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CHARACTERIZATION OF *Artocarpus altilis* POWDER AS A POTENTIAL HEALTH SUPPLEMENT INGREDIENT

(Pencirian Serbuk *Artocarpus atilis* sebagai Bahan Tambahan Kesihatan Berpotensi)

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Abstract

Processing nutrient-dense breadfruit powder with the desired texture has gained lots of attention due to its characteristics heavily influencing its usage in food as an ingredient. This study was initiated to determine the breadfruit's characteristics in relation to its functional properties, thermal behavior, and physicochemical analysis. The native grounded breadfruit (BG) was assessed for its functional properties while its spray-dried powder (BFP and BFP+MD) was subjected to thermal behavior and physicochemical analysis. The physical properties of the breadfruit juice used for preparing BFP and BFP+MD were determined before the spray drying process. The water and oil absorption of BG were 9.08±0.20 g and 2.26±0.15 g, respectively, with the respective gelation properties observed at the concentrations of 13% and 20%. The analysis of breadfruit juice used for preparing BFP and BFP+MD revealed the following properties: pH of 6.39±0.20, TSS of 10.40% and 18.85%, and viscosity of 40 cP and 20 cP, respectively. The IC_{50} for antioxidant activity of breadfruit juice was 58.51±0.34 μg/mL, and its total phenolic content was 369.74±18.41 μg GAE/g. The analysis also revealed the following physicochemical properties of BFP and BFP+MD: moisture content (%) of 5.67±0.81 and 4.23±0.11, hygroscopicity (%) of 4.72±0.18 and 4.04±0.26, water solubility index (%) of 50.74±1.14 and 70.78±2.31, and bulk density (g/mL) of 0.55±0.02 and 0.48±0.01, respectively. BFP+MD demonstrated a lower melting point (28.29°C ± 0.20) than that of BFP (28.64°C ± 0.20). The nutritional value of BFP+MD were as follows: protein (1.7±0.10 %w/w), crude fiber (5.02±0.03 %w/w), fat (3.27±0.11 %w/w), ash (3.80±0.17 %w/w), and carbohydrate (86.84±0.18 %w/w). The evaluated characteristics enable the incorporation of breadfruit into a wide range of supplementary foods for a healthy diet.

Keywords: breadfruit powder, functional properties, thermal behavior, physicochemical analysis

Abstrak

Memproses serbuk sukun yang padat dengan nutrient serta tekstur yang diingini semakin mendapat perhatian kerana ciri-cirinya yang banyak mempengaruhi penggunaannya dalam makanan sebagai bahan ramuan. Kajian ini dilakukan untuk mengenal pasti ciri-ciri sukun dari segi sifat-sifat berfungsinya, tingkah laku terma dan analisis fizikokimia. Sifat-sifat berfungsi telah dikaji menggunakan buah sukun yang dikisar (BG), sementara tingkah laku terma dan analisis fizikokimia dijalankan ke atas sukun yang telah disembur kering (BFP dan BFP+MD). Sebelum disembur kering sifat-sifat fizikal jus sukun untuk kedua-dua BFP dan BFP+MD juga ditentukan. Keputusan BG untuk penyerapan air dan minyak masing-masing ialah 9.08±0.20 g dan 2.26±0.15, manakala sifat pembentukan gel diperhatikan pada kepekatan 13% dan 20%. Keputusan jus sukun untuk kedua-dua BFP dan BFP+MD masing-masing adalah seperti berikut: 6.39±0.20 untuk pH, 10.40% dan 18.85% untuk TSS dan 40 cP dan 20 cP untuk kelikatan,. Nilai IC_{50} aktiviti antioksidan ialah 58.51±0.34 µg/mL, dan jumlah kandungan fenolik ialah 369.74±18.41 µg GAE/g untuk jus sukun. Keputusan fizikokimia untuk BFP dan BFP+MD masing-masing ialah kandungan lembapan (%) (5.67±0.81, 4.23±0.11), higroskopisiti (%) (4.72±0.18, 4.04±0.26), indeks larut air (%) (50.74±1.14, 70.78±2.31) dan ketumpatan pukal (g/mL) (0.55±0.02, 0.48±0.01). BFP+MD menunjukkan takat lebur yang lebih rendah (28.29°C ± 0.20) daripada takat lebur BFP (28.64°C ± 0.20). Kandungan nutrisi BFP+MD yang ditentukan ialah protein (1.7±0.15 %w/w), serat kasar (5.02±0.03 %w/w), lemak (3.27±0.11 %w/w), abu (3.80±0.017 %w /w) dan karbohidrat (86.90 ±0.03 %w/w). Ciri-ciri yang diperhatikan membolehkan serbuk sukun menjadi ramuan dalam pelbagai makanan tambahan yang sihat.

