	1.371	1.621	1.547	1.500
Other countries	15.713	15.779	16.019	16.138	15.680	15.455
Total	116.062	111.463	129.138	119.396	128.181	123.002

From ICO (2010)

around 128 million bags. According to ICO, the consumption of coffee was not affected by the crisis. The consumers will not stop drinking coffee, but instead of drinking high quality coffee, people will start to take coffee of middle quality.

Regarding the exportation, the quantity of coffee exported has been on average at 90.0 million bags of 60 kg per year, with Brazil leading exportations with a share of 28% of this market (Table 3).

Residues Generated in the Coffee Industry

The generation of residues and by-products is inherent in any productive sector. The agro-industrial and the food sectors produce large quantities of waste, both liquid and solid. Coffee is the second largest traded commodity in the world, after petroleum, and therefore, the coffee industry is responsible for the generation of large amount of residues (Nabais et al. 2008). In the last decade, the use of such

Table 3 World exportation of coffee (million bags of 60 kg)

Countries	Exportation					
	2003	2004	2005	2006	2007	2008
Brazil	25.670	26.653	25.956	27.642	28.010	29.486
Vietnam	11.631	14.859	13.432	14.001	17.936	18.417
Colombia	10.244	10.194	10.871	10.945	11.115	12.300
Indonesia	4.795	5.460	6.744	5.280	4.149	4.000
Ethiopia	2.229	2.491	2.435	2.935	2.604	2.500
India	3.707	3.647	2.823	3.699	3.259	3.300
Mexico	2.595	2.361	1.985	2.570	2.912	3.000
Guatemala	3.821	3.310	3.466	3.312	3.726	3.800
Peru	2.503	3.184	2.369	3.881	2.879	3.730
Honduras	2.425	2.779	2.392	2.898	3.312	3.000
Côte d'Ivoire	2.647	2.573	1.819	2.402	2.582	2.600
El Salvador	1.304	1.328	1.280	1.293	1.210	1.200
Nicaragua	1.013	1.311	1.003	1.445	1.259	1.200
Other countries	11.398	10.522	10.613	9.806	1.191	1.191
Total	85.982	90.672	87.188	92.109	96.367	96.622

From ABIC (2009)

wastes has been subject of several studies, but this concern did not exist in past decades (1930 to 1943) when 77 million bags of green coffee were simply burned and released to the sea and in landfills (Cunha 1992). However, this is an important topic explored nowadays.

Coffee silverskin (CS) and spent coffee grounds (SCG) (Fig. 2) are the main coffee industry residues. CS is a tegument of coffee beans obtained as a by-product of the roasting process. It is a residue with high concentration of soluble dietary fiber (86% of total dietary fiber) (Table 4) and high antioxidant capacity, probably due to the concentration of phenolic compounds in coffee beans, as well as to the presence of other compounds formed by the Maillard reaction during the roasting process, such as melanoidins (Borrelli et al. 2004). Microscopic examination (Fig. 2b) shows the presence of fibrous tissues from the surface layers of the CS. The main components of these fibrous tissues are cellulose and hemicellulose. Glucose, xylose, galactose, mannose, and arabinose are the monosaccharides present in CS; glucose being found in major amounts. Proteins and extractives are also fractions present in significant amounts in this coffee waste (Table 4).

SCG is a residue with fine particle size (see Fig. 2d, which is 50-fold magnified), high humidity (in the range of 80% to 85%), organic load, and acidity, obtained during the treatment of raw coffee powder with hot water or steam for the instant coffee preparation. Almost 50% of the world-wide coffee production is processed for soluble coffee preparation (Ramalakshmi et al. 2009). Therefore, SCG is generated in large amounts, with a worldwide annual generation of 6 million tons (Tokimoto et al. 2005). Numerically, 1 ton of green coffee generates about 650 kg of SCG, and about 2 kg of wet SCG are obtained to each 1 kg of soluble coffee produced (Pfluger 1975).

Chemical composition of this residue is shown in Table 4. It can be noted that SCG are richer in sugars than CS, among of which mannose and galactose are the most abundant. Proteins constitute also a significant fraction in SCG (Mussatto et al. 2011).

Coffee Industry Residues Applications

Nowadays, there is great political and social pressure to reduce the pollution arising from industrial activities. Almost all developed and underdeveloped countries are trying to adapt to this reality by modifying their processes so that their residues can be recycled. Consequently, most large companies no longer consider residues as waste, but as a raw material for other processes (Mussatto et al. 2006).

Due to the presence of organic material, CS and SCG are highly pollutant residues, and demand great quantities of oxygen to degrade (Silva et al. 1998). In addition, caffeine, tannins, and polyphenols present in these materials confer a toxic nature to them. Therefore, CS and SCG represent a pollution hazard if discharged into the environment. Despite this negative characteristic and the large amounts

