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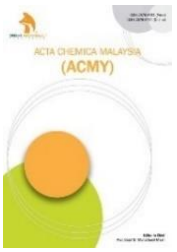

RESEARCH ARTICLE

ULTRASONIC ASSISTED ENZYME EXTRACTION IN PLANT EXTRACTION: BIOACTIVE COMPOUND

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ABSTRACT

The application of bioactive components in modern industries has increased dramatically. Consumers' rising awareness of health and well-being has induced industries such as food, nutraceuticals, cosmetics, and pharmaceuticals to develop products containing bioactive ingredients. The increased demand led to researching other sources for extracting and incorporating the bioactive substances. Ultrasonic enzymatic extraction has developed a highly effective approach for extracting bioactive compounds from plant sources. This novel methodology combines the advantages of ultrasonic waves with the specificity and selectivity of enzymes, providing a promising alternative to existing extraction methods. Although efficient in producing better yields, ultrasonic extraction has met certain limitations, which cause heat generation and high energy consumption. The ultrasonic process can generate heat, potentially leading to the degradation of heat-sensitive compounds during extraction. This review focuses on the properties of ultrasonic enzymatic extraction on bioactive compounds, including the effect of enzymes on ultrasonic extraction and its potential in industries. This study briefly describes the development of this integration method and the application of ultrasonic-assisted enzymatic extraction across sectors in various fields. In the future, more recognition should be given to ultrasonic-assisted enzymatic extraction to enhance production efficiency.

KEYWORDS

Awareness, enzymatic extraction, onsumption, pharmaceuticals

1. INTRODUCTION

Bioactive components are used in various sectors to create better and healthier foods, medicines, and innovative nutritional products. This trend shows that recognition of bioactive comprehensive benefits improves overall health. The demand for bioactive ingredients continues to accelerate, driven by consumer preferences for natural, functional, and health-enhancing products. In recent years, the reaching out of unconventional extraction methods that employ both efficient and environmentally friendly products has caused several conventional techniques, such as maceration, solvent extraction, soxhlet extraction, and distillation, to have drawbacks. However, these traditional methods have long been used for bioactive compound extraction, known as established techniques, to isolate specific compounds from the sources. However, their efficiency has limitations in terms of effectiveness and environmental consequences. Steam distillation, for example, is well known for extracting volatile compounds and essential oil but is unsuitable for non-volatile and polar compounds.

In contrast, Soxhlet extraction can effectively extract nonpolar compounds but consumes a huge amount of solvent and extraction time (Stephane et al., 2021). In the past few years, a more effective extraction technique that can express the limits of conventional methods has emerged, resulting in the development of a variety of unconventional extraction techniques, such as supercritical fluid extraction, microwave-assisted extraction, ultrasonic-assisted extraction (UAE), and enzyme-assisted extraction (EAE). These highly selective approaches can extract particular target compounds, enhancing extraction yield while lowering extraction time and environmental effects (Bitwell et al., 2023).

Bioactive compounds are precious components in the manufacturing industry. The demand for bioactive compounds is expanding rapidly due to the constant development of industries. Innovative action to fulfill the demands has resulted in outstanding improvements in the bioactive compound extraction methods. Ultrasonication is a leading technique commonly used to accelerate the extraction of bioactive compounds from various sources, especially plants. The cavitation force generated by the mechanical process that operated with high-frequency sound waves led to the formation and collision of microbubbles within the extraction solvent. The shear forces that occur during the process disrupt the cell wall and increase the mass transfer between matrix and solvent (Shen et al., 2023). Increasing mass transfer between the sample and solvent can enhance the extraction process.

The existing UAE method is proven to be highly worthy as an extraction technique that can enhance the extraction process, increase the efficiency and selectivity of specific compounds, and decrease solvent use. However, the imperfection of UAE has been reported due to the degradation of certain compounds and physical damage to the cell during the extraction process (Singla and Sit, 2021). The stability and characteristics of products are necessary for bioactive compound production industries to maintain consumer demands and product quality. With the current issues of the UAE technique, including the operating cost of large-scale production, an innovation of the existing process must be considered to sustain the

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efficiency of the extraction process. Enzyme-assisted extraction distributes possibilities to improve the extraction process efficiency by integrating ultrasonication and enzyme treatment techniques.

Enzyme extraction is a technique that uses a specific type of enzyme to help the cell wall degradation and release the intracellular component. The high selectivity properties of the enzyme-subtract extracting process increase the extraction yield, minimize the physical damage, and preserve the sensitive compounds because the process operates under ambient pH and temperature. In the enzymatic method, the enzyme used is selective based on the properties of the target compounds. The specific enzyme can selectively degrade the structural cell wall efficiently and release intracellular compounds into the extraction solvent more effectively. With high selectivity, mild extraction conditions, and environmental sustainability properties, enzyme-assisted extraction is a flexible and effective method for extracting bioactive substances from natural sources (Streimikyte et al., 2022). It helps create value-added products with improved functionality and finds uses in various industries, including biotechnology, food and beverage, medicines, nutraceuticals, and cosmetics. Ultrasonic-enzymatic extraction combines a dynamic mechanism with the cavitation power of ultrasonication and the specificity of enzymes to enhance the release of bioactive compounds embedded in complex matrices.