Kata kunci: serbuk sukun, sifat-sifat berfungsi, tingkah laku terma, analisis fizikokimia

Introduction

As a result of the Covid-19 epidemic expanding into endemic, community well-being has taken precedence. It is critical to focus on acquiring health supplements for easy daily consumption to boost the immune system and reduce the problems associated with chronic diseases. A balanced diet should include an adequate amount of essential nutrients such as antioxidants, complex carbohydrates, low-glycemic index ingredients, and fibers that are readily accessible. Breadfruit (*Artocarpus altilis*) is one of the underutilized tropical plants recently studied for its potential health benefits to humans, either through oral consumption, e.g., food, or topical application, e.g. cosmetic ingredients. Because of its distinct qualities, such as its pale hue and bland sensory profile, it meets the requirements of the food sector, which prefers starch that is stable, white in color, and odorless [1].

Breadfruit (*A. altilis*), also known as *sukun* in Malay is a traditional crop and a reliable staple food that originates from South Pacific countries [2] Breadfruit trees are easy to grow and capable of bearing fruit in abundance. The fruits are highly nutritious and energy-rich and contain large amounts of phytochemicals which exhibit significant antioxidant properties [3, 4]. These compounds are beneficial for human health as they are associated with the prevention of cardiovascular diseases, urinary tract infections, and other chronic illnesses [5, 6]. In addition, antioxidant activity and total phenolic content are an important measure to improve food quality and prolong shelf life without imposing any undesirable effects from the addition of synthetic chemical preservatives [7, 8]. Breadfruit can also be a source of dietary fiber which aids in the regulation of blood sugar in diabetics, the reduction of unfavorable blood lipids (a risk factor for CVDs), and the management of weight. Besides providing essential minerals, breadfruit offers an alternative to gluten-free for those who are gluten intolerant, suffering from Type 2 Diabetes Mellitus, and health-conscious individuals [2-4, 6]. Breadfruit also contains highly resistant starch which has been empirically proven to offer numerous health benefits, including suppressing appetite and feeding the beneficial bacteria in the colon, boosting the number and diversity of bacteria [3]. The rheological behavior of breadfruit starch has been studied extensively in food applications. Based on rheological qualities, the stability of native and modified breadfruit starch has also been examined for its use in emulsion and baking [9]. Physical modification of starch involves the use of chemical or biological agents. Meanwhile, physical modification of starch is frequently favored in food products intended for diet [10]. By considering these properties of breadfruit, researchers can use them as intermediate ingredients or finished products to fulfill the demand of health-conscious consumers.

Apart from its potential use as an energy source, breadfruit offers a wide range of functionalities and diverse nutrients, making it great for functional food applications. Although breadfruit is healthy, it quickly deteriorates physiologically after harvesting. To reduce post-harvest losses and increase breadfruit utilization, the breadfruit can be processed into powder, which is more shelf stable. Conventional methods of oven-drying followed by grinding and spray drying in the making of breadfruit powder can help prolong its shelf life by reducing its moisture content and inhibiting microbial growth and enzymatic activity [11]. Spray drying is often used due to its rapidity and economic value. Maltodextrin is one of the drying aids that acts as a carrier or an encapsulating agent in the drying process. In addition, maltodextrin improves the properties of the powder by increasing its solubility and hygroscopicity and acting as anticaking. The production of breadfruit powder has enabled its application in a vast range of food industries. Some of the applications of breadfruit as a functional food ingredient include breadfruit flour, infant formulas, biscuits, fermented foods, extruded products, and stiff porridge [12]. Yet, the processing of breadfruit powder into a desired texture remains one of the areas that has gained a lot of attention and is under exploration.

There is a lack of research and established data supporting the eligibility of breadfruit powder for applications in food, which is largely influenced by its characteristics. Therefore, the current study focused on evaluating the functional properties, thermal behavior, and physicochemical properties of breadfruit powder. The physicochemical properties including solid and moisture content, bulk density, hygroscopicity, solubility, viscosity, antioxidant and phenolic compound, thermal behavior, and nutritional value were determined. Additionally, the functional properties such as water and oil absorption capacity, and gelation properties were used as complementary data for applications as processed food products. These findings will enhance the significance of our local sources and have a significant impact on product development for diverse age groups, which includes the application as an intermediate ingredient in health supplements for general consumption.