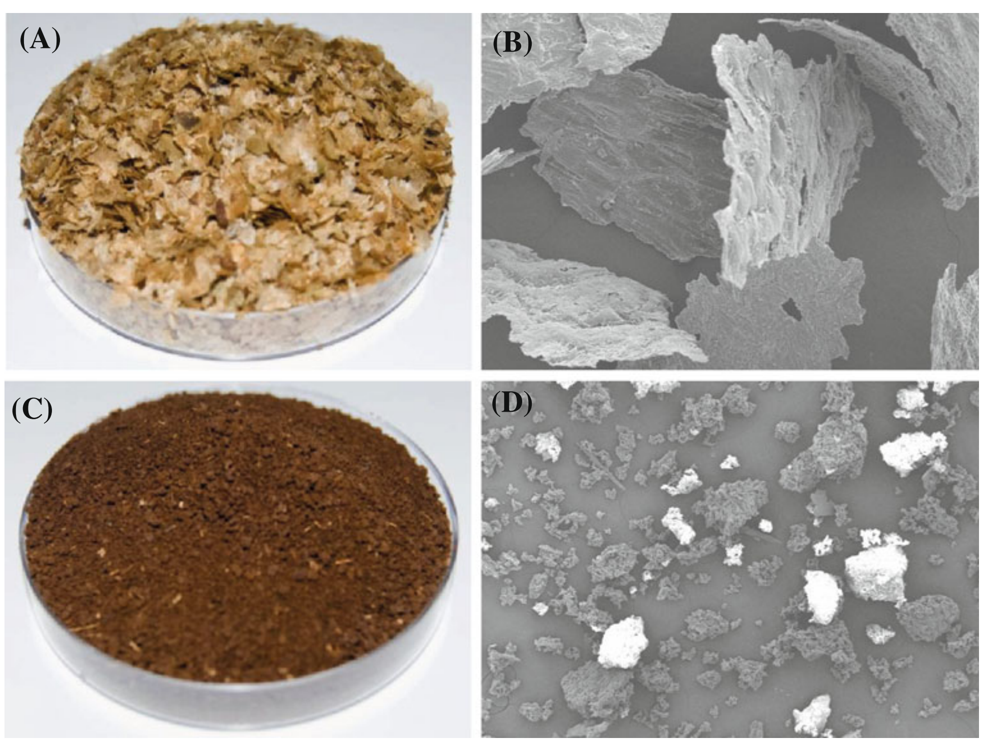

Fig. 2 Appearance of coffee silverskin (**a**, **b**) and spent coffee grounds (**c**, **d**). Scanning electron microscopy (**b**, **d**) of particles at 50-fold magnification

Table 4 Chemical composition (g/100 g) of coffee silverskin (CS) and spent coffee grounds (SCG)

Components	CS		SCG	
	A	B	C	D
Cellulose (glucose)	nd	17.8	8.6	nd
Hemicellulose	nd	13.1	36.7	nd
Xylose	nd	4.7	0.0	nd
Arabinose	nd	2.0	1.7	nd
Galactose	nd	3.8	13.8	nd
Mannose	nd	2.6	21.2	nd
Protein	18.6	16.2	13.6	nd
Fat	2.2	nd	nd	nd
Ashes	7.0	4.7	1.6	nd
Extractives	nd	15.0	nd	nd
Total fibers	62.4	nd	nd	nd
Soluble	53.7	nd	nd	nd
Insoluble	8.8	nd	nd	nd
Organic matter	nd	nd	nd	90.5
Nitrogen	nd	nd	nd	2.3
Carbon/nitrogen (C/N ratio)	nd	nd	nd	22/1

From Borrelli et al. (2004) (A), Carneiro et al. (2009) (B), Mussatto et al. (2011) (C), and ABNT (1987) (D)

nd not determined

that they are generated, there are few studies focusing on their use in different and profitable applications. Besides to add value to these unused materials, finding alternative forms to use them would be useful to decrease their impact to the environment. Among the studies up till now performed with these coffee industry wastes, most of them were focused on the use of SCG. However, the chemical composition data (Table 4) suggest that both residues can be of value as raw material for other processes. Some possible applications already evaluated for the CS and SCG use are described below.

Coffee Silverskin (CS)

In some countries, CS is used as combustible (Saenger et al. 2001) as alternative for its elimination. However, the published data about CS use are scarce. In a biotechnological perspective, Machado (2009) recently evaluated the ability of seven different fungal strains from the genus *Aspergillus*, *Mucor*, *Penicillium*, and *Neurospora* to grow and release phenolic compounds from CS under solid-state cultivation conditions, aiming the biological detoxification of this residue. According to this author, *Penicillium purpurogenum*, *Aspergillus niger* AA20, *Neurospora crassa*, and *Mucor* released high amounts of phenolic compounds (between 2.28 and 1.92 g/l) from the material structure and could be used for biological detoxification of this material, which would be beneficial for their subsequent disposal to the environment.

Regarding the CS use for obtaining value-added compounds, some authors have showed that this coffee residue has antioxidant capacity, and could be considered as a new potential functional ingredient (Borrelli et al. 2004). Murthy et al. (2009) reported the production of α-amylase by *Neurospora crassa* CFR 308 cultivated under solid-state conditions over CS. Mussatto et al. (unpublished results) established the best diluted acid hydrolysis conditions to release the hemicellulose sugars (xylose, arabinose, galactose, and mannose) from CS. Under this condition, a hydrolysate containing about 20 g/l total sugars was obtained, which could be used as substrate in fermentative processes, for example. In this same study, it was verified that *Saccharomyces cerevisiae*, *Pichia stipitis*, and *Kluyveromyces fragilis* yeasts were able to grow when cultivated in CS hydrolysate, attaining biomass concentrations of 5.9, 8.5, and 9.8 g/l, respectively, after 48 h of cultivation.

In a recent study, CS was proved to be an excellent material for use as support and nutrient source during fructooligosaccharides and β-furctofuranosidase production by *Aspergillus japonicus* under solid-state fermentation conditions. This process was considered an interesting and promising strategy to synthesize both products at the industrial level (Mussatto and Teixeira 2010).

