P-ISSN: 2305-6622; E-ISSN: 2306-3599
International Journal of
Agriculture and Biosciences
www.ijagbio.com; editor@ijagbio.com

Review Article

Waste Management and Utilization in Coffee Industry: A Review

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Article History: Received: November 12, 2018 Revised: January 10, 2019 Accepted: September 20, 2019

ABSTRACT

Coffee (*Coffea* species) belongs to the family Rubiaceae and indigenous to Ethiopia; it is the most important beverages utilized in both developed and developing countries of the world. Coffee production and processing for human consumption generates wastes and byproducts like leaves, pulp from the bean, coffee residues, coffee meal and spent coffee grounds that that pollute the environment particularly the wastes generated after harvest unless managed properly. The coffee processing environmental impact are broad and deep throughout the producer and processor which can range from water pollution (surface and underground water), bad odors which may result health problems and concentration of toxic elements in soils, which results decreased land productivity and increased use of chemicals for its solution. Thus, by considering all these problematic issues coffee producers and processors have been found with the support of designers and suppliers of technologies, innovative ways to manage and utilize wastes in various forms. Efforts made innovated different ways of coffee waste utilization like composite, mushroom production, animal feed and as energy source which plays great role in Environment protection and conservation, ensuring food security and increase framer's income as it allows other alternate means of using coffee waste and byproducts. In order to benefit the farmers and others engaged on coffee production and processing, demonstration of the way how to use waste products particularly as mushroom production, as animal feed and generation of energy in scientifically supported ways is very important.

Key words: Coffee Pulp, Coffee Husk, waste coffee ground, compost

INTRODUCTION

Coffee belongs to Rubiaceace family and a major plantation crop grown worldwide and is one of the most popular beverages consumed throughout the world. There are three common species of coffee: *robusta, arabica and liberica*. 75-80% of the coffee produced worldwide is arabica and 20% is Robusta (Woldesenbet *et al*., 2015). *C. canephora* grow at lower altitude and fit well in the eq uatorial, warm and wet tropics below 1000 m. Robusta cof fee is resistant to coffee leaf rust (*Hemileia vastatrix*) and, therefore, with the expansion of coffee production in the world it has been replacing arabica in the areas where coffee leave rust was devastating the production of arabica coffee (Pohlan and Janssens, 2010).

As for Arabica, some early Brazilian coffee was labeled after its major port of export, Santos. There exist also minor coffee species called *Coffea liberica* originated from West Africa around Liberia (Pohlan and Janssens, 2010). Ethiopia is the largest producer of coffee in Sub-Saharan Africa and is the fifth largest coffee producer in the world next to Brazil, Vietnam, Colombia, and Indonesia (Tefera and Tefera, 2013). Indigenous to Ethiopia, *Coffea arabica* L. is the oldest species known and the most traded one in the beginning of the millennium, 60% of world coffee produced was *C. arabica* whereas 40% was *C. robusta* (Bossolasco, 2009).

The world coffee production from harvested area of 10485408 (10.5million) hectare was 8790005 (8.8 million tons) with yield per hectare of 8.38 quintal; Ethiopia contributes 4.78 % to world production and shared 5.34 in terms of area coverage as 561762 hectares of coffee harvested from the country with production from this area 419980 tones and average yield per hectare of 7.48 quintal (FAOSTAT, 2014). Coffee grown at various altitudes ranging from 1200-2750 meters above sea level, where there is sufficient rainfall with an amount between 1500-2500 mm and optimum temperatures between 15-25º. It is grown in two regions of the country namely Oromia and Southern Nations, Nationalities and People Regions (SNNPR). 95% of Ethiopia's coffee is produced by small holder farmers on less than two hectares of land while the remaining five percent is grown on modern commercial farms (Tefera and Tefera, 2013).

Cite This Article as: Argachew Abebe Ademe, Gizachew Hirpa and Wakuma Biratu, 2019. Waste management and utilization in coffee industry: a review. Inter J Agri Biosci, 8(5): 276-281. www.ijagbio.com

Coffee is still Ethiopia's number one export item. It accounts for 25 to 30 percent of Ethiopia's total export earnings, but, its share of total export earnings has gradually declined in recent years as a result of increased exports of other commodities such as gold, flowers, Khat, textiles, and leather products (Tefera and Tefera, 2013 and Tefera and Tefera, 2014).

