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REVIEW: UTILIZATION OF WASTE FROM COFFEE PRODUCTION

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Abstract

Coffee is one of the most valuable primary products in the world trade, and also a central and popular part of our culture. However, coffees production generate a lot of coffee wastes and by-products, which, on the one hand, could be used for more applications (sorbent for the removal of heavy metals and dyes from aqueous solutions, production of fuel pellets or briquettes, substrate for biogas, bioethanol or biodiesel production, composting material, production of reusable cups, substrat for mushroom production, source of natural phenolic antioxidants etc.), but, on the other hand, it could be a source of severe contamination posing a serious environmental problem. In this paper, we present an overview of utilising the waste from coffee production.

Key words

coffee waste product, waste utilization, coffee husk, coffee pulp, silverskin, spent coffee grounds

INTRODUCTION

Coffee is one of the most important agricultural commodities in the world. The three main characteristic features of coffee are acidity, aroma and taste. It is derived from over 1500 chemical substances, 850 volatile and 700 soluble. When coffee is extracted in water, most of the hydrophobic compounds, including oils, lipids, triglycerides, and fatty acids remain in the grounds, as do insoluble carbohydrates like cellulose and various indigestible sugars. Structural lignin, protective phenolics and the wonderful aroma-producing essential oils are also present in coffee (1).

Production of coffee is the industrial process of converting the raw fruit of the coffee plant into the finished coffee (2). These processes generate a lot of solid wastes (by-products) and waste water. The main solid by-products from cultivation and preparation of coffee are spent coffee grounds, by-products of coffee fruit (coffee cherry) and bean processing (coffee husks, peel, pulp). Huge amount of contaminated waters are also produced in several washing steps, with a high carbon load, and thus with high impact on the environment. Other minor wastes may comprise defective green coffee beans and coffee tree leaves during harvest (2).

COFFEE AND ITS PRODUCTION

Coffee is one of the most consumed beverages in the world. An estimated 3.5 billion cups of coffee are consumed worldwide every day. It is grown in over 70 countries and amounts to over 16 billion pounds of beans every year (Tab. 1). That is a lot of beans and when they are only used once and thrown away, it also ontributes to a huge amount of waste (3).

Table 1 Total production of coffee by all exporting countries in thousand 60 kg bags in 2016 (4)

Total	**151 623**
Arabicas	95 204
Colombian Milds	15 779
Other Milds	26 951
Brazilian Naturals	52 474
Robustas	56 419
Africa	16 353
Asia & Oceania	43 110
Mexico & Central America	17 740
South America	74 420

Coffee was traditionally developed as a colonial cash crop. An estimated 11 million hectares of the world's farmland are dedicated to coffee cultivation (5).

Traditional forms of growing coffee naturally grew under a shaded canopy of trees. The sheltering from canopies provides a valuable habitat for indigenous animals and insects, as well as prevents topsoil erosion and removes the need for chemical fertilizers. However, i tis due to increased market demands, that this innocuous form of agriculture has been superseded by “the sun cultivation” techniques. Originating in the 1970's, sun cultivated (or sun grown) coffee is produced on plantations, where forestry is cleared so that coffee is grown in rows as a monoculture with no canopy. The sun-cultivated coffee, in concert with the necessary addition of fertilizer, creates the highest yield of coffee, but eliminates the diversity of plants, which supports an array of insects and animals, posing detrimental impacts to the biodiversity of the region, as well as other environmental harms (6).

The ideal conditions for coffee trees to thrive are found around the world in along the Equatorial zone called „The Bean Belt“, located between latitudes 25 degrees North and 30 degrees South. Finicky Arabica grows best at high altitudes in rich soil, while the heartier Robusta prefers a higher temperature and can thrive on lower ground. Everything from the variety of the plant, the chemistry of the soil, the weather, the amount of rainfall and sunshine, and even the precise altitude at which the coffee grows can affect the taste of the final product (7).