Spent Coffee Grounds (SCG)

Although the toxic character and presence of organic matter in SCG, the discharge of this residue to the environment and sanitary landfill are disposal forms still performed nowadays, but that avoided. A biological treatment of this material with fungal strains from the genus *Penicillium*, *Neurospora*, and *Mucor* could be an interesting alternative to be performed previous the material elimination to the environment since these fungi are able to release phenolic compounds from the SCG structure, decreasing their toxicity (Machado 2009).

In some cases, SCG is used as fuel in industrial boilers of the same industry due to its high calorific power of approximately 5,000 kcal/kg, which is comparable with other agro-industrial residues (Silva et al. 1998). However, attention must be paid to the generation of particulate matter, which may affect the air quality near the industry (ABNT 1987). The possibility of SCG use as animal feed for ruminants, pigs, chickens, and rabbits (Claude 1979; Givens and Barber 1986) have already been also verified, but the high lignin content (≈25%) in this material was considered a limiting factor for its application (Cruz 1983).

More valuable alternatives for SCG use have been recently evaluated. In a study developed by Kondamudi et al. (2008), it was demonstrated that SCG can be used as a potential source to produce biodiesel and fuel pellets, among other value-added products, such as H_2 and ethanol (Fig. 3). SCG contain approximately 15% oil that can be converted into similar amounts of biodiesel by transesterification processes. The remaining solid waste can be used to produce ethanol (Sendzikiene et al. 2004) and fuel pellets (Kondamudi et al. 2008). In this sense, the feasibility of using supercritical fluid extraction processes to obtain the lipid fraction from SCG has also been evaluated (Couto et al. 2009).

Determination of the bioactivity (Ramalakshmi et al. 2009), amino acids (Lago and Antoniassi 2001), sugars (Mussatto et al. 2011), and oil contents (Freitas et al. 2000; Kondamudi et al. 2008) in SCG have also been performed aiming to find alternatives for the reuse of this residue. Nevertheless, few works have been developed in the area of fermentation technology using SCG as substrate. Leifa et al. (2001) investigated the production of *Flammulina velutipes* on SCG and verified that it is possible to use this residue as substrate without any nutritional supplementation for cultivation of edible fungus under solid-state fermentation conditions. SCG probably favored the growth of this fungus strain due to its high protein and moisture contents, which are factors that affect the microorganisms' development (Townsley 1979; Wang et al. 2001). Recently, Murthy and Naidu (2010a) evaluated the efficiency of several coffee by-products as sole carbon source, among them SCG from both Arabica and Robusta varieties as sole, for the production of xylanase from *Penicillium* sp. Despite the low xylanase production using SCG, it was proved to be a good substrate to support fungal growth.

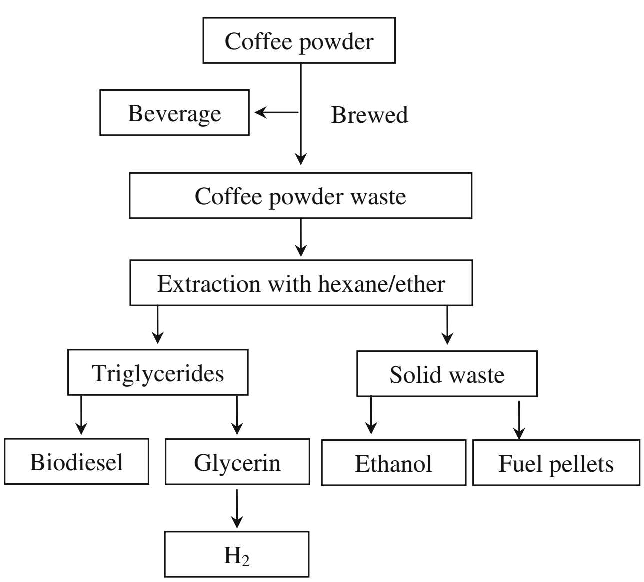

Fig. 3 Schematic presentation of biodiesel and fuel pellets production process from spent coffee grounds (Kondamudi et al. 2008)

Machado (2009) reused SCG as raw material for ethanol production. SCG was subjected to an acid hydrolysis process and the obtained hydrolysate was used as fermentation medium by *Saccharomyces cerevisiae* yeast, being achieved ethanol production results of 50.1% efficiency. Sampaio (2010) successfully used SCG for the production of a distilled beverage. The novel spirit then produced presented characteristics (flavor and presence of volatile compounds) and organoleptic properties acceptable and different when compared to the spirits commercially found. SCG has also demonstrated to be an inexpensive and easily available adsorbent for the removal of cationic dyes in wastewater treatments (Franca et al. 2009b).

Proposed Utilization of Coffee Industrial Residues

Chemical composition of CS and SCG, based on cellulose, hemicellulose, and protein, opens up possibilities for application of these residues in the production of different value-added compounds. Cellulose, for example, is a linear homopolymer of repeated glucose units extensively used for the pulp and paper production. Besides this potential application, cellulose can be converted to sugars such as polysaccharides, oligosaccharides, and monosaccharides by different treatment processes using acids or enzymes as catalysts (Mussatto et al. 2008a; Rinaldi and Schüth 2009). The conversion of cellulose to glucose is the first step in the large-scale chemical utilization of cellulose since this sugar may be subsequently converted to several products of interest such as ethanol (Mesa et al. 2010; Shen and Agblevor 2010), butanol (Qureshi and Ezeji 2008), hydrogen (Pan et al. 2010; Ren et al. 2009), organic acids (Mussatto et al. 2008b; Zhuang et al. 2001), glycerol (Taherzadeh et al. 2002), and hydroxymethylfurfural (Huang et al. 2010), among others.