The coffee industry can be divided into the following sectors in association of their environmental impacts: Nursery, Farm, Pulpery and Finishing (Waugh and Nelson, 2003); from those coffee industries this review paper will focus on the pulpery and finishing coffee industry sectors which are associated with waste generation and disposal.

The agro-industrial and the food sectors produce large quantities of waste, both liquid and solid. Due to the great demand of coffee, coffee industries are responsible for the generation of large number of residues, which are toxic and represent serious environmental problems (Solange *et al*., 2011). The coffee plant, which is indigenous to Ethiopia, is a perennial evergreen dicotyledon. It produces fruit once per year about six to nine months after flowering. The bean (endosperm) represents about 45% of the fruit; the other 55% is generally discarded as waste (pulp and mucilage) (Waugh and Nelson, 2003).

The coffee processing environmental impact are broad and deep throughout the producer and processor. These impacts can range from water pollution (surface and underground water), bad odors which may result health problems and concentration of toxic elements in soils, which results in decreased land productivity and increased use of chemicals for its solution. Due to this tangible problem there is the need to alleviate the negative impacts resulted in association with this product. Thus, by considering this issues Latin-American coffee producers and processors have found with the support of designers and suppliers of technologies, innovative ways to manage and utilize wastes in various forms (Hernandez and Gallozzi, 2010). Since in the middle of the last century, efforts have been made to develop methods for its utilization as a raw material for the production of feeds, beverages, vinegar, biogas, caffeine, pectin, pectic enzymes, protein, and compost (Rathinavelu and Graziosi, 2005). The objective of this review paper is to review the coffee waste management and utilization methods and systems.

Review on coffee waste management and Utilization of Coffee Industry

Concept of coffee wastes and coffee industry

The coffee industry can be divided into the following sectors with their corresponding environmental impact: Nursery (chemical usage, packaging waste), Farm (soil conservation, chemical usage and disruption of biodiversity), Pulpery (waste generation and disposal) and the fourth final coffee industry is Finishing with the same environmental impact with that of the third industry (pulpery). Pulpery is synonymous with coffee processing via wet processing is the generation of substantial amounts of waste, both liquid and solid. Finishing involves the drying, hulling, grading and sorting of coffee and processing for consumption, thus the waste generated in this operation is parchment husk and ground (Waughand Nelson, 2003).

Coffee contains over 1500 chemical substances, 850 volatile and 700 soluble, and when prepared correctly involves 13 independent chemical and physical variables. 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 (Woldesenbet *et al*., 2015).

Coffee production and processing for human consumption gives rise to a number of byproducts that may be used as different purposes. These include leaves, pulp from the bean, coffee residues, coffee meal and spent coffee grounds. The fresh fruit of coffee consists of 45% pulp, 10% mucilage, 5% skin and 40% bean (Didanna, 2014). In coffee producing countries, coffee wastes and by-products constitute a source of severe contamination and a serious environmental problem. For this reason, since the middle of the last century, efforts have been made to develop methods for its utilization as a raw material for the production of feeds, beverages, vinegar, biogas, caffeine, pectin, pectic enzymes, protein, and compost (Rathinavelu and Graziosi, 2005).

Coffee pulp/husk contains some amount of caffeine and tannins, which makes it toxic resulting disposal problem unless managed properly. However, it is rich in organic matters, which makes it an ideal substrate for microbial processes for the production of value added products (Padmapriya *et al*., 2013).

Methods of coffee waste management and utilization of coffee industry

Compost preparation: Coffee pulp solids contain one fifth of the nutrients taken out of the soil by export of the green bean thus good source of humus and organic soil carbon. If coffee pulp is turned over every few days in a heap preserved for a few years as in conventional compost making, it will compost in three weeks into one fifth of the original volume of a stable earthy smelling (Rathinavelu and Graziosi, 2005).