2. Effect of Enzyme on Ultrasonic Extraction

Ultrasonic-enzymatic extraction is a new integration method of the modern extraction process. The fundamental part of integration extraction is the cavitation phenomenon of the ultrasonication that is generated from the high frequency of the ultrasonic sound wave. During the extraction, massive power in kHz is involved, creating tiny bubbles, which are microbubbles and wave into the matrix. The bubbles kept forming and collapsing, and a huge amount of energy was released during collapsing. The energy produced creates a shear force that breaks the molecule's connection and weakens the bonds. The dispersion of particles occurs and allows the solvent penetration into the matrix. The movement of these bubbles creates intense shear forces and localized heating, facilitating the breakdown of cell structures and the release of intracellular components. In addition to cavitation, ultrasonication induces microstreaming, which refers to the rapid movement of solvent molecules near the sample's surface. This convective flow enhances the transport of solutes away from the solid matrix, promoting their dissolution and diffusion into the solvent. Microstreaming contributes to the homogenization of the extraction medium and ensures efficient contact between the solvent and the target compounds (Collis et al., 2010).

Enzyme-assisted extraction (EAE) was categorized as green extraction as it offered safety and green, so it had the minimum environmental effect. Some of the most common enzymes were cellulase, hemicellulase, and pectinases. The enzymes were usually obtained from microorganisms such as fungi, bacteria, and protozoa. The enzyme extraction mechanism was specific because of the high degree of enzyme selectivity. In the ultrasonic enzymatic extraction process, the enzymatic treatment with suitable enzyme concentration and under appropriate temperature and pH was done before continuing with ultrasonication. The principle of enzyme extraction relied heavily on the hydrolysation of the cell wall, which would disrupt the cell integrity and, thus, release the content easily (Gardossi et al., 2010). Enzymatic treatment involves the catalysis of enzymes to break complex biomolecules such as proteins, lipids, and polysaccharides into smaller fragments that are soluble in solvents. Enzymes can enhance solvent accessibility to bioactive compounds within the matrix after breaking down the cell structure. Therefore, the ultrasonication process can operate with high frequency in a shorter time, so the rise of high temperature can be avoided, the degradation of heat-sensitive compound issues can be reduced, and the yield efficiency of bioactive compounds can be increased. As reported, the integration method has shortened the extraction, decreased the requirement for solvent threefold, and lowered the operating temperature by 10 °C, which also resulted in a higher yield (Balasubramaniam et al., 2019; Li et al., 2017; Lin et al., 2023).

3. Advantages of Ultrasonic Enzyme-Assisted Extraction

This integrated approach combines the disruptive forces of ultrasonic waves with the substrate specificity of enzymes to improve extraction efficiency, selectivity, and speed. The extraction process can enhance the cell wall degradation for better exposure of components and solvents. Enzymes can selectively target and break down specific cell wall components, assisting the release of intracellular bioactive compounds. While ultrasonication promotes mass transfer and disrupts cell structures, facilitating the diffusion of enzymes and solvents into the matrix, resulting in more efficient extraction, the synergistic effects can lead to significantly higher extraction yields than single techniques. Combining those treatments can reduce the extraction time by accelerating cell structure breakdown and enhancing target compounds' solubilization. Enzymes catalyzed the hydrolysis of cell wall components, making intracellular substances more accessible, while ultrasonic vibrations allow them to disperse into the extraction solution. This effect allows for faster extraction kinetics, increasing throughput and productivity in industrial applications.

The most significant advantage of this extraction procedure is the preservation of the extracted compound's bioactivity. The process was conducted under normal conditions, which reduces the risk of thermal degradation and denaturation of sensitive compounds. It can preserve the compound's properties and ensure the final product's quality. Lastly, environmental impact can also be minimized because both processes are considered environmentally friendly extraction procedures, as they operate under moderate conditions and do not require harmful substances or high temperatures. The integrated method encourages sustainability and green processing practices by lowering solvent consumption, energy consumption, and processing time. Furthermore, the use of enzymes generated from renewable sources and the possibility of solvent-free extraction improve the process's eco-friendliness.

4. The Ultrasonic Enzyme-Assisted Extraction Potential in Industries

Due to its incredible ability to obtain high-quality bioactive compounds, ultrasonic enzyme-assisted extraction has massive potential for various industries, especially in production and manufacturing industries such as pharmaceuticals and nutraceuticals. Both industries utilized numerous types of bioactive compounds in large amounts to produce natural products and dietary supplements that contained antioxidant, antimicrobial, anti-inflammatory, anti-aging, and other health-related products (Michalak, 2022; Peluso et al., 2017). Ultrasonic enzymatic extraction can efficiently extract most bioactive ingredients, including vitamins, minerals, drugs, and other nutrients, from various resources such as fruit, plants, and vegetables. Most of the extracted ingredients can increase the products' nutritional content and bioactivity, providing benefits such as improved immunity, cardiovascular health, and cognitive performance (Samitya et al., 2021).