Materials and Methods

Material and chemicals

Matured breadfruits and corn oil were bought from a local market in Skudai, Johor, Malaysia. Maltodextrin was purchased from Agrin Chemical (M) Sdn. Bhd. Methanol, Gallic acid, Folin-Ciocalteu reagent, sodium carbonate, 1,1-diphenyl-2-picrylhydrazyl (DPPH), sodium chloride, and anticaking agent of analytical grade were purchased from SIGMA-Aldrich, US.

Preparation of breadfruit powder: Ground breadfruit powder

The matured breadfruits were washed thoroughly to remove dirt and were subsequently peeled. Next, the fruits were sliced with their core removed. Each of these samples was then dried in a hot air oven at 60 °C for six to eight hours. The dried samples were milled and ground into flour (BG) and were sieved through a 100-μm mesh to obtain fine-textured flour. Lastly, samples were packed into polyethylene bags and stored at room temperature for further use.

Spray-dried breadfruit powder

The matured breadfruits were washed thoroughly to remove dirt and were subsequently peeled. Next, the fruits were sliced with their core removed. Water was added to the sliced breadfruits at a ratio of 1:1 (breadfruit: water) and blended using a juice blender to obtain the breadfruit juice. The juice was filtered through a sieve (ASTM E11, 150-μm mesh) and transferred into a beaker. Next, 1 g of anticaking agent was added to the breadfruit juice, and the mixture was homogenized at 8000 rpm for 10 minutes. The spray dryer was set at a constant aspirator rate of 100 %, pump setting of 20%, nozzle speed of 5, and compressed air flow rate of 5 mL/min. Inlet temperatures were set at 180 °C with a constant maltodextrin concentration (30 % w/w) based on a method by Jafari et al. [13]. The process was repeated using the same parameter for breadfruit without maltodextrin. The samples prepared before the analysis were assigned as breadfruit without maltodextrin (BFP) and breadfruit powder with maltodextrin (BFP + MD).

Process yield

The weight of the dry material in the powder and juice was used to determine the spray drying yield. This factor was calculated from the following equation 1 [13]:

$$Yield\ (g) = \frac{P \times S_P}{L \times S_F} \quad (1)$$

where P is the rate of powder production (g/min), S_P is the percent of total solids of the powder, L is the feed flow rate (g/min), and S_F is the percent of total solids of the feed.

Functional properties of breadfruit samples: Water and oil absorption capacity

The water absorption capacity of the starch was studied based on the method by Pestorić et al. [14]. The methods were as follows; sample weighing 3g was dispersed in 25 mL of distilled water and placed in pre-weighed centrifuged tubes. The mixtures were stirred occasionally, held for 30 min, followed by centrifugation for 25 min at 3000 x g. The supernatant was decanted, excess moisture was removed by draining for 25 min at 50 °C, and the sample was reweighed [15]. For the determination of oil absorption, the samples weighed 0.5 g were mixed with 6 mL of corn oil in pre-weighed centrifuged tubes. The contents were stirred for 1 minute with a thin brass wire to disperse the sample in the oil. After a holding period of 30 min, the tubes were centrifuged for 25 min at 3000 x g. The separated oil was then removed with a pipette and the tubes were inverted for 25 min to drain the oil before weighing [16]. The water and oil absorption capacities were expressed as grams of water or oil bound per gram of the sample on a dry basis.

Gelation properties

Test tubes containing starch suspensions of 1%, 7%, 13%, and 20% (w/v) of material in 5 mL of distilled water were heated for 1 h in boiling water followed by rapid cooling under running water. The tubes were further cooled at 4 ℃ for 2 h. The least gelation concentration (LGC) is the concentration at which the sample does not fall or slip when the test tube is inverted [14].

Physical properties of breadfruit juice: pH

A digital pH meter was used to measure the pH of the samples. The digital pH meter was first calibrated using two buffer solutions of pH 7.0 and 4.0. The pH electrode was immersed into the beaker filled with 200 mL of samples and the readings were recorded [17].

Total soluble solids

A digital refractometer was used to measure the samples. The digital refractometer was calibrated by placing a drop of distilled water on its surface. The samples were placed on the surface of the digital refractor with a scale of 0–85 °Brix and the reading was recorded [17].

Viscosity

The viscosity of the samples was determined using a flow test at a shear rate ranging from 0.001 s^{-1} to 1000 s^{-1}, at a temperature of 25 ℃. The data obtained was generated by calculations with respect to the Herschel-Bulkley, Bingham dan Casson model [18].

