Extraction Functional Ingredients from Jackfruit

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Contributor: Veronica Rodriguez-Martinez, Tomás García-Cayuela

Various studies in the literature showed the effect of conventional and non-conventional extraction methods to obtain jackfruit functional ingredients; among the non-conventional methods, some use emerging technologies to extract or as a pre-treatment. Among the studies using conventional extraction, applying solvents such as methanoland oxalic acidstands out, as well as the extraction with hot water. Regarding extraction by emerging technologies, radio frequency-assistedand supercritical fluid (SFE) with CO2extractions have attracted attention owing to their less negative impact on the environment and safety of the final product obtained in comparison with other methods using non-conventional technologies.

Keywords: jackfruit ; jackfruit processing ; by-products ; extraction methods ; phenolic compounds ; pectin ; emerging technologies ; innovative technologies ; functional ingredients ; bioactive compounds

1. Introduction

The most-reported bioactive compounds in jackfruit are phenolic compounds [1] and carotenoids [2]. However, there is evidence of other functional ingredients such as prebiotics including indigestible polysaccharides and oligosaccharides [3][4]; pectin [5]; minerals such as Ca, Fe, K, Mg, and Na [6]; essential fatty acids (EFAs) such as alpha-linoleic and linoleic [7]; and other fatty acids such as palmitic, oleic, stearic, myristic, lauric, capric, and arachidic acids [8], among others. Jackfruit functional ingredients are of great interest owing to their possible applications in the food and pharmaceutical industries, specifically for their health-related benefits. However, these components are not necessarily present in a high amount in jackfruit [9]. For those reasons, there has been an increasing interest in finding strategies for their extraction, especially those focusing on using innovative and emerging technologies.

Various studies in the literature showed the effect of conventional and non-conventional extraction methods to obtain jackfruit functional ingredients; among the non-conventional methods, some use emerging technologies to extract or as a pre-treatment. Among the studies using conventional extraction, applying solvents such as methanol [10] and oxalic acid [11] stands out, as well as the extraction with hot water [12]. Regarding extraction by emerging technologies, radio frequency-assisted [13] and supercritical fluid (SFE) with CO_2 [14] extractions have attracted attention owing to their less negative impact on the environment and safety of the final product obtained in comparison with other methods using non-conventional technologies. Regardless of the extraction method, the yields of a particular functional compound will vary depending on the jackfruit tissue utilized for the extraction; the most common selected tissues for this process are peel and seeds, by-products generated from the fruit consumption.

The limited utilization of pericarp and other inedible parts of the jackfruit makes them a source of contamination [15]. Agro-industrial by-products such as peels, seeds, and residual fruit pulp can be a good natural source of antioxidants such as phenolic compounds [16]. Antioxidants include bioactive compounds capable of counteracting the damage of oxidation processes in the body by assisting chemical reactions [17]. Hence, applying emerging technologies in new processes to transform the jackfruit by-products is useful to obtain functional ingredients or components and may help stop the negative impact on the environment.

The purpose of this publication is to review the following: (1) the most relevant functional ingredients in the jackfruit tissues and by-products; (2) the impact of conventional extraction and assisted extraction by emerging technologies in the functional ingredient yield; and, finally, (3) the functionality and applications of those functional ingredients.

2. Bioactive Compounds of Jackfruit

Regarding fatty acids, Chowdhury et al. [8] reported a total amount of fatty acids of 31.9 mg per 100 g of petroleum ether extract (105 mg per 100 g of whole fruit) in the edible part (fertilized fleshy perianths) of jackfruit.

Jackfruit seeds have many bioactive compounds such as polyphenols, and within these, mainly phenolic acids, flavonoids, and stilbenes [18]. Depending on the extraction technique used, those compounds might present variations in their chemical composition or bioactivity [14]. Kumoro et al. [1] reported values for polyphenols (243 ± 27.0 mg of gallic acid equivalent (GAE)/100 g dry seeds), flavonoids (2.03 ± 0.06 mg EC/100 g dry seeds), tannins (0.06–0.229 mg/100 g of seed), ferulic acid (0.216 mg/100 g of seed), and gallic acid (1.105 ± 0.1 2 mg/100 g of seed).

