Asia-Pacific Journal of Science and Technology: Volume: 30. Issue: 03. Article ID.: APST-30-03-15. Research Article

APST

Asia-Pacific Journal of Science and Technology

https://www.tci-thaijo.org/index.php/APST/index

Published by Research Department,
Khon Kaen University, Thailand

Physical, functional, structural, and pasting characteristics of durian (*Durio zibenthinus* Murr.) seed flour from Kalimantan, Indonesia

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Received 18 March 2024
Revised 25 March 2024
Accepted 18 November 2024

Abstract

Durian, native to Southeast Asia, particularly Indonesia, produces several by-products, including durian seed flour (DSF). Although DSF has gained research interest, its characteristics from Kalimantan, Indonesia remain underexplored compared to those from Thailand and Malaysia. This study investigates the physical, functional, structural, and pasting properties of DSF from West Kalimantan (DSF-WK), representing local durian varieties, and compares it with commercially available DSF in Indonesia (CDSF). Results demonstrated that the DSF-WK had higher lightness (L*), whiteness, swelling power, and water absorption capacity, but lower redness (a*), yellowness (b*), and oil absorption capacity than CDSF. Morphological analysis using SEM-EDX showed both flours had polygonal shapes, with DSF-WK containing carbon (C), oxygen (O), magnesium (Mg), phosphorus (P), and potassium (K), while CDSF contained only C, O, and K. FTIR analysis confirmed similar functional groups in both samples, including C-H, C-O-H, C-O, C-C, $C\text{-}H_2$, and O-H bonds. In addition, the type A-diffraction pattern reflects both the DSF samples. Pasting property analysis via Rapid Visco Analyzer (RVA) revealed DSF-WK had higher peak, trough, and final viscosities, indicating greater thickening ability, but lower breakdown, setback viscosities, peak time, and pasting temperature. Overall, DSF-WK is distinguished by its white color, superior water interaction properties, and distinctive pasting behavior. These features suggest its potential use in food products like noodles and cookies, which require brightness and viscosity. Moreover, its higher swelling power and water solubility suggest its suitability as a base for edible films, highlighting DSF-WK as a promising functional ingredient in food and packaging applications.

Keywords: Colour, durian seed flour, FTIR, microstructure, OAC, pasting properties, WAC, XRD

1. Introduction

Durian is an indigenous exotic tropical fruit from Southeast Asia Plains, including Indonesia, Malaysia, Thailand, the Philippines, and Vietnam, with a unique flavor popular with people worldwide [1–3]. One of the islands in Indonesia that produces abundant durian fruit is Kalimantan Island [4], including West Kalimantan Province (WKP). The WKP contributes 1.23% to the national durian production, with a total of 14672 tons in 2020 [5]. Compositionally, durian fruit has an edible aril (flesh) part that makes up 30-35% of the fruit and the by-products which consist of 45-50% of fruit peels and 20-25% of seeds [2]. However, the durian seed by-products have not been optimally utilized in the community, and are mainly used as snacks prepared by boiling or other cooking techniques [6]. In fact, durian seeds have a complete nutritional content such as protein (2.5%), moisture (51.1%), fat (0.2%), and carbohydrates (46.2%) with a yellowish-white color, making them suitable as alternative functional food materials. To increase the economic value and shelf life of durian seeds, they are processed into durian seed flour (DSF) [2].

DSF is a diversification product of durian seeds, which are widely used as an additive for a substitute in various food products [7,8], bioplastic raw materials [9,10] or for the synthesis of *carboxymethyl cellulose* (CMC) [11], and bioethanol [12]. DSF has relatively complete and balanced nutrients, such as protein (6.00 – 9.08%), fat (0.52 -1.09%), ash (2.86-4.45%), moisture (6.5-10.78%), and carbohydrates (72.49-80.61%) [6,7,9,13]. Most of the carbohydrates are starches, with content ranging from 40.29- 46.81% [2,13], with amylose content of 14.62-22.76 % d.b [2,9]. Besides the nutritional properties, understanding functional properties, morphology, and other structural properties, such as functional groups and crystallinity patterns, and the pasting properties of the Indonesian DSF is necessary for selecting appropriate processing and further application in food system products [14,15]. Earlier research has shown overwhelming information regarding these topics in Thailand and Malaysia [1, 2, 16]. However, studies that take native DSF from Indonesia as the main subject are still rarely explored.