Antioxidant activity of breadfruit samples

The antioxidant activity of fresh breadfruit and spray-dried breadfruit powder samples was measured by DPPH radical scavenging activity under minimal light conditions [19]. Samples of 0.4 g of breadfruit powder were weighed and dissolved in 40 mL of 80% (v/v) aqueous methanol to obtain a concentration of 10 mg/mL, followed by 20 minutes of sonication. Ascorbic acid was prepared as a standard reference at concentrations ranging from 1.25 to 200 µg/mL. Next, 0.1 mM DPPH solution was prepared by dissolving 2 mg of DPPH in 50 mL of 80% (v/v) methanol. Then, 0.5 mL of the ascorbic acid standards were added with 2 mL of DPPH solution in tubes and mixed well. After leaving the tubes in the dark for 30 minutes, the absorbance of the standards was measured using a UV-Vis spectrophotometer (DLAB SP-V1000) at 517 nm. These steps were repeated for the samples. The percentage of free radical scavenging activity at different concentrations was calculated using the formula (Eq.2):

$$DPPH\ scavenging\ activity\ (\%) = \frac{A_{517}\ control - A_{517}\ sample}{A_{517}\ control} \times 100 \quad (2)$$

A graph of free radical scavenging activity against the concentration of the standards and samples was plotted using a Microsoft Excel spreadsheet. From the graph, the linear regression ($y = ax + b$) obtained was used to determine the IC_{50} by using the formula (Eq.3):

$$IC_{50} = \frac{50-b}{a} \quad (3)$$

Total phenolic content of breadfruit samples

The total phenolic content (TPC) of fresh breadfruit and spray-dried breadfruit powder samples was measured using Folin-Ciocalteu colorimetric assay [18, 20]. Initially, 0.5g of dried breadfruit powder samples were extracted by mixing them in 10 mL of 80% (v/v) aqueous methanol solution, followed by 25 minutes of sonication. Next, 0.5 mL of the samples were introduced into the test tubes and added with 1.5 mL of Folin-Ciocalteu's reagent and 1.2 mL of 7.5% (w/v) sodium carbonate solution. The test tubes were vortexed, covered with parafilm, and allowed to settle for 90 minutes. The calibration curve was plotted by mixing 1 mL aliquots of 500, 250, 125, 62.5, and 31.25 µg/mL Gallic acid solutions with 1.5 mL of Folin-Ciocalteu's reagent and 1.2 mL of 7.5% (w/v) sodium carbonate solution. The absorbance was measured using a UV-Vis spectrophotometer at 765 nm. The absorbance was measured to determine the total phenolic content (TPC) in the samples using the formula (Eq.4):

$$TPC = C1 \times \left(\frac{V}{m}\right) \quad (4)$$

where C = total phenolic content in µg/g (in Gallic acid equivalent), $C1$ = concentration of Gallic acid established from the calibration curve (µg/ml), V = volume of extract (ml), and m = the weight of the plant extract (g).

Physicochemical properties of spray-dried breadfruit powder: Moisture content

The moisture content of the breadfruit powder samples was determined by a moisture analyzer (AND MX-50) at 80 ℃ until a constant weight was obtained [21].

Hygroscopicity

The hygroscopicity of the samples was determined by the method described by Cai and Corke (2000). Approximately 1 g of each breadfruit powder sample was weighed onto a crucible and placed in an airtight desiccator at a temperature of 25 ℃ with saturated NaCl solution (75% RH) for one week. The hygroscopicity (%) was calculated using the following formula (Eq.5):

$$Hygroscopicity\ (\%) = \frac{(W1\% + MC\%) \times 100}{(W1\% + 100)} \quad (5)$$

where,

$$W1\% = \frac{(Weight\ of\ sample\ after\ equilibrium - Weight\ of\ sample)}{Weight\ of\ sample} \times 100$$

$$MC\% = Moisture\ content\ of\ sample\ powder$$

Water solubility index

The solubility index (WSI) of the spray-dried breadfruit powder samples was determined using the method by [13, 22] with some modifications. Each powder sample weighed 2.5 g was dissolved in 30 mL of distilled water and stirred on a hotplate stirrer for 30 minutes. The mixture was centrifuged at 3000 × g for 10 minutes. The supernatant was placed in a preheated oven at 105 ℃ until a constant weight was obtained. The solubility of the breadfruit powder samples was calculated (Eq. 6) by:

$$WSI\ (\%) = \frac{Dried\ supernantant\ weight}{Initial\ sample\ weight} \times 100 \quad (6)$$

Bulk density

The bulk density of the samples was measured by pouring 2 g of each sample into a 10-mL graduated cylinder and vibrating using a vibrator. The occupied volume was observed [13, 21, 4] and the bulk density was calculated by the following equation (Eq.7):

$$Bulk\ density\ (g/mL) = \frac{m}{v} \quad (7)$$

where *m* is the mass of the breadfruit powder sample (g) and *v* is the volume (mL) occupied in the cylinder.