Some studies reported the oils present in jackfruit seeds. The main fatty acids present are linoleic and linolenic acid [1]. Nagala et al. [19] evaluated the oils' fatty acids composition and antioxidant potential in five different jackfruit species. Their study found jackfruit to be a good source of essential fatty acids (EFAs) with a notable antioxidant activity; higher percentages were observed in the DPPH test for Artocarpus integer (98.4 ± 0.2% of inhibition/50 μL), followed by Artocarpus integrifolia (98.2 ± 0.3% of inhibition/50 μL) and Artocarpus heterophyllus (87.4 ± 0.2% of inhibition/50 μL). Additionally, the seeds are good sources of minerals, such as potassium, which has the highest concentration (2470 ppm), followed by calcium, magnesium, and sodium; the seed's kernel contains 148.50 ppm of iron [1]. Jackfruit seeds also contain 400 mg/g extract of non-reducing sugar, a potential prebiotic ingredient [4].

According to Zhang et al. [10], jackfruit peel extracts have a higher total phenolic content and total flavonoids than extracts from pulp, seeds, and flakes. These authors reported 48.04 mg GAE/g DM and 2.79 mg of quercetin equivalents (QE)/g DM, respectively [10]. Sharma et al. [20] reported that the jackfruit shell is a potential source of β-carotene, ascorbic acid, and polyphenols such as catechin and chlorogenic acid; the amounts found of phenolic and flavonoids were 158 ± 0.34 mg GAE and 10.0 ± 0.64 mg CE, respectively. Finally, Chowdhury et al. [8] reported a total amount of fatty acids of 34.3 mg/100 g of petroleum ether extract (12.6 mg/100 g of whole fruit) in the outer rind of jackfruit.

3. Methods Used in the Extraction of Functional Ingredients from Jackfruit

Research performed using conventional technologies to extract jackfruit functional ingredients focused on phenolic compounds, pectin, jacalin, and prebiotics. The majority of the studies in the literature utilized jackfruit by-products instead of the edible part, mostly to give them added value and reduce their environmental impact [21]. Additionally, this approach allows using all parts of the fruit, which means a lower economic cost to obtain the matrix or raw material for the extraction [11]. **Table 1** presents some of the reported works comparing the yields obtained from different extraction methods, solvents, and processing conditions.

Table 1. Conventional extraction of functional ingredients from jackfruit parts.

Part	Technique	Extraction Conditions	Functional Ingredients and Yields	Ref.
Pulp	**Alkaline hydrolysis**	**2.00 g of sample mixed with 8.00 mol/L of NaOH, liquid-solid ratio of 20 mL/g, and extraction time of 4 h.**	**Non-extractable polyphenols64.90 mg GAE/10 g DM**	[22]
	Acid hydrolysis	**2.00 g of sample mixed with 9.00% of H_2SO_4, liquid-solid ratio of 20 mL/mg, and extraction time of 4 h.**	**Non-extractable polyphenols21.80 mg GAE/10 g DM**	
	Enzymatic hydrolysis	**2.00 g of sample mixed with 2.40 mg/mL of cellulase and pectinase at mass ratio 2:1, liquid-solid ratio of 20 mL/g, and extraction time of 90 min.For all hydrolysis in this section, pH 2.00 and centrifuged at 2795× *g* for 15 min. Ethyl ether/ethyl acetate (1:1, *v*/*v*, 30 mL) was used to extract supernatant three times.**	**Non-extractable polyphenols25.00 mg GAE/10 g DM**	

