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The influence of extraction parameters on spent coffee grounds as a renewable tannin resource

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ABSTRACT

Spent coffee grounds that are left behind during the coffee brewing process consist of valuable tannin compounds which makes them ideal material as a renewable tannin resource. For this reason, the concept of cleaner production had been applied in practice and a tannin extraction process with spent coffee grounds as raw material was investigated in the present study. Among the extraction key factors, namely sodium hydroxide concentration, extraction temperature, liquid to solid ratio, and extraction time, the former three factors had exerted a considerable effect on spent coffee ground tannin extraction yield and its reactivity. However, extraction time had only marginal effects which could be simply neglected in the tannin extraction process. These observations imply that spent coffee grounds can be reused as a renewable tannin resource by properly selecting the extraction parameters in order to produce the spent coffee ground tannin with desirable extraction yield and reactivity. By taking both the spent coffee ground tannin extraction yield and reactivity into consideration, the optimum extraction conditions are; 5% sodium hydroxide concentration, 100 °C extraction temperature, 30 min extraction time, and 8.23 liquid to solid ratio, so that tannin with a high extraction yield (21.02%) and high reactivity (29.69%) could be recovered. The present study provides an understanding on the impact of the extraction parameters on isolated spent coffee ground tannin as well as to fill up academic deficiencies in spent coffee grounds, which, in turn, could serve as a reliable guideline for the development of a full-scale, sustainable spent coffee ground tannin extraction process in coffee industries.

1. Introduction

Coffee is one of the most common and popular beverages throughout the world (Daglia et al., 2000). People drink coffee not solely due to its fragrance, but also as a refreshment beverage to energize and work out the brain. With the flourishing development of many well-known international and national coffee chains, drinking coffee has lately became a trend among the younger generation in Malaysia; as a result, consumption of coffee has increased. This statement is supported by the biannual report of the Foreign Agricultural Service, United States Department of Agriculture (USDA), as domestic coffee consumption in Malaysia had achieved 650 thousand bags (60 kg each) in June 2013/14, up by 30% from the previous year.

During the coffee brewing process, a dark brown solid residue with high humidity known as spent coffee grounds (SCG[1]) is produced (Zuorro and Lavecchia, 2012; Mussatto et al., 2011b). It accounts for approximately 6,000,000 tons annually worldwide (Tokimoto et al., 2005). This worthless residue waste is normally simply discarded into dust bins, and finally, sent to landfills. Nonetheless, SCG is highly pollutant due to the presence of caffeine, tannins, and polyphenols that confer a toxic nature to the material, and the presence of organic matter also makes it requires a huge quantity of oxygen to degrade (Mussatto et al., 2011b; Silva et al., 1998). Simultaneously, methane, which is a greenhouse gas and even more harmful than carbon dioxide will also be created in the landfills and contribute to global warming (Crumbley, 2009). Furthermore, if SCG is not properly handled and simply being piled up, fermentation of the residues might cause spontaneous

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[1] Spent coffee grounds.

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combustion, as occurred in some storage sites (Silva et al., 1998). Therefore, instead of ordinary disposal methods, a more sustainable method should be explored for the reuse of SCG, not only to reduce the threat towards the environment, but also as a solution to the management of household and beverage waste.

Brazil is the world's largest coffee producer (Prata and Oliveira, 2007). The processing of coffee contributes a huge amount of agricultural waste to the society (Prata and Oliveira, 2007). During instant coffee production process, only 0.33 kg–0.45 kg of instant coffee is produced from 1 kg of green coffee beans (Acevedo et al., 2013), whereas the remaining residues known as spent wastes contribute up to 45% of the total by-product in the coffee industry (Murthy and Madhava Naidu, 2012). Traditionally, spent coffee grounds are commonly reused as fuel for soluble coffee processing plants in Brazil (Silva et al., 1998). Silva et al. (1998) even point out that the heat value of SCG is similar to coal and higher than wood and other biomass residues such as jute stems, rice husks, coconut fibre, wheat straw, cotton twigs, corn ears as well as sugar cane bagasse.

Nestle, a well-known multinational food and beverage company, also puts environmental initiatives into practice. Currently, there are more than 22 Nestle factories around the world that are using SCG as supplemental fuel and this action has successfully made the company to replace up to 26.7% of energy consumption by using the SCG as renewable fuel resources (Nestlé, 2014). Moreover, as one of many companies in the food service business, Starbucks Coffee Company is also committed to reduce the environmental impact of SCG. This statement is proven by the launching of "Grounds for Your Garden" campaign in 1995, where the complimentary five-pound bags of soil-enriching SCG were distributed to the public for gardening and compost pile as they have high availabilities of potassium, phosphorus, copper, and magnesium, and will give a very positive impact on soil amendment (Starbucks, 2015; Sunset, 2009). Besides that, SCG can also be used as nitrogen resources for gardening, as well as acting as natural herbicides to get rid of weeds and allowing the garden to flourish beautifully (Crumbley, 2009).