Differential scanning calorimeter analysis

The thermal behavior of the breadfruit powder samples was determined using the differential scanning calorimeter (DSC), (Mettler Toledo DSC1). Using standard indium and sapphire, the instrument was calibrated for heat flow and temperature. Fifteen milligrams of each sample were accurately weighed into the DSC aluminum sample and flowed using the pan and sealed with a lid while an empty pan with a lid was used as a reference. The process began by decreasing the temperature to -80 ℃ at a heating rate of 10 ℃/min, followed by a scanning from -80 ℃ to 80 ℃ at the same heating rate. Dry nitrogen gas was used as the purge gas at a flow rate of 50 mL/min [21, 23].

Nutritional value of breadfruit samples

The proximate analyses were performed to estimate the moisture, ash, fat, protein, and crude fiber contents of the breadfruit samples based on the AOAC Official Method [24]. Moisture content was determined using the oven drying method at 100 ℃ for at least five hours until a constant weight was obtained. Ash content was determined by the total mineral or inorganic residue remaining in food after either ignition or complete oxidation of organic matter following the application of the dry-ashing method. The protein content was determined based on the total nitrogen content using the Kjeldahl method. Fat content was assessed via the extraction using a non-polar solvent by the Soxhlet extraction method. The carbohydrate content in the sample was calculated by the energy difference. The calculation of the energy (kCal) of the sample was performed as follows:

$$Energy\ (in\ kCal) = 4 \times (Proteins\ and\ carbohydrates\ mass\ in\ grams) + 9 \times (mass\ of\ fat\ in\ grc \quad (8)$$

Results and Discussion

Functional properties of ground breadfruit

As depicted in Table 1, the water and oil absorption capacities of the BG sample were 9.08 ± 0.20 g/g and 2.26 ± 0.15 g/g, respectively. Oil absorption capacity is important for storage and stability especially in the development of rancidity during the storage period. In addition, a high absorption capacity allows for retaining flavor, improving mouthfeel, and increasing the soft texture in the mouth [25, 4].

Table 1. Water and oil absorption capacities of spray-dried breadfruit powder samples

Sample	Water Absorbed (g/g)	Oil Absorbed (g/g)	Gelation Capacity Concentration (% w/v)			
			1	7	13	20
BG	9.08 ± 0.20	2.26 ± 0.15	-	-	+	+

Abbreviation: Grounded breadfruit (BG). Value is expressed as mean ± standard deviation (n=3). Symbol minus (-) as no gelation and (+) as has gelation capacity

Table 1 illustrates the gelation capacities of the spray-dried breadfruit powder samples. BG with 1% (-) and 7% (-) concentration showed no gelation capacity while BG with (+)13% and (+) 20% showed gelation capacity. In food industries, the gelling ability of spray-dried fruit powder is a desirable quality [25]. A higher least gelation capacity (LGC) indicates a lower ability to form a stable gel. Stable gelling formation is ideal in components with higher protein content due to the greater intermolecular contact, especially during cooking [4].

Process yields and physical properties of breadfruit juice

From the results shown in Table 2, the BFP+MD sample generated a higher yield (41.229 g) than the BFP sample (33.112 g). Noticeably, the addition of maltodextrin as a filler improved the process yield and increased the total solid content yet did not alter the pH value of the breadfruit juice. These results indicate that the addition of maltodextrin to spray-dried fruit powders does not alter their pH [17]. Moreover, the pH significantly improved the functional properties of the powder after spray drying. Thus, it is necessary to maintain a particular pH to obtain certain functionalities [26].

Table 2. Yield and physical properties of breadfruit juice

Samples	Yield (g)	pH	TSS (%)	Viscosity (cP)
BFP	33.112	6.19 ± 0.20	10.40	40
BFP+MD	41.339	6.39 ± 0.20	18.85	22

Abbreviation: Breadfruit juice without maltodextrin (BFP); Breadfruit juice with 30% maltodextrin (BFP+MD). Note that the parameters were measured for the breadfruit juice that will be spray-dried into powder.

The sample with 30% maltodextrin contained higher total solid content (18.85%) than the one without (10.40%). Solid content determines the percentage yield and quality of a product [27, 28]. Viscosity is also an important parameter to consider as it influences the emulsifying ability of powders [29]. BFP+MD exhibited a low viscosity (22 cP) compared to BFP (40 cP). This result is consistent with the findings by [30] who reported that the increase in maltodextrin concentration resulted in a reduced viscosity of spray-dried avocado powder.