Padmapriya (2013), revealed as Coffee pulp is a source of nutrients: 0.5% of composted pulp is nitrogen, 0.15% is phosphorus, and 0.5% is potassium. Therefore, pulp was treated and used as organic fertilizer. The pulp left in piles, for 3 to 12 months, turns into rich, black humus that can be used for composting. Another way of composting is to mix coffee husk with cattle manure and burring the mixture in pits or heaps. These plays a great role in improving soil properties thus increasing yield and using organic fertilizers also helps to reduce the need to buy inorganic fertilizers, hence saving the farmers money.

Dzung (2013) researched on Coffee husk (875 kg) which has organic carbon of 50.83%, over 20% lignin; 1.27% total N; high potassium (2.46% K) and C/N ratio of 40.02; mixed with 10% cow manure (w/w), supplemented 2% lime (w/w), 0.5% urea (w/w) and water to reached 60% humidity of the mixture. One kilogram of effective microorganisms containing *Trichoderma sp.* and *Streptomyces sp.* being suspended in 50 liters of fresh water and sprayed for 1000kgs of the mixture. After three months of the of composting process the obtained Organic carbon (OC%) of coffee husk reduced from 50.8% down to 28.2%

after composting and nitrogen content increased from 1.27% up to 2.07%. The result leads to reducing C/N ratio down to 13.6 after three months composting. The C/N ratio traditionally considered as a parameter to determine degree of maturity of compost.

Similarly, Shemekite *et al*. (2014) investigated composts preparation by mixing coffee husks with cow dung and with fruit/vegetable wastes in proportions of 4:1 and 2:1 (on fresh weight basis). From the investigation the result obtained showed that total nitrogen percentage was increased with composting duration which is due to the concentration effect caused by carbon loss associated with mineralisation of the organic matter regardless of the magnitude for both coffee husk mixed with cow dung and fruit/vegetable wastes. They also reported the addition of cow dung and fruit/vegetable wastes to coffee husk, however, significantly contributed to the decomposition of the ligno-cellulosic compounds of the husk, resulting in higher N losses in these mixed composts.

Ulsido and Li (2016) have been studied different organic fertilizers on chickpeas in Ethiopia reported that the use of compost made from coffee pulp as an amendment to the topsoil statistically and numerically improved the physicochemical properties of the soil thereby enhanced the yield components of chickpeas under a greenhouse condition. Coffee pulp compost amended topsoil gave a significantly higher above ground and below ground fresh and dry weight compared with the non-amended topsoil and topsoil amended with sawdust compost.

Similarly, Gomes *et al*. (2013) revealed both fresh and composted SCG (Spent Coffee Ground) increased slightly the dry weight (dw) and daily growth rate when compared. This improvement in plant growth could be related to the richness of fresh SCG on mineral nutrients, especially on N. However, for higher fresh SCG amounts the biomass was reduced to values inferior to those observed in control samples. Fresh SCG has known to contain high amounts on toxic compounds such as caffeine, tannins and chlorogenic acids. Therefore, an increased on fresh SCG amounts in the soil may consequently result in an increased of levels on these toxic compounds, which could ultimately reduce plant growth. The results from the composted SCG treatment indicated that the composting process probably reduces the amounts on these phytotoxic compounds.

Energy source: The coffee processing industries have various environmental impact which are broad and deep throughout the producer and processing countries. As this tangible problem needs solutions to reduce the negative impacts resulted in association with this crop, Latin-American coffee producers and processors have found, with the support of designers and suppliers of technologies, innovative ways to manage and utilize wastes in various forms, among which the use of these wastes as an alternative energy source was the innovated idea (Hernandez and Gallozzi, 2010).

In order to extract coffee oil extraction and then Biodiesel, there is the need to optimize the feedstock as follows: generally, dried SCG affords a higher yield than wet SCG, from this fact the sample used throughout the Boualdab (2016) experiment was dried for 2h at 150°C and the water content in the SCG was found to be 62.97% w. Although excessive drying causes a loss in the oil extraction yield; therefore, it should be done as quickly and gently as possible. The next is prepetition of the solvent to be used (hexane). Additionally, these procedures followed serious steps which was almost similar with the procedure indicated in (Fig. 1) and needs specific time for quality output which is mainly 30 min (ideally 90 min) and specific temperature (70°C) for extraction time. After consideration of preconditions for oil extraction, the next stage aimed at applying these latter in order to produce a considerable quantity of coffee oil that is to be used as the raw material for biodiesel production (Boualdab, 2016).

