Resources, Conservation & Recycling 128 (2018) 110–117

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Review

# Chemical composition and value-adding applications of coffee industry by-products: A review

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ARTICLE INFO

*Keywords:*
Coffee waste
Coffee by-products
Value-adding applications
Ecotoxicology

ABSTRACT

Processing urban waste is becoming a major challenge, with the current state and forecasted increase in urbanisation. Finding novel approaches to reduce and recycle this waste, using value-adding applications, is paramount if we are to meet the needs of a growing population. Organic waste is of particular concern, as much of this can be treated and recycled for horticulture practices, but most find their final sink in landfill. With coffee now the second largest commodity worldwide, recycling these nutrient-rich by-products could reduce the amount of organic waste sent to landfill, whilst producing value adding products. Some chemical compounds present in these by-products, such as caffeine, tannins and chlorogenic acid are of ecotoxicological concern and can limit their value-adding applications. The aim of this literature review was to 1) characterise the waste obtained from the coffee industry; 2) outline the current value adding applications; 3) highlight limitations that prevent full utilization of coffee by-products and 4) discuss possible solutions that could maximize by-product utilization and ameliorating their negative environmental impacts. It was concluded that full utilization of these by-products is not always achieved, even though there is evidence to support their potential. This was mainly due to a lack of infrastructure and cross-chain networks between applications.

## 1. Introduction

The global population is predicted to rise up to 11 billion by the middle of the century, with around a third of all people concentrated in urban cities and towns (UNDESA, 2014). With this change in population dynamics, we are now faced with the pressing challenge of processing urban waste, requiring a move towards more sustainable practices (Hoornweg and Bhada-Tata, 2012). Organic waste is one of the highest contributors to municipal solid waste (MSW) in Australia, with a high potential for energy recovery from landfill biogas and advanced waste treatment of garden waste, paper and timber (Randell et al., 2014). Although a large proportion of organic waste is recycled, it is still the second highest material category for disposal rates at over 6.0 Mt, suggesting more innovative recovery methods are required to reduce this wastage (Randell et al., 2014).

Globally, coffee is the second largest commodity and produces an estimated 0.5 and 0.18 t of coffee pulp (CP) and husk (CH) respectively per tonne of fresh coffee (Roussos et al., 1995) and six million tonnes of spent coffee grounds (SCG) per year (Mussatto et al., 2011b). According to the International Coffee Organisation (ICO, 2017), annual coffee production increased from 140 to 152 million 60 kg bags since 2010, thus minimizing coffee by-products presents a serious challenge (Fig. 1). Utilizing these by-products as a base or substrate for value adding applications is an effective way to minimize their wastage as landfill.

Current value adding applications include biofuel (Woldesenbet et al., 2016), mushroom (Thielke, 1989), and fertiliser (Hachicha et al., 2012) production, along with enzyme (Battestin and Macedo, 2007), dietary fibre (Ballesteros et al., 2014), and bioactive compound extraction (Murthy and Naidu, 2012a). The feasibility of by-products for particular applications can be limited due to their composition. The presence of phenolic compounds such as caffeine and tannins limits their use in animal feeds due to their anti-nutritional properties (Low et al., 2015). Similarly, the presence of chlorogenic acid limits their application as a plant fertiliser as it is phytotoxic (Franklin and Dias, 2011). Furthermore, there is mounting evidence that these bioactive compounds are of ecotoxicological concern. Developmental, behavioral and morphological abnormalities have been observed in a variety of aquatic organisms due to exposure to caffeine and tannins, including algae, sea urchin and fish (Meriç et al., 2005; Rodriguez et al., 2014; Zarrelli et al., 2014). Chlorogenic acid has negative effects on seed germination and plant growth (Al-Charchafchi and Al-Quadan, 2010).

Bioremediation using solid-state fermentation (SSF) and submerged fermentation are potential methods for detoxifying coffee by-products

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http://dx.doi.org/10.1016/j.resconrec.2017.10.001
Received 21 July 2017; Received in revised form 25 September 2017; Accepted 1 October 2017

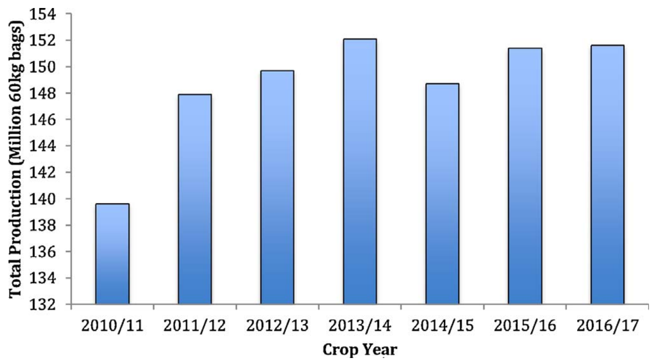


**Fig. 1.** Global coffee production between 2010 and 2017 obtained from the International Coffee Organisation.

while producing value added products such as enzymes (Mussatto and Teixeira, 2010). However, these methods can be costly, require technical expertise and infrastructure for operation. Composting and vermicomposting offer a simple and low-cost solution for detoxifying by-products that maximize their utilization. A study comparing bioaugmented and control mixtures of SCG showed that compost inoculated with a fungal strain (*Tinea versicolor*) displayed a reduction in volatiles, along with an increase in C and N (Hachicha et al., 2012). Similarly, Brand et al. (2000) showed that a strain of *Aspergillus* sp. had high efficiency in caffeine degradation in culture, demonstrating the high potential of microbes in the detoxification process.