Coffee trees produce berries (Fig. 1), called coffee cherries that turn bright red when they are ripe and ready to pick. The fruit is found in clusters along the branches of the tree. The skin of a coffee cherry (the exocarp) is thick and bitter. However, the fruit beneath it (the mesocarp, pulp) is intensely sweet and has the texture of a grape. Next comes the parenchyma, a slimy, honey-like layer, which helps protect the beans. The beans themselves are covered by a parchment-like envelope called the endocarp. This protects the two, bluish-green coffee beans, which are covered by yet another membrane, called the spermoderm or silverskin (8).

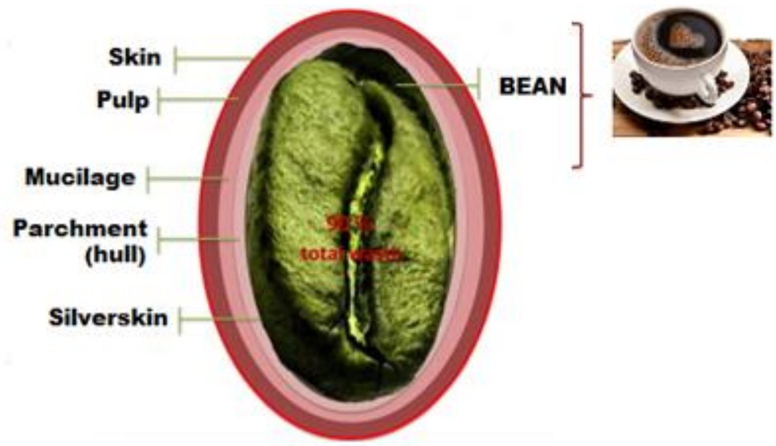

Fig. 1 *The coffee cherry fruit* (9)

Coffee production is a complex sequence of technological processes:

- *Planting* – coffee seeds are generally planted in large beds in shaded nurseries, planting often takes place during the wet season, so that the soil remains moist while the roots become firmly established;
- *Harvesting the cherries* – depending on the variety, it take approximately 3 to 4 years for the newly planted coffee trees to bear fruit, there is typically one major harvest a year (10);
- *Processing the cherries* – depending on location and local resources, coffee is processed by one of three different methods known as dry, wet and semi-dry processing, although all methods aim at removing the fruit flesh of coffee cherry, they do it in different ways (10, 11, 12);
- *Drying the beans* – if the beans have been processed by the wet method, the pulped and fermented beans must now be dried to approximately 11 % moisture to properly prepare them for storage;
- *Milling the beans*;
- *Exporting the beans*;
- *Tasting the coffee* – coffee is repeatedly tested for quality and taste;
- *Roasting the coffee* – roasting transforms green coffee into the aromatic brown beans, after roasting, the beans are immediately cooled either by air or water;
- *Grinding coffee* – generally, the finer the grind, the more quickly the coffee should be prepared;
- *Brewing coffee* (10).

LIFE CYCLE OF COFFEE AND UTILIZATION OF ITS WASTE PRODUCT

A summary diagram of the coffee cherries post-harvest handling techniques is represented in Fig. 2, where the steps contributing to the major generation of solid residues (i.e. spent coffee ground, coffee cherry, coffee husks, peel and pulp) are highlighted. Huge amounts of contaminated waters are also produced in several washing steps, with a high carbon load and therefore with high impact on the environment. Other minor wastes may comprise defective green coffee beans and coffee tree leaves during harvest (2).