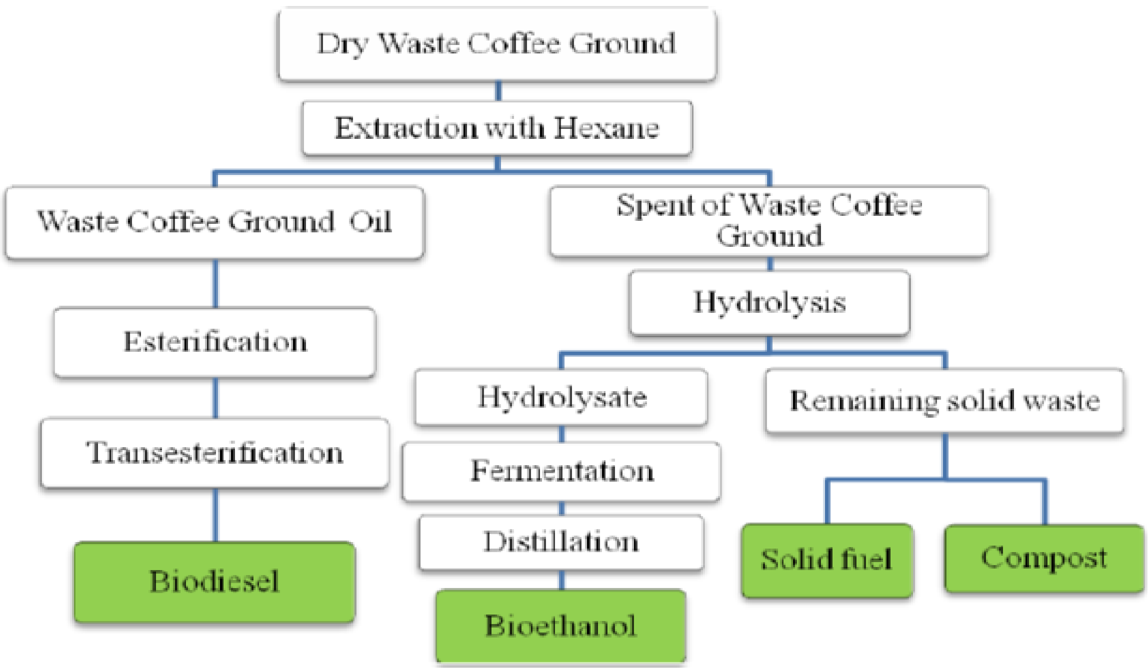

Fig. 1: Schematic representation of the production of waste coffee ground biodiesel that yield high value-added by-products: bioethanol, fuel pellets and compost. Source: Haile (2013).

The first step in the oil extraction procedure is to actually weigh the appropriate amounts of coffee grounds and solvent. A quantity of 300.00 g of waste coffee grounds (collected from the local cafe) and 1500mL of hexane are used and swirling was performed manually to mix the flask's content. The oil extraction time and temperature are then set to 30 min and 70°C respectively, the flask was closed tightly by means of a glass and stopper wrapped with parafilm in order to prevent the solvent from evaporating. The flask was then placed in a bain-marie to ensure a fast and homogeneous heating of the large flask used and oil extracted.

After the oil extraction Vacuum filtration over a sintered funnel was followed and the filtration process continued until the solid present in the oil completely separated over cotton wool. At the end another vacuum filtration over a sintered funnel by using this time a two-neck 1L round bottom flask (the purpose behind using vacuum filtration instead of a gravity filtration is to speed up the process). This filtration went very smoothly.

However, within collected oil the presence of residual hexane was suspected (slight odor of hexane vapors in the oil), so the distillation at 100°C was prolonged and this step actually reduced the yield. For the sake of the oil extra pure, the hexane-free oil obtained in the previous step was centrifuged for 3 min. This resulted the removal of a small, viscous and jelly like fraction and also yield reduction occurred. Finally, brownish liquid oil with a concentrated coffee smell was resulted.

