Supercritical Fluid Extraction as a Green Extraction

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Extraction is a technique of isolating components from natural materials using chemical or physical methods. The world has turned to using green extraction as part of its efforts to preserve the environment. Green extraction is based on procedures that require less energy, allow for the use of alternative solvents and sustainable natural resources, and offer a safe and high-quality extract. Supercritical fluid extraction (SFE) procedures are compatible with the principles of green extraction.

supercritical fluid extraction natural pigments

1. Introduction

The use of sustainable natural products has become increasingly important in response to the growing awareness of the adverse effects of synthetic products on the environment [1]. Therefore, it is necessary to choose suitable extraction methods and conditions to obtain excellent extraction yields for natural products. Natural colorants, extracted from plants, animals, insects, and minerals, are bioresources for pigments and dyes with no negative environmental effects. Natural colorants have grown in acceptance as a result of their coloring qualities and health-promoting benefits, in addition to their low cytotoxicity compared with synthetic colorants [[2],[3]]. These colorants can enhance the antimicrobial properties of textiles [4][5][6][7][8][9]. Natural pigments such as anthocyanins, carotenoids, and chlorophylls show outstanding antimicrobial activity against various pathogens, including different bacterial and fungal strains. These natural colorants exhibit a high potential for applications in various fields, particularly textiles, the food industry, and pharmaceuticals [10][11][12][13][14][15].

One of the most crucial processes in the production of natural colorants is pigment extraction [16]. The initial step of the extraction process is to separate the crude pigment from the starting material. In plant materials, most bioactive molecules are located inside plant cells that are enclosed with a pectocellulosic wall comprising a complex of cellulosic structures that consist of sugar alcohols and ether linkages between carbohydrates and proteins and is also strengthened by lignin [17]. Plant material can be extracted using various methods. Traditional techniques such as maceration and Soxhlet extraction are typically used [16]. Recently, nonconventional techniques such as pressurized liquid extraction (PLE), microwave-assisted extraction (MAE), ultrasound extraction (UAE), pulsed electric fields extraction (PEFE), and supercritical fluid extraction (SFE) have allowed for the use of alternative solvents while ensuring a safe, cost-effective, and high-quality extraction [18][19]. Compared with traditional procedures, the extraction methods described above are preferable. These nonconventional methods can function in the absence of light and oxygen at high temperatures or pressures, with minimal organic solvent use and short extraction times. The main difficulties with traditional extraction methods are their extended extraction times, expensive toxic solvents, limited selectivity, and heat breakdown of thermally labile chemicals. These restrictions can be overcome using nonconventional extraction methods [20]. Therefore, it is necessary to select a suitable extraction method and conditions to obtain an excellent extraction yield for natural products. A suitable extraction technique helps to increase the extraction yield and prevent the degradation of extracted pigments, leading to the production of natural colorants of higher quality [16]. The SFE method has several advantages that make it a promising green alternative. This technology may provide nontoxic solvents that can be easily removed from the extract, with a low extraction temperature, high recovery of bioactive compounds (particularly for the extraction of heat-sensitive colorants), rapid mass transfer, excellent selectivity, continuous flow of fresh fluid, and scale-up for industrial processes [21]. Therefore, the extraction of natural antimicrobial dyes and pigments using SFE has attracted the interest of researchers. In addition, the optimization of SFE conditions is necessary to enhance the technique's extraction efficiency. In this respect, several SFE parameters, such as flow rate (FR), particle size (PS), temperature (Temp), time (T), pressure (P), sample weight (SW), and co-solvent ratio and type, can be optimized to enhance the overall extraction using supercritical fluids (SCFs). In addition, the SFE system involves the use of a supercritical fluid (SCF) (typically carbon dioxide (CO_2), which has supercritical properties higher than 31.1 °C and 7.38 MPa) to isolate the target compounds under optimal operating conditions [22][23][24].

2. Green Extraction

Extraction is a technique of isolating components from natural materials using chemical or physical methods. Recently, the world has turned to using green extraction as part of its efforts to preserve the environment [25][26]. Green extraction is based on procedures that require less energy, allow for the use of alternative solvents and sustainable natural resources, and offer a safe and high-quality extract. SFE procedures are compatible with the principles of green extraction. It is considered the most effective alternative for traditional solvent extraction methods of bioactive substances, especially when supercritical carbon dioxide ($scCO_2$) is used as the green solvent. The six principles of the green extraction of natural products are as follows [27][28][29]:

(a) Innovation through using sustainable plant resources

Green extraction requires either intense culture or in vitro development of plant cells or organisms to protect natural products from extinction. Natural colorants can be obtained from natural resources such as plants, animals, and fungi, but in a manner that preserves the rights of future generations.

(b) Use of alternative solvents, principally water and safe solvents

Using the SFE technique, the active components can be produced without any solvent residue. CO_2, which is frequently used in the SFE method, is a nonflammable odorless gas formed when fossil fuels are burned, alcohol is fermented, and during human and animal respiration. The SFE technique uses compressed supercritical CO_2 ($scCO_2$) at a pressure of up to 300 MPa and a temperature of 30 to 40 °C to replace organic solvents such as hexane in the extraction process.

(c) Reduced energy consumption by energy recovery using innovative technologies

Extraction is affected by economic and environmental issues, which require a drastic decrease in energy consumption and waste production. Compared with traditional extraction techniques, the SFE method is a rapid extraction. Further steps are not required to save time or energy.

(d) Production of co-products instead of waste to include bio- and agro-refining industries

Extraction operations produce a wide variety of additional materials such as co-products, by-products, or waste. According to the biorefinery concept, plant materials are used in an integrated manner. Plants contain various refined compounds. Each component of a plant can be isolated and used to produce a variety of products. The SFE procedure at low temperatures allows for the discovery of new compounds that enhance the value of the extract by producing co-products that can be functionalized.

(e) Reduced unit operations and safe-controlled processes

Reducing the number of stages in a production chain lowers costs and makes better use of the energy. The optimal procedure appears to be a single-stage process. Supercritical fluid extraction has the benefit of using a clean solvent and producing an extract using technology with a minimal number of discrete operations.

(f) Nondenatured and biodegradable extracts without contaminants

The extract must adhere to all the laws, regulations, quality standards, and market demands. In addition, the extract guarantees no harm to humans or the environment. According to this principle, the SFE technique protects thermally labile target compounds. In addition, the SFE extract has no solvent residue, making it highly pure.

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