There is an urgent need for applications that obtain maximum utilization of coffee by-products, and given the chemical composition of these by-products, this is highly feasible. The aims of this literature review are to 1) characterise the waste obtained from the coffee industry; 2) outline the current value adding applications and chemical composition of each component; 3) highlight limitations that prevent full utilization of coffee by-products and 4) determine the feasibility of by-product utilization and ameliorating their negative environmental impacts.

## 2. Coffee by-products

Coffee cherries are the fruit from coffee plants or shrubs, which belong to the family Rubiaceae. There are two commercially explored species of coffee plants, including *Coffea arabica* (Arabica) and *Coffea canephora* (Robusta), which account for 75% and 25% respectively, of the world's coffee production (Mussatto et al., 2011b). The coffee process begins with removal of the external components of the coffee cherry, either through dry or wet methods, leaving only green coffee beans. The dry method is commonly used for Robusta and produces a husk, while the wet method is mainly used for Arabica and produces pulp as a by-product. The external components include the skin, pulp/husk and silver skin (Fig. 2), with silver skin being the main by-product of the roasting process.

### 2.1. Coffee pulp and husk (CP and CH)

Depending on the processing method, either wet or dry, coffee pulp and husk are the first by-products of the industrial process, and account for 29% and 12% of the overall coffee cherry (dry weight). The amount of coffee pulp and husk produced for a single tonne of fresh coffee is 0.5 and 0.18 t respectively (Roussos et al., 1995). Pulp and husk are rich in carbohydrates, mineral and proteins, however they also contain organic compounds such as tannins, chlorogenic acid and caffeine (Table 1) (Fan et al., 2003).

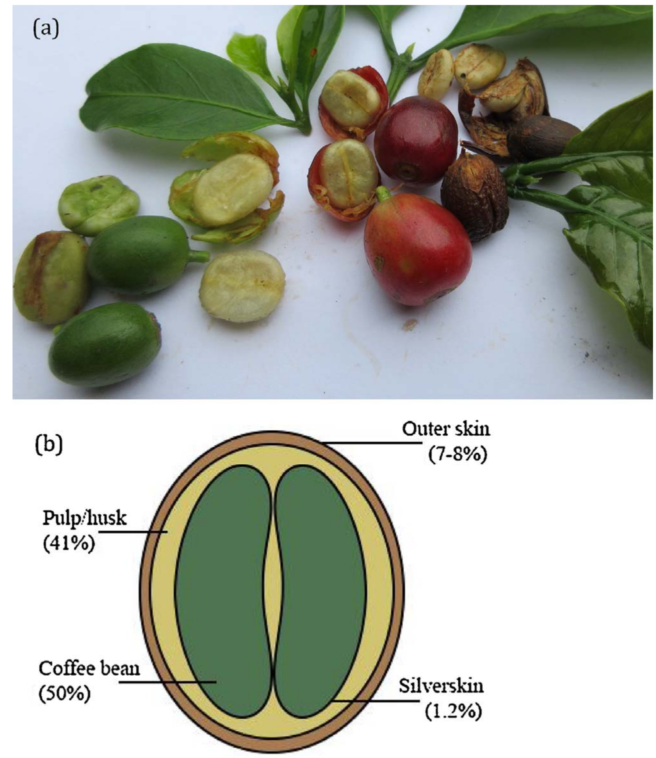


**Fig. 2.** Stages of coffee cherry development from immature fleshy green (left) to dried mature (right) fruits (a) and diagrammatic representation of dried mature fruits showing compositional percent (b). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

### 2.2. Coffee silver skin (CSS)

The second by-product, coffee silver skin, is produced during the roasting process. The CSS is the integument of the coffee bean, and although it accounts for only a small fraction of the total coffee berry (1–2%), it is high in total dietary fibre, antioxidant activity and phenolic compounds (Murthy and Naidu, 2012a). Borrelli et al. (2004) used the gravimetric enzymatic method to determine total dietary fibre (TDF) of 62.4 per 100 g of product, with cellulose and hemicellulose the main constituents (Mussatto et al., 2011b). The composition of CSS indicates dietary fibre and antioxidant adjuncts for food industries as potential value adding applications.

### 2.3. Spent coffee grounds (SCG)

The coffee bean accounts for approximately 50% of the coffee cherry dry weight and produces spent coffee grounds as the final by-product of the coffee industry. SCG are generated during the production of solubilized instant coffee, whereby roasted, ground coffee beans are heat or steam treated to produce a coffee extract for consumption. The residue remaining after extracting is referred to as SCG. Annually, an estimated six million tonnes of SCG is produced worldwide (Mussatto et al., 2011a), with one tonne of green coffee producing 650 kg of SCG (Murthy and Naidu, 2012b). As urban SCG is often separated at the point of drink preparation from other wastes, it is feasible to prevent this from reaching landfill by developing coffee waste removal infrastructure.

## 3. Chemical composition and compounds of ecotoxicological concern

The chemical composition of coffee by-products changes substantially through dry and wet processing, roasting and brewing, with