Hemicelluloses are heteropolymers constituted by 5-carbon sugars such as xylose and arabinose, and 6-carbon sugars including mannose, galactose, and others. As well as glucose can be released from cellulose, these pentose and hexose sugars may also be released from the hemicellulose structure by means of some chemical or enzymatic pretreatment (Mussatto and Roberto 2004). Xylose and arabinose can be converted to furfural, or polyols like xylitol or arabitol (Mussatto and Roberto 2005; Saha and Bothast 1996). Furfural once served as the raw material for nylon until displaced by butadiene, a chemical currently derived from petroleum (Wang and Huffman 1981). Xylose can also be used for the production of ethanol (Silva et al. 2010) as well as mannose and other hexose sugars (Jorgensen et al. 2010; Machado 2009). Low molecular weight aliphatic compounds (ethylene and propylene) could be derived from ethanol produced by fermentation of these sugars (Mussatto et al. 2006). Mannose may be used also for the production of polyols like mannitol, which has great application in the food industry (Ghoreishi and Shahrestani 2009). Figure 4 summarizes other potential applications for cellulose and hemicellulose fractions present in CS and SCG.

In addition to cellulose and hemicellulose, the protein content is also significant in CS and SCG. Therefore, and also due to the large continuous supply and relative low cost, both coffee industry residues could be considered as adjunct for human food. Other protein-rich residues like brewer's spent grain have been successfully evaluated for nutritional enrichment of food products (Miranda et al. 1994). Incorporation of CS and SCG for the manufacture of flakes, breads, biscuits, and aperitif snacks would be an interesting alternative for application of these materials and should be also evaluated.

Besides the aforementioned applications, it is worth mentioning that the simultaneous presence of polysaccharides, proteins, and minerals makes CS and SCG substrates of high biotechnological value, which might be used, for example, as substrates or solid supports in fermentative processes, for microorganisms' cultivation, and extraction/production of compounds with applications in the food and pharmaceutical industries. Selection of the most potential microorganisms' strains and the establishment of the best process conditions are the main challenges to efficiently convert those components into value-added products.

In fact, there are a number of feasible uses for CS and SCG, but up till now, these residues remain few explored as raw material for the recovery and/or production of value-added compounds, as well as nutritional source for food products (Murthy and Naidu 2010b). This is a research area with great potential to expand in the future for economical and environmental viewpoints.

Attention should also be paid to finding economical methods for drying SCG since this material in the wet form (approximately 80% moisture content) requires high cost of transportation.

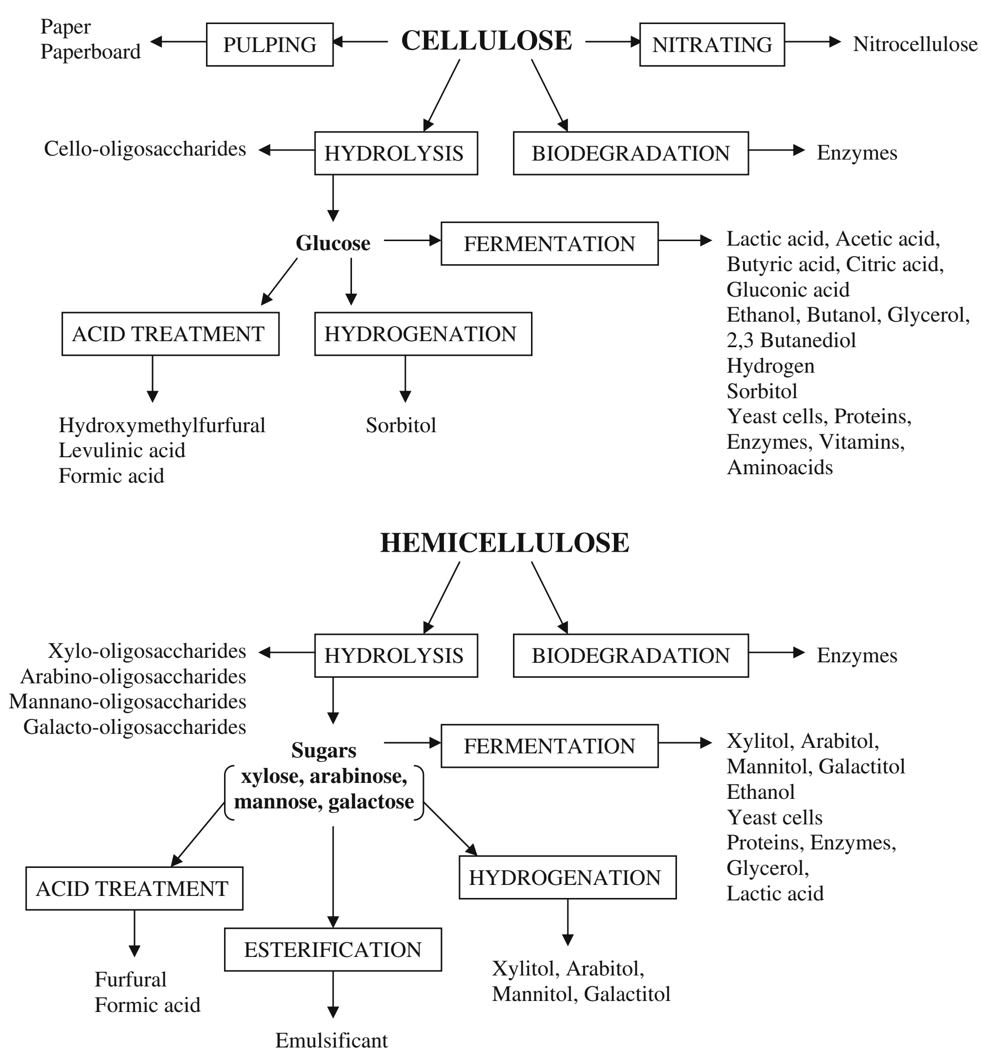

Fig. 4 Possible applications for cellulose and hemicellulose fractions present in coffee silverskin and spent coffee grounds