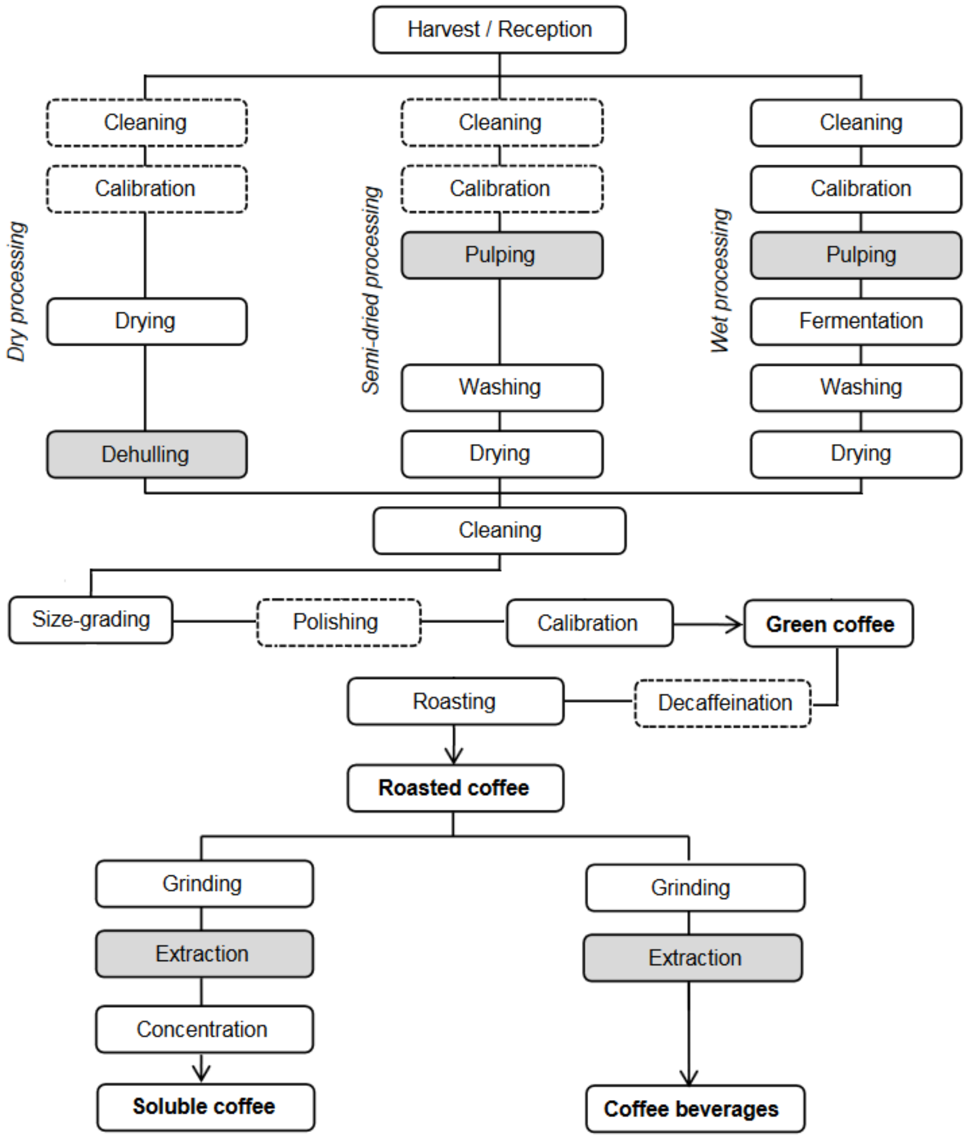

***Fig. 2** The life cycle of coffee products and residues generation steps (grey boxes indicate major steps of coffee solid residues production)* (2)

Depending on the method chosen for coffee processing, different by-products may be produced:

- *Pre-roasting coffee by-products*
  - dry processing: coffee cherry husks,
  - semi-dry and wet processing: coffee pulp,
- *Post-roasting coffee by-products:* coffee silverskin, spent coffee grounds (2).

Coffee cherry husks

The main by-product from the dry method (also termed as “unwashed”) is the coffee cherry husk (Fig. 3a) which is composed of the dried skin, pulp and parchment (2, 13). It representing about 12 % of the berry on dry-weight basis. About 0.18 tons of husks are released from 1 ton of fresh coffee fruits, producing around 150 to 200 kg of commercial green coffee (2).

Fig. 3 *Major coffee by-products (a – Husks, b – Pulp, c – Silverskin, d – Spent coffee grounds)*

Coffee husks are composed of 58 – 85% of carbohydrates, 8 – 11% of proteins, 0.5 – 3% of lipids, 3 – 7% of minerals, and minor amounts of bioactive compounds, such as caffeine (∼ 1%), chlorogenic acid (∼ 2,5%) and tannins (∼ 5%) are also present in this residue (2, 13, 14).