Part	Technique	Extraction Conditions	Functional Ingredients and Yields	Ref.
Seed	Conventional solvent	(1) Phenolics were extracted with a solid–solvent ratio of 2.50:25.00 g/mL at 30 min in 95.00% ethanol concentration.	(1) Total phenolic content: 122.17 ± 0.41 μg GAE/mL Total flavonoid content: 0.47 ± 0.02 mg CE/mLCondensed tannin: 0.34 ± 0.08 mg CE/mL	[18]
		(2) Prebiotics were extracted at 60 °C, extraction time of 15 min, and L/S ratio at 10:1(*v/w*) using 50.00% ethanol as a solvent.	(2) Average extraction yield: 20.25%Average non-reducing sugar: 400 mg/g extract	[4]
	Reverse micellar extraction	Sodium bis(2-ethylhexyl) sulfosuccinate (AOT)-based reverse micellar system. Aqueous phase pH 4.58, 125.00 mM NaCl and 40.00 mM AOT, 300 rpm for 20 min at room temperature.	Jacalin yield: 88.04 ± 1.30%	[23]
	Enzymes	Phenolics were extracted by dissolving 2.50 g of dry powder sample in 50 mL of 0.10 M phosphate buffer (pH 4.00) according to a solid/liquid ratio of 1:20 (g/mL) and adding an aqueous enzyme solution (Viscozyme® L).	Total phenolic content: 10.54 ± 1.41 mg GAE/g DM Total flavonoid content: 0.19 ± 0.03 mg QE/g DM	[21]
	Hot water	Phenolics were extracted by weighing out 0.50 g of powdered material and extract with 25 mL of distilled water by placing it in a boiling water bath at a temperature of 90 °C for 5 min.	Total phenolic content: 41.65 ± 13.95%	[12]
	Pressurized hot water	Phenolics were extracted by mixing 10.00 g of dry powder samples with 200 mL of distilled water in a 1000 mL pressure cooker according to a solid/liquid ratio of 1:20 (g/mL).	Total phenolic content: 7.02 ± 0.39 mg GAE/g DM Total flavonoid content: 0.48 ± 0.13 mg QE/g DM	[21]
	Maceration	Phenolics were extracted by placing 50.00 g of sample in 200 mL of ethanol for 196 h with daily manual stirring at room temperature (25 °C).	Total phenolic content: 1.892 ± 0.009 mg GAE/g	[14]
	Soxhlet	Recycle 150 mL of ethanol over 5.00 g of sample in a Soxhlet apparatus for 6 h.	Total phenolic content: 12.075 ± 2.131 mg GAE/g	[14]
Peel	Conventional solvent	(1) Phenolics were extracted by dispersing 2.00 g of samples in 60 mL of 90.00% methanol at a solid/liquid ratio of 1:30 (g/mL) and extracted at room temperature for 6 h in a shaker at 100 rpm.	Phenolics (1) Total phenolic content: 48.04 mg GAE/g DM Total flavonoid content: 2.79 mg QE/g DM	[10]
	Conventional solvent	(2) Phenolics were extracted with methanol following a 48 h incubation at 24 °C. (3) Pectin was extracted with oxalic acid, 90 °C, and 60 min.	(2) Phenolics: 17.07 ± 5.16 mg/g Total flavonoid content: 28.55 ± 12.42 mg/g (3) PectinPectin yield: 38% 39.05 ± 0.59 g/g of pectin	[6]
	Pressurized hot water	Phenolics were extracted by mixing 10.00 g of dry powder samples with 200 mL of distilled water in a 1000 mL pressure cooker according to a solid/liquid ratio of 1:20 (g/mL).	Total phenolic content: 47.22 ± 2.31 mg GAE/g DM Total flavonoid content: 11.52 ± 0.81 mg QE/g DM	[21]
	Extraction assisted with subcritical water	Extraction temperature 138 °C, extraction time 9.15 min, L/S ratio 17.03 mL/g.	Pectin yield: 149.60 g/kg (dry matter).	[15]
	Enzymes	Phenolics were extracted by dissolving 2.50 g of dry powder sample in 50 mL of 0.10 M phosphate buffer (pH 4) according to a solid/liquid ratio of 1:20 (g/mL) and adding an aqueous enzyme solution (Viscozyme® L).	Total phenolic content: 14.19 ± 0.85 mg GAE/g DMTotal flavonoid content: 1.25 ± 0.07 mg QE/g DM	[40

DM: dry matter, GAE: gallic acid equivalent, QE: quercetin equivalents, CE: catechin equivalent.