Antioxidant activity and total phenolic content of breadfruit

In this study, DPPH free radical scavenging activity was used to determine the antioxidant activity and expressed in µg/mL of methanolic extract concentration required to inhibit 50% of the free radicals (IC_{50}). The capacity of the extract/sample to scavenge free radicals through hydrogen donation was assessed using the DPPH test. DPPH molecule is considered a stable free radical. DPPH appears purple/violet in a methanolic solution and will decolorize into shades of yellow in the presence of antioxidants [31]. The DPPH assay was used to measure the scavenging activity of breadfruit samples with ascorbic acid as a positive control. The free radical-scavenging antioxidants in the fruits donate hydrogen to the unpaired electron of the DPPH molecule, turning the purple-colored DPPH into its reduced form which is yellow.

Follin-Ciocalteu's colorimetric assay was performed to analyze TPC in the breadfruit samples. Follin-Ciocalteu reagent is a yellow phenol reagent containing phosphotungstate and phosphomolybdate. The reagent changes from yellow to blue when phenolic compounds are present in the sample. The changes are due to redox reactions, through which the samples turn the Follin-Ciocalteu reagent into its reduced form. Gallic acid, a type of phenolic acid was used as a standard. From the standard curve obtained, the absorbance values of the samples were used to determine the TPC which were expressed in terms of µg/mL GAE/g.

Table 3. TPC and antioxidant activity of fresh breadfruit and spray-dried breadfruit powder

Samples	TPC (µg GAE/g)	IC_{50} of DPPH (µg/mL)
BF_{fresh}	369.74 ± 18.41	58.51 ± 0.34
BFP+MD	745.26 ± 13.60	105.11 ± 3.61

Abbreviation: Freshly prepared breadfruit juice (BF_{Fresh}); Spray-dried breadfruit powder with 30% maltodextrin (BFP+MD). Value is expressed as mean ± standard deviation (n=3).

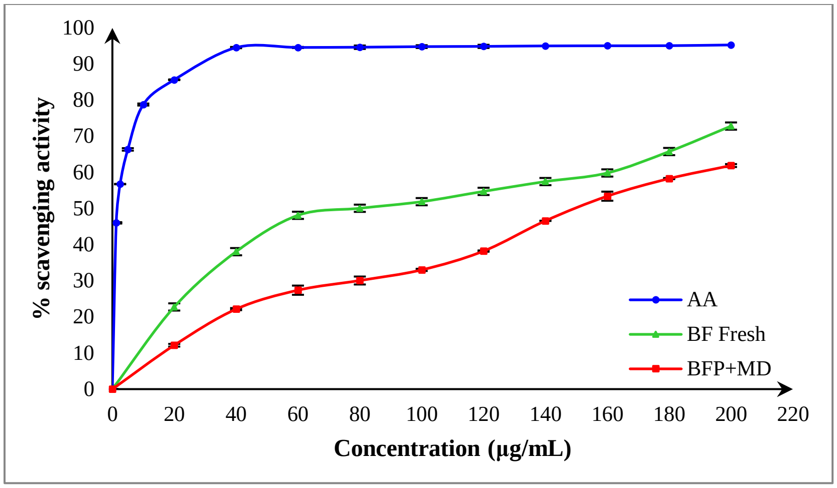

Figure 1. DPPH free radical scavenging activity of breadfruit samples. Abbreviation: Ascorbic acid (AA) as a standard, freshly prepared breadfruit juice (BF_{Fresh}) and spray-dried breadfruit powder with 30% maltodextrin (BFP+MD). Value is expressed as mean ± standard deviation (n=3)

Table 3 and Figure 1 illustrate the TPC and antioxidant activity of fresh breadfruit and spray-dried breadfruit powder with 30% maltodextrin added. Spray-dried breadfruit powder with 30% maltodextrin contained a higher total phenolic content (745.26 ± 13.60 µg GAE/g) than the fresh breadfruit (369.74 ± 18.41 µg GAE/g). Maltodextrin addition improved the phenolic contents in breadfruit during the spray drying process. In the DPPH assay, the lower the IC_{50} the better it can scavenge the radicals which are the propagators of the autoxidation of lipid molecules, and thereby break the radical-free reaction [32]. In addition, fresh juice was expected to contain higher antioxidant activity. Table 3 shows that the fresh breadfruit samples exhibited a lower IC_{50} (58.51 ± 0.34 µg/mL) than the spray-dried samples added with 30% maltodextrin (105.11 ± 3.61 µg/mL), suggesting a higher antioxidant activity in the fresh sample. Different phytochemicals with antioxidant activity have different levels of tolerance toward high temperatures and conformational changes which vary in different types of fruits [33].