Many application approaches have been studied for coffee cherry husks re-utilization, as substrate for biogas (2, 15, 16) and alcohol production (14, 17), biosorbents for cyanide (18), biosorbents for the removal of heavy metals from aqueous solutions (19), biosorbents for the removal of dyes from aqueous solutions (2, 20), biosorbent for defluoridation of water (21), biosorbent for lead (II) (22), for preparing ion exchange material (23), converted into fuel pellets (24) or extracted for bioactive substances recovery (2). Besides, coffee husks demonstrated to be suitable candidates for a more direct use as substrate for edible mushrooms production (25, 26) or composting (27, 28). Coffee husks are also utilised as a potential functional ingredient in food production (using the ground coffee husk as a food supplementary for usage in smoothies, granolas and juices. The high concentration of caffeine and tannins in coffee husks, which are negative in environmental perspective, could be extracted for use in "energy drinks". The high content of dietary fibres in coffee husk constitutes a problem for the development of a beverage, but the fibres canbe included in a food product of "energy bars", by grinding the whole coffee husk, and thereby including all antioxidants and fibre into the product. The coffee husk could also be launched as allergic-friendly, since it is naturally gluten free. Using the coffee husk for brewed tea is called coffee cherry tea. Coffee husk is a useful substrate for the mould-, yeast- and enzyme production, owing to its high amount of fermentable sugars (13).

Coffee pulp

Coffee pulp is the first by-product obtained during wet or semi-dry processing and represents 29% dry-weight of the whole cherry. For every 2 tons of commercial green coffee produced, 1 ton of coffee pulp is obtained. Coffee pulp (Fig. 3b) comprises the exocarp (outerskin) as well as the mesocarp (fleshy portion) (2). It is essentially rich in carbohydrates (21 – 32%), proteins (5 – 15%), fats (2 – 7%), and minerals (9%), and contains also considerable amounts of tannins, polyphenols and caffeine (2, 29). The organic components present in coffee pulp (dry weight) include tannins 1.8 – 8.56%, total pectic substances 6.5%, reducing sugars 12.4%, non reducing sugars 2%, caffeine 1.3%, chlorogenic acid 2.6% and total caffeic acid 1.6% (29).

Similarly to coffee husks, coffee pulp has been studied to be reused for mushroom production (30, 31), composting (32), biogas production (33), bioethanol production (34), converted into fuel briquettes or pellets (35), enzymes production such as pectinases or cellulases (36, 37), and also for food production (converts coffee pulp into a nutritious flour, which can be used for baking or cooking, or even as an addition to smoothies, soups, or sauces) (38).

After undergoing the primary processing, green coffee is now available for roasting, which will alter completely its physical and chemical composition, and consequently, the by-products produced. These last coffee remains are produced immediately after roasting – coffee silverskin – and after beverage preparation, in industrial or at cafeteria/household environments (2).

Coffee silverskin

Coffee silverskin (Fig. 3c), frequently known as „chaff“, is the first coffee industry residue produced in consuming countries since it is released during roasting (Fig. 2), if the leaves were not polished before shipping. It consists of the tegument of coffee beans, and thus has a very low mass, comprising 4.2% of the green coffee bean, with reduced environmental impact highly rich in soluble dietary fibre (54% of total dietary fiber) and compounds with antioxidant capacity, particularly phenolic compounds (2).

Published data on coffee silverskin reuse are scarce. Aiming at the extraction value-added compounds, some authors have showed that this coffee residue constitutes a fine source of antioxidants and dietary fibres and may be considered as a new potential functional ingredient (2, 39). Furthermore, coffee silverskin maybe used as support and nutrient source during the fructooligosaccharides and β-furctofuranosidase production by *Aspergillus japonicus* under solid-state fermentation conditions, used as raw material to produce fuel bioethanol (2); magnetically modified coffe silverskin was also tested for the removal of xenobiotics from wastewater (methylene blue) (40) or, because of its powerful antioxidant capacity, coffee silverskin aqueous extract may be used for other applications, such as antiaging cosmetics and dermaceutics (41, 42).