Some research that has investigated the functional, morphology, and pasting properties of DSF in Indonesia was exemplified by Malini et al. [8], which characterizes the nutritional and pasting properties of DSF from Palembang, Sumatra. Other research was reported by Kumoro and Hidayat [6] who examine the effect of fermentation on the functional (water solubility, swelling power, water adsorption capacity, and oil adsorption capacity) and thermal properties of DSF from Gunung Pati, Central Java, Indonesia. More recently, Kumoro and Hidayat [17] also reported the effect of soaking time in sodium metabisulfite on the physicochemical and functional properties of DSF. In West Kalimantan, scholars have studied the characterization of the nutritional and partial structural properties (particle size, microstructure, and thermal properties) of DSF from West Kalimantan (DSF-WK), as reported by Permatasari et al. [13]. Despite these growing studies, the information on the color, functional properties, morphology, functional groups, crystallinity patterns, and pasting properties of DSF-WK has been rarely explored, thus needing further investigation. This study attempted to assess the DSF-WK characteristics, including its color, functional properties, morphology, functional groups, crystallinity patterns, and pasting properties. Commercial durian seed flour (CDSF), widely circulated in the Indonesian market, was used as a comparison and purchased from an online shopping platform.

2. Materials and methods

2.1 Materials

This study used two different types of DSF: the durian seed flour from West Kalimantan (later known as DSF-WK) and the Indonesian market's CDSF. The DSF-WK was produced in our previous study [13]. It was processed from the durian seed obtained from the "*tembaga*" durian farmers in Sanggau, West Kalimantan, Indonesia. Meanwhile, the Indonesian market's CDSF was purchased via an online shopping platform from Banguntapan, Bantul, Yogyakarta, Indonesia. This DSF was produced by "Kusuka" Ubiku. All chemicals used to analyze amylose content had an analytical grade obtained from the Laboratory of Chemistry and Biochemistry of Food and Agricultural Product, Department of Food Science and Biotechnology, Faculty of Agricultural Technology, Universitas Brawijaya. Finally, the distilled water and oil were purchased from a local chemical store in Malang City.

2.2 Analysis Methods of DSF

2.2.1 Determination of amylose content

One of the primary analyses performed was the determination of the amylose in the DSF. The amylose was determined using the spectrophotometer method at 620 nm, using the iodine colorimetric reaction [18].

2.2.2 Color Analysis

Additionally, the color characteristics of DSF was also examined. The colors parameters, such as L*, a*, and b* were determined using the Colour Reader CR-100 (Minolta, Japan) [19]. The value obtained was calculated using Equation 1 to estimate the degree of whiteness (DoW).

$$DoW = 100 - \sqrt{(100 - L^2) + a^2 + b^2} \quad (1)$$

2.2.3 Determinination of water solubility, swelling power, water absorption capacity, and oil absorption capacity

The water solubility (WS), swelling power (SP), water absorption capacity (WAC), and oil absorption capacity (OBC) from DSF were determined using the method described by Baraheng and Karrila [1]. To determine WS and SP, the process began by mixing the 0.1 g (W_1) of DSF with 10 mL of distilled water. The mixture was heated in a water bath at 85 °C for 30 min and then cooled at room temperature before centrifuging at 4000 rpm for 30 min. The supernatant was dried at 105 °C until constant weight (W_2), and the wet sediment was also weighed (W_3). Equations 2 and 3 were used to calculate the WS and SP.

$$WS = \frac{W_2}{W_1}\ x\ 100 \quad (2)$$

$$SP = \frac{W_3}{W_1} \quad (3)$$

For WAC or OBC, 1 g (W_d) of DSF was weighed and dissolved in a centrifuge tube in 10 mL of distilled water or palm oil. The mixture was then vortexed for 2 minutes until homogenized and left to stand for 30 min at room temperature. After this, the mixture was centrifuged at 4000 rpm for 30 min. The liquid on top was removed, and any excess water or oil was drained for 25 min. The remaining sediment was weighed and noted as W_s. The Equation 4 was used to calculate the WAC or OBC.

$$WAC\ or\ OBC = \frac{W_s - W_d}{W_d} \quad (4)$$

2.2.4 Determination of morphology, functional group, and XRD pattern

The morphology, functional group, and XRD pattern of the DSF in this study were assessed using methods described by Witoyo et al. [20]. To begin with, the morphology of the DSF and its elements were mapped using scanning electron microscopy-energy dispersive x-ray (SEM-EDX) (FEI type Inspect S50, Japan) at an area inspection of 20 μm. Next, the functional groups of the DSF were observed using an FTIR spectrophotometer (IRSpirit–T, Shimadzu, Japan) at wavenumbers 4000 – 400 cm^{-1} with a resolution of 4 cm^{-1} and the number of scans of 10 times. Finally, the XRD pattern of the DSF was analyzed using an X-ray diffractometer (E'xpert Pro, PanAnalytical Brand, USA) at 2θ from 10-50° with a voltage target of 40 kV. The FTIR spectra and XRD pattern results of both samples were combined and analyzed using Origin 2016 Trial Version (OriginLab Corporation, USA).