Conclusions

The importance of coffee in the world economy cannot be overstated. It is one of the most valuable primary products in world trade. Its cultivation, processing, trading, transportation, and marketing provide employment for millions of people worldwide. Coffee is crucial to the economies and politics of many developing countries; for many of the world's least developed countries, exports of coffee account for a substantial part of their foreign exchange earnings in some cases over 80%. Coffee is a traded commodity on major futures and commodity exchanges, most importantly in London and New York (ICO 2010).

As a consequence of this big market, the coffee industry is responsible for the generation of large amounts of wastes, CS and SCG being the main residues generated. Finding alternatives for use of these residues is of great importance due to their toxic character, which can be harmful if disposed into the environment. Up till now, there are few reports about the use of CS and SCG as raw material for other processes. Valorization of them would be interesting from environmental and economic standpoints, because would contribute with (1) a reduction of their impact to the environment by the toxicity decrease, (2) generation of compounds of added value, and (3) creation of more jobs. Although some attempts have been made to reuse CS and SCG, further researches are necessary in order to elucidate the potential of these coffee residues in bioprocesses, mainly in the area of the fermentation technology, exploring all their possible applications. Both residues are rich in polysaccharides, proteins, and minerals, and thus are substrates of high biotechnological value. CS and SCG might represent a great alternative, for example, as substrates or solid supports in fermentative processes for the extraction/production of compounds with important applications in the food and pharmaceutical industries.

References

ABIC (2009). World exportation of coffee. Available at: http://www.abic.com.br/estat_exporta_ppaises.html. Accessed 05 March 2010.

ABNT—Associação Brasileira de Normas Técnicas (1987), Resíduos Sólidos—Classificação—NBR 10.004. ABNT, Rio de Janeiro, Brazil.

Andueza, S., Maeztu, L., Dean, B., de Peña, M. P., Bello, J., & Cid, C. (2002). Influence of water pressure on the final quality of arabica espresso coffee. Application of multivariate analysis. *Journal of Agricultural and Food Chemistry, 50*, 7426–7431.

Andueza, S., Maeztu, L., Pascual, L., Ibanez, C., de Peña, M. P., & Cid, C. (2003). Influence of extraction temperature on the final quality of espresso coffee. *Journal of the Science of Food and Agriculture, 83*, 240–248.

Andueza, S., Vila, M. A., Peña, M. P., & Cid, C. (2007). Influence of coffee/water ratio on the final quality of espresso coffee. *Journal of the Science of Food and Agriculture, 87*, 586–592.

Arya, M., & Rao, J. M. (2007). An impression of coffee carbohydrates. *Critical Reviews in Food Science and Nutrition, 47*, 51–67.

Baggenstoss, J., Poisson, L., Luethi, R., Perren, R., & Escher, F. (2007). Influence of water quench cooling on degassing and aroma stability of roasted coffee. *Journal of Agriculture and Food Chemistry, 55*, 6685–6691.

Belitz, H.-D., Grosch, W., & Schieberle, P. (2009). Coffee, tea, cocoa. In H.-D. Belitz, W. Grosch, & P. Schieberle (Eds.), *Food Chemistry* (4th ed., pp. 938–951). Leipzig: Springer.

Bell, L. N., Wetzel, C. R., & Grand, A. N. (1996). Caffeine content in coffee as influenced by grinding and brewing techniques. *Food Research International, 29*, 185–189.

Borrelli, R. C., Esposito, F., Napolitano, A., Ritieni, A., & Fogliano, V. (2004). Characterization of a new potential functional ingredient: coffee silverskin. *Journal of Agricultural and Food Chemistry, 52*, 1338–1343.

Carneiro, L.M., Silva, J.P.A., Mussatto, S.I., Roberto, I.C., & Teixeira, J.A. (2009). Determination of total carbohydrates content in coffee industry residues. In: 8th International Meeting of the Portuguese Carbohydrate Group, GLUPOR, pp 94, 6–10 September 2009, Braga, Portugal (Book of abstracts).

Claude, B. (1979). Étude bibliographique: utilisation dês sous-produits du café. *Café Cacao Thé, 23*, 146–152.

Comité Français du Café. (1997). *Café—a la découverte du café*. Paris: Adexquation Publicite.

Couto, R. M., Fernandes, J., Gomes da Silva, M. D. R., & Simões, P. C. (2009). Supercritical fluid extraction of lipids from spent coffee grounds. *Journal of Supercritical Fluids, 51*, 159–166.

Cruz, G. M. (1983). Resíduos de cultura e indústria. *Informe Agropecuário, 9*, 32–37.

Cunha, M. R. (1992). Apêndice estatístico. In E. L. Bacha & R. Greenhill (Eds.), *150 anos de café* (pp. 286–388). Rio de Janeiro: Marcellino Martins & E. Johnston.

Czerny, M., & Grosch, W. (2000). Potent odorants of raw Arabica coffee. Their changes during roasting. *Journal of Agricultural and Food Chemistry, 48*, 868–872.

Czerny, M., Mayer, F., & Grosch, W. (1999). Sensory study on the character impact odorants of roasted arabica coffee. *Journal of Agricultural and Food Chemistry, 47*, 695–699.

