Holistic exploitation of spent coffee grounds: recovery of phenolic compounds and use as biosorbent

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Coffee is one of the most widely consumed beverages, the second most popular after water. According to the International Coffee Organization (ICO), coffee consumption would increase from 1.24 million bags of coffee to 169.34 million bags by the year 2019/2020 (ICO, 2019). During the different stages of coffee processing, huge amounts of solid residues (wastes) in the form of coffee pulp, coffee silver skin (CSS), spent coffee grounds (SCG), and coffee husk (CH) are produced (Banu *et al* 2020). SCG is a wet organic material with lignocellulosic structure, containing a high concentration of bioactive compounds, such as polysaccharides, proteins, lipids, aliphatic acids, alkaloids, tannins, and polyphenols (Cruz *et al* 2012; Mussatto *et al* 2011).

According to Murthy *et al* (2012) and Mata *et al* (2018), 1 ton of green coffee beans generates approximately 650 kg of SCG, while 1 kg of soluble coffee leads to the production of 2 kg of SCG. The majority of this waste is still discarded as solid waste in landfills, burned posing a severe environmental threat while sometimes it is used as a feedstock or as fertilizer. Due to its high availability and low-cost, many researchers have focused their efforts on valorization of SCG as adsorbent (Franca *et al* 2009; Kim and Kim 2020), as a valuable substrate for biodiesel production (Caetano *et al* 2013), and as a source of valuable compounds such as polysaccharides (Simões *et al* 2013), phenols (Mata *et al* 2018), tannins (Banu *et al* 2020; Choi and Koh (2017); Low *et al* 2015) etc.

The aim of this study is the revalorization of spent coffee grounds and the recovery of valuable components, turning SCG into an economical material for the recovery of bioactive compounds. Conventional recovery methods, such as solvent extraction, are time-consuming and require high quantities of solvent and energy. Thus, several studies on the development and the usage of environmentally friendly recovery methods have been carried out based on their appealing characteristics, such as lower solvent and energy consumption, shorter extraction time, and higher recovery yield. For this purpose, two extraction techniques (microwave-assisted extraction, MAE and ultrasound-assisted extraction, UAE) have been selected and used in comparison with conventional maceration extraction, CME. In ultrasound-assisted extraction, extraction temperature (20-60 °C), solvent type (0-100% aqueous ethanol), amplitude level (20-60%), and solvent/solid ratio (8-24 mL/g) were the factors investigated with respect to extraction yield. In the case of microwave extraction, the effects of solvent type (0-100% aqueous ethanol), solvent/solid ratio (8-24 mL/g), and microwave power (100-600 Watt) were studied using a response surface methodology. The optimum extraction method and operating conditions were determined.

Finally, another objective of the present work was to study the enhancement of the optimum extraction procedure by enzymatic pre-treatment using two different enzymes, cellulase and pectinase, under different operating conditions (enzyme concentration, 2-4% w/w; treatment time, 60-220 min; water/solid ratio, 2/1-6/1 mL/g).

Treated SCG, after extraction, can potentially be used as a biosorbent for the recovery of valuable compounds from other food industry wastes, aiming to a holistic exploitation of SCG. Many researchers have focused their efforts on optimizing adsorption by development of novel low-cost adsorbents with high adsorptive capacity. Application of food waste materials is gradually becoming of great concern, because these wastes are unused resources and can cause serious disposal problems. Thus, another purpose of this work is to investigate the efficiency SCG after recovery of its phenolics as biosorbent for removal of phenolic compounds from olive mill wastewater. Olive-mill wastewater (OMW) is a characteristic by-product of olive-oil production and a major environmental problem in the Mediterranean area, because of its high and toxic organic load. Only recently, in relation to the major interest for the natural compounds with biological activities, researchers have begun to consider the recovery of polyphenols, as high value compounds, transforming OMW from effluents to raw material with high potential economic value. It was proved that polyphenols are substances with biological activity (antioxidative, antimicrobial etc.), which can be used in numerous applications in the pharmaceutical, cosmetics, and food industries. Many studies on the recovery of polyphenols from OMW are conducted on small scale and several techniques are used individually or in combination. Among them, physical adsorption method is generally considered to be the best effective, low cost, and most frequently used method for the removal of phenolic compounds.

Thus, after extraction, the solid residue of the filtration was dried and passed through sieves. Initially, batch experiments took place, in order to determine the optimum adsorption conditions, investigating the equilibrium time and afterwards the effects of various parameters.

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