Then, ultrasonic enzymatic extraction has excellent potential in the food and beverage industries due to the food industry's continued development, and the demand for nonthermal and green technologies is approaching (Mehta et al., 2022). This technology can reduce time and energy consumption because bioactive compounds such as food flavoring, natural coloring, and additives are necessary substances in these industries (Nieto, 2020). The cosmetic and dermatology industries also show a great future for ultrasonic enzymatic extraction approaches. Natural resourced products with high purity and quality are in demand, especially skincare and personal care products. The natural ingredients are commonly plant-based and can be extracted from herb and botanical plants containing flavonoids, Vitamins, and polyphenols that act as antioxidants and help nourish the skin (Rudrapal et al., 2022).

Some of the bioactive compounds, such as phenolic and essential oil, can also act as preservatives and antimicrobials that can increase the product shelf life and reduce the use of synthetic or chemical preservatives such as paraben and sodium sorbate that are harmful to skin cells for long term used (Glaz et al., 2023; Villalobos-Delgado et al., 2019). By extracting natural ingredients with increased purity and sustainability, this extraction method can help develop a safe, effective, and eco-friendly method that satisfies consumer desire. In conclusion, Enzyme-assisted extraction of bioactive compounds from plants offers environmentally friendly, potential value for the food and nutraceutical industries (Puri et al., 2012).

The table below highlights common bioactive compounds used in various industries, their natural sources, and their primary bodily functions (Ampofo and Ngadi, 2022). Additionally, ongoing research continues to uncover new bioactive compounds and elucidate their potential health benefits, further expanding our understanding of their roles in human health and nutrition.

Bioactive compound	*Sources*	*Function*
Polyphenols	Fruits, Vegetables, Tea, Wine	Antioxidant, Anti-inflammatory, Cardiovascular health, Anti-aging (Serino and Salazar, 2018)
Flavonoids	Fruits, Vegetables, Cocoa, Red wine	Antioxidant, Anti-inflammatory, Immune support, Neuroprotection (Lee et al., 2020)
Omega-3 Fatty Acids	Fish, Algae, Flaxseeds, Walnuts	Cardiovascular health, Brain function, Anti-inflammatory (Laye et al., 2018; Wall et al., 2010)
Carotenoids	Fruits, Vegetables, Carrots, Spinach	Vision health, Antioxidant, Skin health (Junji and Terao, 2023)
Vitamins (e.g., Vitamin C, Vitamin E)	Fruits, Vegetables, Nuts, Seeds	Immune support, Skin health, Antioxidant, Wound healing (Pullar et al., 2017)
Phytoestrogens	Soybeans, Flaxseeds, Whole grains	Hormone balance, Bone health, Menopausal symptoms (Lagari and Levis, 2014)
Prebiotics	Chicory root, Garlic, Onions	Gut health, Probiotic support, Digestive health
Probiotics	Yogurt, Fermented foods, Supplements	Gut health, Digestive balance, Immune support
Peptides	Milk, Eggs, Legumes, Seafood	Muscle building, Skin repair, Antimicrobial (Nakatsuji and Gallo, 2012)
Essential Oils	Herbs, Spices, Flowers, Citrus fruits	Aromatherapy, Skin care, Stress relief, Antimicrobial

5. Conclusion

The literature study suggests that ultrasonic enzymatic assisted extraction can accelerate the bioactive compound extraction, increase the production yield, and maintain the quality and stability of the bio-ingredients. This integration method also has the potential to be attracted as a great deal to improve bioactive compound production in various industries. This paper discusses the extraction of bioactive compounds to improve the extraction process's effectiveness. In conclusion, ultrasonication-assisted extraction is an adaptable method for extracting bioactive chemicals from natural sources. This approach uses ultrasound's mechanical properties and enzyme specialty, providing speedy, efficient, and environmentally friendly extraction solutions within various sectors.

In terms of developing this new method, some obstacles must be addressed to maintain its performance and increase efficiency, especially in large-scale production. Firstly, optimizing the parameters during the extraction process must be determined and maintained. The least significant condition can affect the enzyme activity and lessen the cell intracellular cell form matrix process to the solvent. Next, different types of matrices and bioactive compounds extracted probably have different development methods. The method is basically based on the type of cell that needs to break down the properties of targeted bioactive compounds. Lastly, the challenge that needs to be addressed is the processing cost and the plan complexity. Implementing this integration technique requires specialized equipment to deliver high-frequency waves for massive production. The industrial scale of ultrasonic systems often involves sophisticated control systems to manage parameters such as frequency, power, and treatment time. Instead of the challenges, continued research and innovation in ultrasonication-assisted extraction can open new avenues for sustainable production, value addition, and product development in the natural goods product industries.

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