Furthermore, Shanooba et al. [18] tested the combination of different solid–solvent ratios, solvent concentrations, and times to extract polyphenols from jackfruit seeds through the conventional solvent extraction (CSE) method. They concluded that the best extraction performance was with 95% ethanol for 30 min at a solvent ratio of 2.5:25 g of jackfruit seed powder/mL of ethanol [18]. Likewise, Zhang et al. [10] reported that, when using 90% methanol for 6 h to extract phenolics, jackfruit peel yields were 4.95, 4.65, and 4.12 times higher than other parts of the fruit such as seeds, pulp, and flake, respectively. However, when comparing the phenolic content obtained from the peel to that from the fiber or core, the one from the fiber is higher (23.28 ± 4.73 mg/g), followed by the peel (17.07 ± 5.16 mg/g), and finally, the core (15.68 ± 3.74 mg/g), using a CSE with methanol as solvent followed by 48 h incubation [6].

Sundarraj et al. [11] conducted experiments to determine the best temperature and time conditions for pectin extraction with oxalic acid from jackfruit peel. They found that the best performance results corresponded to 90 °C and 60 min. Meanwhile, Bhornsmithikun et al. [4] studied the effects of temperature, extraction times, and liquid-solid ratios' variations for the extraction of prebiotics, finding that a 50% ethanol extraction for 15 min at 60 °C at a ratio of 10:1 (v / w) had the best yields of non-reducing sugar content. More recently, Mohamad et al. [23] reported the extraction of jacalin from jackfruit peel using a sodium bis (2-ethylhexyl) sulfosuccinate/isooctane reverse micellar system.

Some studies on the extraction of functional ingredients present in jackfruit have applied emerging technologies to assist in the process, such as ultrasounds, microwaves, and radio frequency, as a combined treatment or as a pre-treatment to the samples to facilitate further extraction. The results varied according to the technology used, the matrix, and the compounds of interest extracted, as shown in **Table 2**. Among those studied, some resulted in higher performance than conventional methods alone when using techniques including ultrasonic-microwave assisted extraction (UMAE) and ultrasound-assisted extraction (UAE) [24]. Implementing emerging technologies to extract functional ingredients from jackfruit has not been fully explored, which presents a window of opportunity for new research.

Table 2. Emerging technologies of assisted extraction of functional ingredients from jackfruit parts.