Daglia, M., Papetti, A., Gregotti, C., Berté, F., & Gazzani, G. (2000). In vitro antioxidant and ex vivo protective activities of green and roasted coffee. *Journal of Agriculture and Food Chemistry, 48*, 1449–1454.

Dutra, E. R., Oliveira, L. S., Franca, A. S., Ferraz, V. P., & Afonso, R. J. C. (2001). A preliminary study on the feasibility of using the composition of coffee roasting exhaust gas for the determination of the degree of roast. *Journal of Food Engineering, 47*, 241–246.

EPA, United States Environmental Protection Agency (2010). Available at: http://www.epa.gov/chief/ap42/ch09/final/c9s13-2.pdf. Accessed 13 May 2010.

Etienne, H. (2005). Somatic embryogenesis protocol: coffee (*Coffea arabica* L. and *C. canephora* P.). In S. M. Jain & P. K. Gupta (Eds.), *Protocol for somatic embryogenesis in woody plant* (pp. 167–168). Dordrecht: Springer.

Feria-Morales, A. M. (2002). Examining the case of green coffee to illustrate the limitations of grading systems/expert tasters in sensory evaluation for quality control. *Food Quality and Preference, 13*, 355–367.

Franca, A. S., Mendonça, J. C. F., & Oliveira, S. D. (2005). Composition of green and roasted coffees of different cup qualities. *LWT—Food Science and Technology, 38*, 709–715.

Franca, A. S., Oliveira, L. S., Oliveira, R. C. S., Agresti, P. C. M., & Augusti, R. (2009a). A preliminary evaluation of the effect of processing temperature on coffee roasting degree assessment. *Journal of Food Engineering, 92*, 345–352.

Franca, A. S., Oliveira, L. S., & Ferreira, M. E. (2009b). Kinetics and equilibrium studies of methylene blue adsorption by spent coffee grounds. *Desalination, 249*, 267–272.

Franková, A., Drábek, O., Havlík, J., Száková, J., & Vanek, A. (2009). The effect of beverage preparation method on aluminium content in coffee infusions. *Journal of Inorganic Biochemistry, 103*, 1480–1485.

Freitas, S.P., Monteiro, P.L. & Lago, R.C.A. (2000). Extração do óleo da borra de café solúvel com etanol comercial. In: I Simpósio de Pesquisa dos Cafés do Brasil, pp 740–743, 26–29 September 2000, Poços de Caldas/MG, Brazil (Book of expanded abstracts).

Fujioka, K., & Shibamoto, T. (2008). Chlorogenic acid and caffeine contents in various commercial brewed coffees. *Food Chemistry, 106*, 217–221.

Ghoreishi, S. M., & Shahrestani, R. G. (2009). Innovative strategies for engineering mannitol production. *Trends in Food Science and Technology, 20*, 263–270.

Ginz, M., Balzer, H. H., Bradbury, A. G. W., & Maier, H. (2000). Formation of aliphatic acids by carbohydrate degradation during roasting of coffee. *European Food Research and Technology, 211*, 404–410.

Givens, D. I., & Barber, W. P. (1986). In vivo evaluation of spent coffee grounds as a ruminant feed. *Agricultural Wastes, 18*, 69–72.

Gonzalez-Rios, O., Suarez-Quiroza, M. L., Boulanger, R., Barel, M., Guyot, B., Guiraud, J.-P., et al. (2007a). Impact of “ecological” post-harvest processing on coffee aroma: I. Green coffee. *Journal of Food Composition and Analysis, 20*, 289–296.

Gonzalez-Rios, O., Suarez-Quiroza, M. L., Boulanger, R., Barel, M., Guyot, B., Guiraud, J.-P., et al. (2007b). Impact of “ecological” post-harvest processing on coffee aroma: II. Roasted coffee. *Journal of Food Composition and Analysis, 20*, 297–307.

Grembecka, M., Malinowska, E., & Szefer, P. (2007). Differentiation of market coffee and its infusions in view of their mineral composition. *Science of the Total Environment, 383*, 59–69.

Hernández, J. A., Heyd, B., & Trystram, G. (2008). On-line assessment of brightness and surface kinetics during coffee roasting. *Journal of Food Engineering, 87*, 314–322.

Huang, R., Qi, W., Su, R., & He, Z. (2010). Integrating enzymatic and acid catalysis to convert glucose into 5-hydroxymethylfurfural. *Chemical Communications, 46*, 1115–1117.

ICO, International Coffee Organization (2010). Available at: http://www.ico.org/. Accessed 05 March 2010.

Jorgensen, H., Sanadi, A. R., Felby, C., Lange, N. E. K., Fischer, M., & Ernst, S. (2010). Production of ethanol and feed by high dry matter hydrolysis and fermentation of palm kernel press cake. *Applied Biochemistry and Biotechnology, 161*, 318–332.

Kondamudi, N., Mohapatra, S. K., & Misra, M. (2008). Spent coffee grounds as a versatile source of green energy. *Journal of Agricultural and Food Chemistry, 56*, 11757–11760.

Kumazawa, K., & Masuda, H. (2003). Investigation of the change in the flavor of a coffee drink during heat processing. *Journal of Agricultural and Food Chemistry, 51*, 2674–2678.

Lago, R.C.A. & Antoniassi, R. (2001). Composição centesimal e de aminoácidos em cafés. In: II Simpósio de Pesquisa dos Cafés do Brasil. Available at: http://www.coffeebreak.com.br/ocafezal.asp?SE=8&ID=373. Accessed 02 December 2008.