Spent coffee grounds

Spent coffee grounds (Fig. 3d) are the waste product from brewing coffee. Coffee brews are usually prepared with an Arabica coffee or Arabica/Robusta blends, from single or different geographical origins, being available to consumers as roasted beans, whole or ground, or even as instant/soluble coffee. Thus, under the "spent coffee grounds" term, one can include those obtained from the soluble coffee industry as well as those produced after brewing at cafeterias or at home (2). About 0.91 g of the spent coffee grounds are produced per 1 g of ground coffee, and about two kilograms of wet spent coffee grounds are produced for every kilogram of instant coffee made (2, 43). Chemical composition of coffee brews is dependent on the extractive efficiency, which relies on diverse factors, including the coffee species, roasting degree, grinding grade, coffee/water ratio, water quality, temperature, pressure and percolation time. Therefore, different extraction processes will lead to sensorial and chemically distinct brews and, thus, distinct spent coffee grounds (SCG). In fact, industrial spent coffee constituents are much more effectively extracted, thus resulting in more chemically exhausted remains, in comparison to the spent coffee obtained after brewing from cafeterias/household environments (2).

SCG are composed of 12.4% cellulose, 39.1% hemicellulose (3.6% arabinose, 19.07% mannnose, 16.43% galactose), 23.9% lignin, 2.29% fat, 17.44% protein, and 60.46% of total dietary fibres (44). It makes them an interesting sources of raw materials for different applications. The differences in chemical composition of SCG presented in other papers probably reflect the variety of beans and processes used in roasting and extraction (9).

A potential use of SCG has been as a source for biodiesel production (45), bioethanol production (46), production of fuel pellets (47), as burning fuel in the industrial soluble industry directly (2), steam production (48), production of reusable cups (49), production of a spirit beverage (51), as source of sugars (51), as composting material (52, 53), as a sorbent for metal ions removal (54), as an adsorbent for dye removal (55, 56), as a substrate for mushroom production (57), as a source of natural phenolic antioxidants (58), and as a biomaterial in the pharmaceutical industry, in the food industry and in the polymer industry (59).

Coffee waste water

The environmental impact of wet and semi-wet processing is considerable. Problems occur through large amounts of effluents disposed into watercourses heavily loaded with organic matter rather than its inherent toxicity. Providing the self purification of the watercourse is exceeded, the microbial degradation reduces the level of oxygen to anaerobic conditions under which no higher aquatic life is possible (60).

Depending on the processing technology applied, quantities of coffee waste water vary. Modern mechanical mucilage removal machines producing semi-washed coffee use only about 1 m^3 per tonne of fresh cherry (without finish fermentation and washing), whereas the traditional fully washed technique without recycling uses up to 20 m^3 per tonne of cherry. In order to treat waste water properly and at reasonable costs, the amounts of waste water must be minimised. The main pollution in coffee waste water stems from the organic matter set free during pulping when the coffee pulp is removed and the mucilage texture surrounding the parchment is partly disintegrated. Pulping water consists of quickly fermenting sugars from both pulp and mucilage components. Pulp and mucilage consist to a large extend of proteins, sugars and the mucilage in particular of pectins, i.e. polysaccharide carbohydrates (60).

Depending on the processing method applied, further waste water evolves in the form of hydrolysed pectins from fermentation and washing. During fermentation, long chain pectins are split by enzymes (pectinase, pectase) into short chain pectin oligosaccharides. Oligosaccharides are soluble in alkaline and neutral solutions, but in acid conditions they are thrown out of solution as Pectic acid. In the presence of calcium or other multivalent ions, the pectic acid fragments are cross linked into a non-soluble gel of calcium pectate (60).