Transesterification was the reaction used for biodiesel production and also followed some basic steps. Chemical reaction between triglycerides, contained oil extracted through series process from SCG and an alcohol (mainly Methanol). Methanol was favored over Ethanol because it is the smallest alcohol which makes it react faster with the triglyceride, less hygroscopic and is more affordable than any other alcohol. Potassium hydroxide was used as the first catalyst as it dissolves much faster than sodium hydroxide. The time and temperature of the reaction was adjusted to 1h and 60°C respectively (Boualdab, 2016).

After the appropriate quantities of each reactant and the catalyst determined, the oil was preheated in a 100mL round bottom flask at a temperature of 60°C in order to reduce its viscosity and improve its miscibility with the methoxide solution. The methoxide solution was prepared by mixing the assigned amounts of methanol and potassium hydroxide in a vial fitted with a stir bar. The vial was then placed in a bain-marie at 40°C over a stirring hot plate to promote and accelerate the solubility of KOH (potassium hydroxide) in methanol.

The methoxide solution is then added to the oil and the reaction mixture is heated at 60°C for an hour under vigorous stirring. Finally, the reaction mixture is transferred to a separatory funnel to separate the layers of biodiesel and glycerin. An extra portion of methanol was poured in the funnel to prevent a quick jellification of the mixture caused by glycerin. As no layer separation occurred, 25mL of hot water was added to the mixture in order to induce the layer separation as glycerin is water soluble while biodiesel is not.

Generally, Boualdab (2016) followed all those procedures and used spent coffee ground collected from cafe having weight of 300g as feedstock and extracted 30.84g of oil which accounted about 10.28% of spent coffee ground which was used as feedstock. The quantity of crude biodiesel was 18.16g which accounted 58.24% of extracted oil, thus 300g of SCG produced 18.16g of crude biodiesel which was 6% of the weight of spent coffee ground.

Similarly, Haile (2013) experimented on the WCG (Waste Coffee Ground) sample supplied from TOMOCA PLC coffee shop (Addis Ababa, Ethiopia). All solvents and analytical grade chemicals were obtained from chemistry department (Addis Ababa University, Ethiopia). WCG collected from TO.MO.CA PLC (Addis Ababa, Ethiopia) was dried in an oven (moisture content 57.6% w/w) and the oil was extracted with hexane using a soxhlet apparatus as described on (Figure 1) and obtained oil yield of 19.73% w/w on dry weight basis.

The variation in oil content may be due to the difference between oil content may be the moisture content of raw material: the water content in the SCG was found to be 62.97% w in the case of Boualdab (2016) which gave 18.16g of crude biodiesel which was 6% of the weight of spent coffee ground or 58.24% on the basis of extracted oil and in the case of Haile (2013) the moisture content of coffee ground sample was 57.6% w/w which gave oil yield of 19.73% w/w on dry weight basis.

Woldesenbet *et al*. (2016) conducted an experiment on mucilage and pulp juice (one barrel, 200 L each) which were collected from Bonga, Teppi, Goma II and Limu Kosa wet coffee processing factories. The collected wastes of coffee were hydrolyzed with different concentrations of sulfuric acid and separately heated at 85, 100 and 115°C for 1 h using oil thermostat. This study has been clearly shown the possibility of producing ethanol from wet coffee waste. The utilization of wet coffee waste as an alternative energy production reduces the environmental pollution and dependence on oil and petroleum in Ethiopia. It also provides alternative energy solutions for small scale holders.

Animal feed: Coffee production and processing for human consumption gives rise to a number of byproducts that may be used as ruminant feeds. These include leaves, pulp from the bean, coffee residues, coffee meal and spent coffee grounds. The fresh fruit of coffee consists of 45% pulp, 10% mucilage, 5% skin and 40% bean. To produce coffee the fruit is processed to free the bean from the pulp, which accumulates in large quantities and is used in some areas as roughage for cattle. The fruit can be processed by either a dry method or by a wet soaking method. The pulp from the dry method is fibrous and rather poor roughage, whereas that from wet processing has much greater feed value. Coffee pulp from the wet method can be fed to lactating dairy cattle at levels below 20% of the diet without affecting milk production (Didanna, 2014).