Leifa, F., Pandey, A., & Soccol, C. R. (2001). Production of *Flammulina velutipes* on coffee husk and coffee spent-ground. *Brazilian Archives of Biology and Technology, 44*, 205–212.

Lima, D. R. (2003). *Café e Saúde: Manual de Farmacologia Clínica, Terapeutica e Toxicologia*. Rio de Janeiro: Medsi Editora.

Machado, E.S.M. (2009). Reaproveitamento de resíduos da indústria do café como matéria-prima para a produção de etanol. MSc thesis, Department of Biological Engineering, University of Minho, Braga, Portugal.

Mesa, L., González, E., Cara, C., Ruiz, E., Castro, E., & Mussatto, S. I. (2010). An approach to optimization of enzymatic hydrolysis from sugarcane bagasse based on organosolv pretreatment. *Journal of Chemical Technology and Biotechnology, 85*, 1092–1098.

Miranda, M. Z., Grossmann, M. V. E., & Nabeshima, E. H. (1994). Utilization of brewers’ spent grain for the production of snacks with fiber. 1. Physicochemical characteristics. *Brazilian Archives of Biology and Technology, 37*, 483–493.

Murthy, P.S. & Naidu, M.M. (2010a). Production and application of xylanase from *Penicillium* sp. Utilizing coffee by-products. Food Bioprocess Technology, doi:10.1007/s11947-010-0331-7.

Murthy, P.S. & Naidu, M.M. (2010b). Recovery of phenolic antioxidants and functional compounds from coffee industry by-products. Food and Bioprocess Technology, doi:10.1007/s11947-010-0363-z.

Murthy, P. S., Naidu, M. M., & Srinivas, P. (2009). Production of α-amylase under solid-state fermentation utilizing coffee waste. *Journal of Chemical Technology and Biotechnology, 84*, 1246–1249.

Mussatto, S. I., & Roberto, I. C. (2004). Alternatives for detoxification of diluted acid lignocellulosic hydrolyzates for use in fermentative processes: a review. *Bioresource Technology, 93*, 1–10.

Mussatto, S. I., & Roberto, I. C. (2005). Acid hydrolysis and fermentation of brewer’s spent grain to produce xylitol. *Journal of the Science of Food and Agriculture, 85*, 2453–2460.

Mussatto, S. I., & Teixeira, J. A. (2010). Increase in the fructooligosaccharides yield and productivity by solid-state fermentation with *Aspergillus japonicus* using agro-industrial residues as support and nutrient source. *Biochemical Engineering Journal, 53*, 154–157.

Mussatto, S. I., Dragone, G., & Roberto, I. C. (2006). Brewer’s spent grain: generation, characteristics and potential applications. *Journal of Cereal Science, 43*, 1–14.

Mussatto, S. I., Dragone, G., Fernandes, M., Milagres, A. M. F., & Roberto, I. C. (2008a). The effect of agitation speed, enzyme loading and substrate concentration on enzymatic hydrolysis of cellulose from brewer’s spent grain. *Cellulose, 15*, 711–721.

Mussatto, S. I., Fernandes, M., Mancilha, I. M., & Roberto, I. C. (2008b). Effects of medium supplementation and pH control on lactic acid production from brewer’s spent grain. *Biochemical Engineering Journal, 40*, 437–444.

Mussatto, S. I., Carneiro, L. M., Silva, J. P. A., Roberto, I. C., & Teixeira, J. A. (2011). A study on chemical constituents and sugars extraction from spent coffee grounds. *Carbohydrate Polymers, 83*, 368–374.

Nabais, J. M. V., Nunes, P., Carrott, P. J. M., Carrott, M. R., García, A. M., & Díez, M. A. D. (2008). Production of activated carbons from coffee endocarp by CO_2 and steam activation. *Fuel Processing Technology, 89*, 262–268.

Navarini, L., & Rivetti, D. (2010). Water quality for Espresso coffee. *Food Chemistry, 122*, 424–428.

Navarini, L., Nobile, E., Pinto, F., Scheri, A., & Suggi-Liverani, F. (2009). Experimental investigation of steam pressure coffee extraction in a stove-top coffee maker. *Applied Thermal Engineering, 29*, 998–1004.

Neves, C. (1974). *A estória do café* (p. 52). Rio de Janeiro: Instituto Brasileiro do Café.

Oliveira, A. L., Cabral, F. A., Eberlin, M. N., & Cordello, H. M. A. B. (2009). Sensory evaluation of black instant coffee beverage with some volatile compounds present in aromatic oil from roasted coffee. *Ciência e Tecnologia de Alimentos, 29*, 76–80.

Pan, C., Zhang, S., Fan, Y., & Hou, H. (2010). Bioconversion of corncob to hydrogen using anaerobic mixed microflora. *International Journal of Hydrogen Energy, 35*, 2663–2669.

Pandey, A., Soccol, C. R., Nigam, P., Brand, D., Mohan, R., & Roussos, S. (2000). Biotechnological potential of coffee pulp and coffee husk for bioprocesses. *Biochemical Engineering Journal, 6*, 153–162.

Parras, P., Martínez-Tomé, M., Jiménez, A. M., & Murcia, M. A. (2007). Antioxidant capacity of coffees of several origins brewed following three different procedures. *Food Chemistry, 102*, 582–592.

Pérez-Martínez, M., Caemmerer, B., de Peña, M. P., Cid, C., & Kroh, L. W. (2010). Influence of brewing method and acidity regulators on the antioxidant capacity of coffee brews. *Journal of Agricultural and Food Chemistry, 58*, 2958–2965.