Parts	Technique	Extraction Conditions	Functional Ingredients and Yields	Ref.
Pulp	Ultrasound-assisted extraction	1.00 g of sample finely crushed with 5–10 mL of ethanol-water (80–20; *v*/*v*), ultrasonicated (15 min at 40 °C), and centrifuged (15 min at 7500 rpm).	Phenolic acids Raw pulp Gallic acid: 9.70 μg/g Ferulic acid: 8.04 μg/g Tannic acid: 4.87 μg/g Ripe pulp Gallic acid: 19.31 μg/g Ferulic acid: 2.66 μg/g Tannic acid: 5.24 μg/g	[25]
Seed	Ultrasound-assisted extraction	7.00 g of sample in 210 mL of solvent (ethanol) and mix. Ultrasound equipment with a probe is used for 4 min at 70% power (maximum power-500 W) and a frequency of 20 kHz.	Total phenolic content: 0.841 ± 0.067 mg GAE/g	[14]
	Microwave-assisted extraction	Immerse 1.00 g of the powdered sample in 100 mL of ethanol using an ETHOS-Milestone extractor, 5 min extraction time, 450 W microwave power, and 50 °C of extraction temperature.	Phenolic compounds yield: 17.34 mg/g%	[26]
	Supercritical fluid extraction with CO_2	7.00 g of sample is placed into a column (127.5 mm length × 10 mm diameter and internal volume of 10 cm^3) to form the bed of fixed particles. Conditions: temperature of 50 °C, pressure of 12 MPa, CO_2 flow rate of 4.0 mL min^{-1}, and extraction time of 150 min.	Total phenolic content: 0.937 ± 0.004 mg GAE/g	[14]
Peel	Radio frequency-assisted extraction	Radio frequency time of 61.50 min, the ratio of liquid to solid 20.63:1 mL/g, and pH 2.61.	Pectin yield: 29.40%	[13]
	Ultrasonic microwave-assisted extraction	Ultrasound time: 29 min, microwave time: 10 min, power 50 of W, 86 °C, and solid to liquid ratio of 1:48 g/mL.	Pectin yield: 21.50%	[27]
	Ultrasound-assisted extraction	Liquid-solid ratio of 15:1 mL/g, pH of 1.60, sonication time of 24 min, and temperature of 60 °C.	Pectin yield: 14.50%	

GAE: gallic acid equivalent.

4. Functionality and Application of Functional Ingredients from Jackfruit

Furthermore, other phenolic compounds present in the jackfruit, such as artocarpesin, norartocarpetin, and oxyresveratrol, have remarkable anti-inflammatory activity by suppressing nitric oxide (NO) and prostaglandin E2 (PGE2) production [28]. Similarly, pharmacological studies on pectin present in jackfruit showed its antioxidant, anti-tumor, and anti-inflammatory biological properties [27]. Jackfruit is also a good source of vitamin C and vitamin A, for which it has shown antiviral, antibacterial, and a good aiding in preventing blindness caused by macular degeneration [29]. Additionally, as Cardona [29] reported, its potassium content may help prevent cardiovascular accidents and reduce the heart attack risk by lowering blood pressure. Swami et al. [2] showed that jackfruit could help strengthen bones due to its high magnesium content, an essential nutrient in the calcium absorption process that works synergistically to strengthen and prevent bone-related disorders. Thanks to the positive health effects offered by the properties of jackfruit described above, different industries have focused on taking advantage of them.

Some of the most relevant applications for the functional ingredients present in jackfruit are related to the pharmaceutical industry. The antioxidant properties of phenolic and carotenoid compounds, in addition to the anti-inflammatory properties of flavonoids and the antibacterial effects of extracts obtained from different parts of jackfruit, are of great interest owing to their potential incorporation into [30], for example, therapeutic agents for treating infectious diseases and their potential health benefits by positively affecting heart's function, conditions of the skin, and prevention of ulcers and cancer development [2].

Odoemelam [31] reported that jackfruit seed flour could be used as a functional ingredient as it helps to reduce the concentration of gluten in baked goods. Thanks to their antimicrobial properties, nanoparticles generated from jackfruit seeds were proposed as agents against foodborne pathogens [2]. Reported research results on improving chocolate cream properties by incorporating jackfruit flour showed a significant increase in the content of polyphenols (127.00 mg/g), carotenoids (160.16 mg/g), and antioxidant activity IC50 (42.75 μg/mL), while positively affecting the product's sensory properties such as viscosity and color [32].

Regarding jackfruit pectin, some possible uses in the food industry are as a gelling agent, emulsifier, stabilizer, and thickener agent in preparing jams, marmalades, and substitute for fats in various food formulations [13]. Meethal et al. [33] prepared snack bars using jackfruit seed flour and tested different formulations to compare their physicochemical, sensory, and nutritional changes during storage. Their results showed that the highest phenolic content in their formulations was 44.94 ± 0.21 mg GAE/g, while the highest antioxidant activity was 59.34 ± 0.26%, concluding that a jackfruit seed meal is a low-cost option for the preparation of value-added nutritional products [33].

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