As the coffee pulp is rich in nutrients, it can be dried and used as animal feeds. Further application, the pulp needs to be treated with $Ca(OH)_2$ as soon as possible to prevent the development of fungi and dried under pressure. Alternatively, the pulp can be mixed with sugar cane molasses or urea and other inorganic substances and put in silos. The silage can be used after 3 weeks and can be stored up to 18 months. However, using coffee pulp as animal feeds is limited due to the cost for drying the pulp sometimes exceeds the gain (Padmapriya, 2013). Similarly, Nueez *et al*. (2015) conducted experiment on dried industrial coffee pulps which will be used as a source of protein for ruminant animals were formulated using carbohydrates (milled corn, corn bran, molasses, alfalfa hay) and fibrous residues (corn stubble, sugar cane mash). From the finding they concluded that dried industrial coffee pulp can be included in diets for ruminant livestock as a source of protein to support meat and milk production.

As they are not recommended, it is possible to reduce the levels of caffeine and tannin waste and by-products of coffee to increase their use in animal feed. Physical (percolation), chemical (alcohol extraction) or microbiological (fermentation) methods may help reducing caffeine content and enhance animal performances (Brand, 2000).

Rahimnejad *et al*. (2015) reported as improved growth performance of olive flounder was observed by dietary inclusion of 5% CG; they used coffee beans roasted at 180–210°C for 15 min and Fish meal was used as the primary protein source and fish oil was used as the lipid source all ingredients were thoroughly mixed with 30% distilled water and pellets were prepared using a laboratory moist-pelleting machine. Fiesel *et al.* (2014) reported that polyphenol rich plant products improve growth performance by influencing the gut micro biota when used as dietary supplements.

Mushroom production: Most of the fungi have strong enzyme and ability of utilizing complex organic compounds which occur as agricultural wastes and industrial by products; Mushroom fungi are also the member of them. Furthermore, agricultural wastes can also be served as bedding material for mushroom cultivation (Baysal and Peker, 2001).

Coffee pulp is used as planting soil for mushroom production. After having fermented for two days, the pulp is pasteurized with hot water, drained, dried, and mixed with mushroom spores, then, they are put in plastic bags. After 3 - 4 weeks, the mushrooms grow out of the holes in the bags and are collected. One bag allows 2-3 mushroom-harvests. The mushroom can be eaten or dried and sold in the market. Considering the large amount of coffee pulp generated every harvesting season, the income from mushroom growing is significant for farmers (Padmapriya, 2013).

Shimelis (2011) studied the cultivation of mushroom (*Pleurotus ostreatus)* on two main substrates namely coffee parchment and coffee husk, supplemented with different agricultural waste (18% Wheat bran and 2% ash, 18% Nug meal and 2% ash, 18% cow dung and 2% ash, 10% wheat bran, 8% chicken manure and 2% ash individually); and achieved good biological efficiency from aerobic composted coffee husk and parchment than fresh substrate. However, as the yield obtained from the control (coffee parchment and husk without any treatment) lower when compared to supplemented substrate, it is important to supplement the media.

Alemu (2013) used about 4 kg of fresh coffee and sholla leaves by mixing thoroughly with 80 g cow dung, ash and water to moisten for production of *P. ostreatus* mushrooms; the result obtained showed, coffee wastes, other agricultural wastes and by-products could be more economical, ecological and can improve food quality and reduce food scarcity.

Summary and conclusion

Coffee is a major plantation crop grown worldwide and is one of the most popular beverages consumed throughout the world. Coffee production and processing for human consumption gives rise to various byproducts include leaves, pulp from the bean, coffee residues, coffee meal and spent coffee grounds that may be used for different purposes, unless managed properly causes risk to environment and other living things. The coffee processing environmental impact are broad and deep throughout the producer and processor. These Impacts can range from water pollution (surface and underground water), bad odors which may result health problems and concentration of toxic elements in soils, which results in decreased land productivity and increased use of chemicals for its solution. Due to these problems, there is the need to alleviate the negative impacts resulted in association with this product. Efforts made innovated different ways of coffee waste utilization as composite, mushroom production, animal feed and as energy source and other means which play great role in environment protection and conservation, food security and increase framer's income as it allows other alternate means of using coffee waste and byproducts.

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