Physicochemical properties of spray-dried breadfruit powder

The physicochemical properties are important in ensuring the suitability of spray-dried breadfruit powder to be utilized as food or food ingredients. Physicochemical properties such as moisture content, bulk density, hygroscopicity, and WSI are discussed in this section.

Table 4. Physicochemical properties of spray-dried breadfruit powder samples

Samples	Moisture Content (%)	Hygroscopicity (%)	WSI (%)	Bulk Density (g/mL)
BFP	10.80 ± 0.03	4.715 ± 0.18	50.74 ± 1.14	0.55 ± 0.02
BFP+MD	4.23 ± 0.11	4.035 ± 0.26	70.78 ± 2.31	0.48 ± 0.01

Abbreviation: Spray-dried breadfruit powder without maltodextrin (BFP); Spray-dried breadfruit powder with 30% maltodextrin (BFP+MD). Value is expressed as mean ± standard deviation (n=3). Water soluble index (WSI)

The spray-dried breadfruit powder samples were tested for their physicochemical and the results are summarized in Table 4. In general, the addition of 30% maltodextrin did affect the physicochemical properties of spray-dried breadfruit powder. The moisture content analysis revealed that the moisture content in spray dried-breadfruit powder with 30% maltodextrin was lower (4.23 ± 0.11%) than spray dried-breadfruit powder without 30% maltodextrin (10.80 ± 0.03%). These findings were similar to [34] which revealed that the increase in maltodextrin concentration resulted in a decrease in moisture content and water activity of spray-dried "cempedak" powder. In industrial practice, only the powder with a moisture content below 10% is considered microbiologically safe [35] suggesting that the spray-dried breadfruit powder fulfilled this criterion. A low moisture content will also prolong the shelf life of food products by preventing microbial activity that induces food degradation [11, 36].

The sample added with 30% maltodextrin also showed lower hygroscopicity (4.035 ± 0.26%) than the one without (4.715 ± 0.18%). Hygroscopicity can be described as the tendency of a solid substance to absorb moisture from the surrounding atmosphere. Pure spray-dried fruit powders usually exhibit a high level of hygroscopic behavior. However, a spray-dried breadfruit powder with lower hygroscopicity is favored to prevent or minimize undesirable effects such as caking. Additionally, hygroscopicity determines the moisture content and behavior of adsorption isotherms at which high hygroscopic levels may lead to unwanted effects such as caking during food processing and manufacturing [37].

The addition of 30% maltodextrin increased the WSI of spray-dried breadfruit powder by 20.04 ± 0.08%. These results are consistent with [38] who reported that the addition of maltodextrin enhanced the solubility of fig powder. Producing spray-dried breadfruit powder with high WSI is desirable for producing functional food ingredients because WSI determines the powder's behavior and stability in aqueous phases [39].
The bulk density of the sample added with 30% maltodextrin exhibited a lower bulk density (0.48 ± 0.01 g/mL) than the pure sample (0.55 ± 0.02 g/mL). These findings are supported by Pui et al. [34] who described that the increase in maltodextrin resulted in a decrease in the bulk density of spray-dried "cempedak" powder. An increase in bulk density is necessary for packaging, as it enables the food product to be packed in greater quantity within a constant volume [40].

Differential scanning calorimeter analysis

DSC analysis was performed to evaluate the thermal behavior of spray-dried breadfruit powder samples. Table 5 and Figure 2 summarize the thermodynamic properties of the samples. Based on Table 5, the addition of maltodextrin in the breadfruit influences the melting temperature of both breadfruit powders, with BFP showing a higher melting temperature (28.64± 0.20 ℃) than BFP+MD (28.29± 0.20 °C) yet demonstrating a lower enthalpy (ΔH 1.99 J/g) than the BFP+MD (ΔH 2.37 J/g). This finding is similar to Nevin and Rajamohan [41] which revealed that the addition of maltodextrin with a low molecular weight requires a lower temperature but a higher enthalpy to achieve an optimum melting temperature. Furthermore, the presence of shorter glucose polymer chain lengths in maltodextrin may affect the level of stickiness and the melting temperature [23].

Table 5. The melting temperature, A1 and ΔH of spray-dried breadfruit powder samples

Samples	A1 (°C)	ΔH (J/g)
BFP	28.64 ± 0.20	1.99 ± 0.20
BFP+MD	28.29 ± 0.20	2.37 ± 0.20

Abbreviation: Spray-dried breadfruit powder without maltodextrin (BFP); Spray-dried breadfruit powder with 30% maltodextrin (BFP+MD). Value is expressed as mean ± standard deviation (n=3).