Petracco, M. (2001). Beverage preparation: brewing trends for the new millennium. In R. Clarke & O. Vitzthum (Eds.), *Coffee: Recent Developments*. Oxford: Blackwell Science.

Pfluger, R. A. (1975). Soluble coffee processing. In C. L. Mantell (Ed.), *Solid wastes: origin, collection, processing, and disposal*. New York: Wiley.

Qureshi, N., & Ezeji, T. C. (2008). Butanol "a superior biofuel" production from agricultural residues (renewable biomass): recent progress in technology. *Biofuel, Bioproducts and Biorefining, 2*, 319–330.

Ramalakshmi, K., Rao, J. M., Takano-Ishikawa, Y., & Goto, M. (2009). Bioactivities of low-grade green coffee and spent coffee in different in vitro model systems. *Food Chemistry, 115*, 79–85.

Ratnayake, W. M. N., Hollywood, R., O'Grady, E., & Stavric, B. (1993). Lipid content and composition of coffee brews prepared by different methods. *Food and Chemical Toxicology, 31*, 263–269.

Rawel, H. M., & Kulling, S. E. (2007). Nutritional contribution of coffee, cacao and tea phenolics to human health. *Journal of Consumer Protection and Food Safety, 2*, 399–406.

Ren, N., Wang, A., Cao, G., Xu, J., & Gao, L. (2009). Bioconversion of lignocellulosic biomass to hydrogen: potential and challenges. *Biotechnology Advances, 27*, 1051–1060.

Rinaldi, R., & Schüth, F. (2009). Acid hydrolysis of cellulose as the entry point into biorefinery schemes. *ChemSusChem, 2*, 1096–1107.

Sacchetti, G., Di Mattia, C., Pittia, P., & Mastrocola, D. (2009). Effect of roasting degree, equivalent thermal effect and coffee type on the radical scavenging activity of coffee brews and their phenolic fraction. *Journal of Food Engineering, 90*, 74–80.

Saenger, M., Hartge, E.-U., Werther, J., Ogada, T., & Siagi, Z. (2001). Combustion of coffee husks. *Renewable Energy, 23*, 103–121.

Saha, B. C., & Bothast, R. J. (1996). Production of L-arabitol from L-arabinose by *Candida entomaea* and *Pichia guilliermondi*i. *Applied Microbiology and Biotechnology, 45*, 299–306.

Sampaio, A.R.M. (2010). Desenvolvimento de tecnologias para produção de etanol a partir do hidrolisado da borra de café. MSc thesis, Department of Biological Engineering, University of Minho, Braga, Portugal.

Santos, E. J., & Oliveira, E. (2001). Determination of mineral nutrients and toxic elements in Brazilian soluble coffee by ICP-AES. *Journal of Food Composition and Analysis, 14*, 523–531.

Sendzikiene, E., Makareviciene, V., Janulis, P., & Kitrys, S. (2004). Kinetics of free fatty acids esterification with methanol in the production of biodiesel fuel. *European Journal of Lipid Science and Technology, 106*, 831–836.

Shen, J., & Agblevor, F. A. (2010). Modeling semi-simultaneous saccharification and fermentation of ethanol production from cellulose. *Biomass and Bioenergy, 34*, 1098–1107.

Silva, M. A., Nebra, S. A., Machado Silva, M. J., & Sanchez, C. G. (1998). The use of biomass residues in the Brazilian soluble coffee industry. *Biomass and Bioenergy, 14*, 457–467.

Silva, J. P. A., Mussatto, S. I., & Roberto, I. C. (2010). The influence of initial xylose concentration, agitation, and aeration on ethanol production by *Pichia stipitis* from rice straw hemicellulosic hydrolysate. *Applied Biochemistry and Biotechnology, 162*, 1306–1315.

Sobésa Café (2008). Available at: http://www.sobesa.com.br. Accessed 05 March 2010.

Taherzadeh, M. J., Adler, L., & Lidén, G. (2002). Strategies for enhancing fermentative production of glycerol—a review. *Enzyme and Microbial Technology, 31*, 53–66.

Taunay, A.E. (1939). História do café no Brasil. No Brasil Imperial 1822–1872, tomo I, v. 5. Departamento Nacional do Café, Rio de Janeiro, Brazil.

Tokimoto, T., Kawasaki, N., Nakamura, T., Akutagawa, J., & Tanada, S. (2005). Removal of lead ions in drinking water by coffee grounds as vegetable biomass. *Journal of Colloid and Interface Science, 281*, 56–61.

Townsley, P. M. (1979). Preparation of commercial products from brewer's waste grain and trub. *MBAA Technical Quarterly, 16*, 130–134.

Trugo, L. (2003). Coffee. In B. Caballero, L. Trugo, & P. Finglas (Eds.), *Encyclopedia of Food Sciences and Nutrition* (2nd ed.). London: Academic.

Trugo, L. C., & Macrae, R. (1984). A study of the effect of roasting on the chlorogenic acid composition of coffee using HPLC. *Food Chemistry, 15*, 219–227.

Wang, S.-C., & Huffman, J. B. (1981). Botanochemicals: supplements to petrochemicals. *Economic Botany, 35*, 369–382.

Wang, D., Sakoda, A., & Suzuki, M. (2001). Biological efficiency and nutritional value of *Pleurotus ostreatus* cultivated on spent beer grain. *Bioresource Technology, 78*, 293–300.

Zhuang, X. L., Zhang, H. X., Yang, J. Z., & Qi, H. Y. (2001). Preparation of levoglucosan by pyrolysis of cellulose and its citric acid fermentation. *Bioresource Technology, 79*, 63–66.