Without the use of nutrients supplementation, Leifa et al. (2001) have successfully demonstrated the cultivation of *Flammulina velutipes* by using SCG as substrate in solid state cultivation (SSC). Initially, the moisture content and spawn rate on SSC of SCG were studied in order to determine the ideal cultivation conditions. After that, the study proceeded to the cultivation of *F. velutipes* as well as to analyse the final contents of the substrate. Ideal cultivation conditions were achieved at 55% moisture content and 25% spawn rate. Besides that, the first primodia of fructification occurred 21 days after inoculation and the biological efficiency achieved about 78% with two flushes in 40 days. All of these collecting data obviously show that the SCG has the potential to be utilized as the substrate for cultivation of edible fungus.

Research by Cruz et al. (2012) have studied the use of SCG for lettuce (*Lactuca sativa* L.) cultivation. With the presence of low amounts of SCG (up to 10%) in the cultivation media, higher amount of xanthophylls, β-carotene, and chlorophylls were found in the cultivated lettuce leaves. Similar observations were also obtained on photosynthetic pigments and lettuce plant growth by Gomes et al. (2013). The collected findings even suggested that composted SCG should be applied instead of fresh SCG in order to achieve greater soil mineralisation as well as to increase the uptake of mineral nutrients by the cultivated lettuce plants. Both of these observations are particularly interesting from a nutritional point of view.

Works by Mussatto et al. (2011a), Panusa et al. (2013) and Zuorro and Lavecchia (2013) have focused and highlighted on the use of SCG as a valuable source of natural antioxidants. For this reason, SCG has been subjected to different extraction media and conditions to study its phenolic yield and antioxidant activity in order to identify the ideal extraction method. This idea was even extended by Ranic et al. (2014) where a microwave-assisted extraction method was applied to recover SCG antioxidants rather than using conventional extraction techniques.

The feasibility of recovering phenolic compounds from SCG had also been evaluated by Zuorro and Lavecchia (2012, 2011). By selecting the best conditions, over 90% of phenolic compounds were successfully recovered from the starting waste materials. Moreover, the high calorific value of SCG, even after the phenolic extraction process, further suggested that the remaining solid residue can be used as a renewable energy resource for heating purposes. This integration of phenolic recovery with SCG as solid fuel enabled the discarded SCG to be fully reused, contributing to both environmental protection and energy efficiency.

The direct use of SCG as bio-adsorbent has further expanded the usage of this type of solid waste. In the research work conducted by Azouaou et al. (2010) and Kyzas (2012a), SCG had demonstrated a noticeable performance on the removal of heavy metals such as copper (II) ions (Cu^{2+}), chromium (VI) ions (Cr^{6+}) and cadmium (II) ions (Cd^{2+}) from aqueous solutions. This observation confirmed the applicability of SCG as a low-cost adsorbent for industrial effluent treatment processes. Besides that, SCG is also applicable in industrial textile wastewater treatment. Kyzas (2012b) had evidenced this statement, whereby the decolourisation (Remazol Red 3BS, Yellow gelb 3RS and Brillant Blue RN) of textile wastewater could be carried out by simply adding the SCG. The repeated adsorption–desorption cycles even attested to the strong reuse potential of SCG as dye adsorbent since it could be reused up to ten times without significantly jeopardizing its adsorption performance.

The recovery of other bioactive compounds in SCG has become a subject of exploration for other potential uses of SCG. As evidenced by Acevedo et al. (2013), except for polyphenolic compounds, diterpenes (kahweol and cafestol) and lipids have been successfully recovered from SCG, and the latter compound may have vital applications in cosmetic products due to its high levels of linoleic acid and palmitic acid. Besides that, the production of bio oil from SCG is another proposed application (Chaiya, 2011). The reported findings revealed that the extracted SCG bio oil could be utilised for fuel purposes since it has shown common fuel properties. Moreover, the extracted SCG oil could also be used as the sole carbon source for the production of polyhydroxyalkanoates (PHAs), which, in turn, can be fabricated into a polymer that exhibits similar properties to poly-3-hydroxybutyrate biopolymers (Cruz et al., 2014). In the latest work reported by Tehrani et al. (2015), the production of bioethanol using SCG as raw material had once again proven the potential usage of discarded SCG in bio-fuel industries. These findings indirectly imply that SCG can simply displace nonrenewable fossil fuels and serve as a renewable resource for power generation.

The use of SCG oil in sunscreens and health care applications was introduced by Chiari et al. (2014). Thanks to the high antioxidant activity and phenolic compounds in SCG oil, the synergistic effects of conventional synthetic sunscreen (ethylhexylmethoxycinnamate) and SCG oil have further increased the sun protection factor by 20%. Moreover, *in vivo* results also show that the incorporation of SCG oil has no cytotoxic effect for skin and liver cells. The addition of SCG oil has been expected to decrease the skin cell exposure to ionizing radiation as well as to deactivate reactive oxygen species (ROS) that originated from the metabolism of skin cells or even those created by the radiation that was not blocked. These findings are important to suggest that the SCG is promising natural resources to be used in sunscreen formulations for protection against skin damage and at