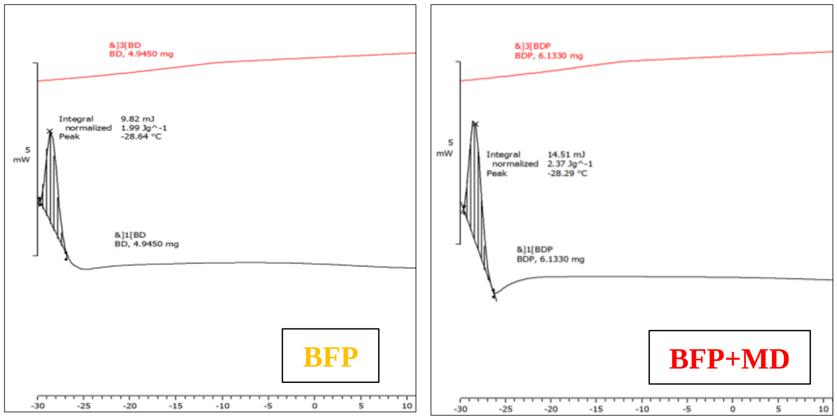

Figure 2. DSC thermogram of BFP and BFP+MD powder samples

Nutritional value of breadfruit samples

Proximate analysis is an important index to determine and classify nutritional values such as carbohydrates, protein, and fat content in a sample [42, 43]. Figure 3 and Table 6 depict the composition of nutritional values in the breadfruit samples obtained from the proximate analysis.

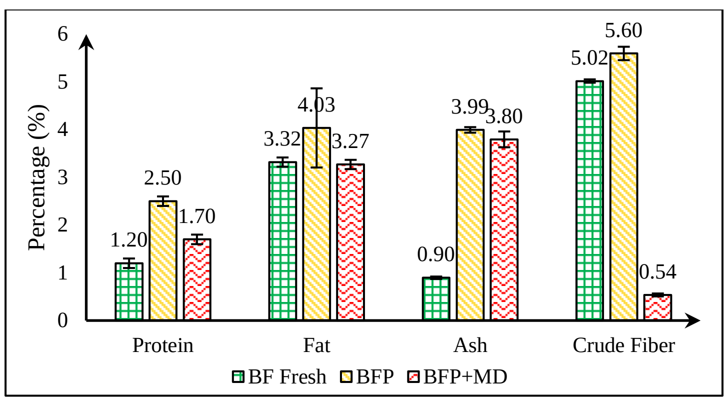

Figure 3. Nutritional value of the breadfruit samples

Table 6. Composition of carbohydrate and energy content of the breadfruit samples

Samples	Components	
	Carbohydrate (% w/w)	**Energy (kCal)**
BF_{Fresh}	10.42 ± 0.15	76.35 ± 0.78
BFP	73.08 ± 0.92	338.62 ± 3.79
BFP+MD	86.84 ± 0.18	383.80 ± 0.63

Abbreviation: Spray-dried breadfruit powder without maltodextrin (BFP); Spray-dried breadfruit powder with 30% maltodextrin (BFP+MD). Value is expressed as mean ± standard deviation (n=3).

Figure 3 shows that the spray-dried BFP samples generally contained the highest nutritional contents namely protein, fat, ash, and crude fiber (2.50 ± 0.10 % w/w, 4.03 ± 0.83 % w/w, 3.99 ± 0.06 % w/w, 5.60 ± 0.14 % w/w, respectively) compared to BFP + MD (1.70 ± 0.10 % w/w, 3.27 ± 0.11 % w/w, 3.80 ± 0.17 % w/w, respectively). The results demonstrate that both the BFP and BFP + MD samples of breadfruit retain their nutritional value despite the crude fiber content. Noticeably, the BFP + MD contained the lowest crude fiber content (0.54 ± 0.03) compared to BF_{Fresh} (5.02 ± 0.04 % w/w) and BFP (5.60 0.14 % w/w). The low crude fiber content was probably due to the less soluble solid content in the breadfruit slurry before the spray dry process. Table 6 shows that BFP and BFP + MD contained high carbohydrate contents thus contributing to higher energy value.

Conclusion

Physicochemical, functional, and thermal properties determined in this research are important parameters for adding value to breadfruit processing and its utilization. These characteristics are principally responsible for the final product quality. Breadfruit as a whole is high in nutrients and a good source of energy and possesses extinguishing characteristics. Therefore, it can be potentially used in a variety of food products to offer health benefits. In addition, breadfruit powder with adequate antioxidant and total phenolic contents can be potentially incorporated into health supplementary products. Its favorable functional properties make it a suitable ingredient in the formulation of advanced food products without compromising the needs of health-conscious consumers.

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