Waste water from mechanical mucilage removers (following the pulping) contains a certain amount of sugars (disaccharide carbohydrates), but its apparent gel like texture comes from the segments of undigested mucilage and pectic substances which have been removed from the parchment by mechanical means. In order to be biodegraded, the solid materials have to be fermented, acidified and hydrolysed by natural fermentation in a later stage (60).

During fermentation and acidification of sugars in the waste water, pectin oligo-sacharides get out of solution and float on the surface of the waste water. The remaining highly resistant materials left in the effluent water are acids and flavanoid colour compounds from coffee cherries. At around pH 7 and over, flavanoids turn waste water into dark green to black colour staining rivers downstream from coffee factories. However, flavanoids do not do any harm to the environment nor add significantly to the Biological Oxygen Demand (BOD) or Chemical Oxygen Demand (COD) (60).

Values for BOD indicating the amount of oxygen needed to break down organic matter are high in coffee waste water (up to 20.000 mg l^{-1} for effluents from pulpers and up to 8.000 mg l^{-1} from fermentation anks). The BOD should be reduced to less than 200 mg l^{-1} before let into natural waterways.

Resistant organic materials which can only be broken down by chemical means indicated by the COD make up around 80% of the pollution load and are reaching 50.000 mg l^{-1} and more. The material making up the high COD can be taken out of the water as precipitated mucilage solids. Other substances to be found in small amounts in coffee waste water are toxic chemicals like tannins, alkaloids (caffeine) and polyphenolics. However, these toxic substances mainly stay in the disposed solids of the coffee pulp (60).

During the fermentation process in the effluents from pulpers, fermentation tanks and mechanical mucilage removers, sugars will ferment in the presence of yeasts to alcohol and CO_2. However, in this situation the alcohol is quickly converted to vinegar or acetic acid in the fermented pulping water. The simplified chemical formula for biological fermentation of 6 carbon sugars by yeasts to ethanol is typified by the fructose to ethanol reaction:

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 . \quad [1]$$

Ethanol is quickly broken down by bacteria into acetic acids. This complex enzymatic catalysed reaction is simplified as

$$2CH_3CH_2OH + O_2 \rightarrow 2CH_3COOH . \quad [2]$$

The acidification of sugars will drop the pH to around 4, and the digested mucilage will be precipitated out of solution and will build a thick crust on the surface of the waste water, black on top and slimy orange/brown in colour underneath. If not separated from the waste water, this crust will quickly clog up waterways and further contribute to anaerobic conditions in the waterways (60).

Coffee waste waters are high in organic loadings and exhibit a high acidity. When washed or semi washed coffee is processed in large quantities, untreated effluents greatly exceed the self-purification capacity of natural waterways. In order to overcome the pollution potential of processing waste waters, a clear understanding of waste water constitution in inevitable to design a feasible treatment system. Especially when expanding wet coffee processing or setting up new large scale processing operations, treatment of waste waters needs to be considered (60).

CONCLUSION

Coffee is the world's second most valuable traded commodity, behind only petroleum. Largely irrespective of how coffee is grown, discharges from coffee processing plants represent a major source of river pollution. Ecological impact result from the discharge of organic pollutants from the processing plants to rivers and waterways, triggering eutrophication of water systems and robbing aquatic plants and wildlife of essential oxygen. In order to overcome the pollution potential of processing waste waters, a clear understanding of waste water constitution in inevitable to design a feasible treatment system.

Coffee industry is also responsible for the generation of large amounts of solid wastes. 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. Depending on the type of coffee waste (coffee cherry husks, coffee pulp, coffee silverskin or spent grounds), there are many application approaches of the coffee waste utilization. For example, this waste can be used as sorbent for the removal of heavy metals and dyes from aqueous solutions, production of fuel pellets or briquettes, for preparing ion exchange material, production of a spirit beverage, substrate for edible mushrooms production, source of natural phenolic antioxidants, production of reusable cups, substrate for biogas and alcohol production, biodiesel production or composting, and as well as a biomaterial in the pharmaceutical industry. Finding alternatives for the use of these residues is of great importance, which is due to their toxic character, which can be harmful if disposed into the environment.

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