2.2.5 Determination of pasting properties

The pasting properties of DSF were measured using a rapid visco analyzer (RVA TecMaster, Newport Scientific, Australia), with observed parameters including peak viscosity (PV), trough viscosity (TV), breakdown viscosity (BV), final viscosity (FV), setback viscosity (SV), peak time (PT) and temperature pasting (TP). For testing, the 3 g (dw) of DSF samples (moisture content of 14%) was mixed with the distilled water (± 25 mL) to reach a total weight of 28 g, and the testing condition was referred to the Tongdang [21].

2.2.6 Data Analysis

The amylose content, color, and functional properties were analyzed using a paired t-test using Mini Tab 17 with a 95% confidence level. The morphology, functional groups, crystallinity patterns, and pasting properties between samples were analyzed descriptively and compared with previous studies.

3. Results and Discussions

3.1 Amylose content, functional, and color properties of DSF

Table 1 displays the amylose content of DSF, highlighting a significantly higher content found in DSF-WK (19.64%) compared to CDSF (14.63%). To date, there is no specific information available on the classification of amylopectin in DSF. However, when viewed through the classification of rice starch, the DSF-WK and CDSF were classified as having low amylose content [22]. According to Zhang et al. [22], rice starch can be categorized as waxy (<2%), very low (5–12%), low (12–20%), intermediate (20–25%), or high (>25%) based on the amylose it contains. Moreover, the amylose content in this study was lower than that of other DSFs (22.65% d.b) [9], or durian seed starch (DSS) (22.76-23.30% d.b) [1]. Amylose, a non-branched polymer with a molecular weight of approximately 10^6 [9], is part of the starch granules in DSF that swells during gelatinization when water is present during heating, allowing amylose to diffuse, exit, and create a gel [23]. Its content plays a crucial role in determining the function of flour or starch in foodstuffs, influencing attributes such as swelling power, water solubility, pasting properties, rheological properties, gelatinization properties, and cooking qualities [14,15]. Additionally, high amylose content is a nutrient source that promotes a slow digestive process and has beneficial physiological effects [24].

The color of flour is an essential factor to consider in industrial applications. Any pigmentation in the raw material can affect the quality and acceptability of the final product. Table 1 presents the color of DSF, including the L*, a*, b*, and DoW. In this study, DSF-WK had significantly higher L* and DoW than CDSF. This indicates that DSF-WK has a brighter and more white appearance than CDSF. This result was confirmed through visual observation of DSF, as shown in Figure 1. Interestingly, the L* value of DSF-WK was higher than the results reported by Malini et al. [8] (80.27) and Kumoro and Hidayat [17](65-80). Notably, it fell within the same range as DSF from Medan, Indonesia (82.84 – 87.65) [25] but remained lower than the L* value of DSS (92-93) [23].

Scholars explain that the positive a* value of flour indicates the presence of redness color, while the positive b* value indicates the yellow color of flour [15]. In our context, the a* value of DSF-WK was lower and slightly little reddish than CDSF. However, both DSF-WK and CDSF had significantly higher a* values than the data reported by Malini et al. [8]. In addition, CDSF had a significantly higher b* (yellow color) than DSF-WK. The a* and b* colors in DSF are also correlated with the carotenoid pigment, a pigment with a yellow color that is contained naturally in durian seed [26, 27]. It might be because the carotenoid pigment in DS-WK was lower than in CDS. However, this study, as well as previous studies, have not thoroughly explored carotenoid levels in durian seeds, highlighting the need for further testing for future research. Interestingly, Wisutiamonkul et al. [26] reported that on days two and six, the total carotenoid concentrations in the control fruit pulp rose sharply from 28 µg/g to approximately 40 µg/g fresh weight (FW).

Furthermore, the b* value of DSF-WK was lower, but CDSF had a higher value than Malini et al. [8], who reported that the a* and b* values of DSF were 1.49 and 13.69, respectively. In other parameters, the DoW in DSF-WK and CDSF in this study was lower than the DoW of DSS (more than 90) [23]. However, the DoW in both DSF-WK and CDSF was higher than the results of the study by Simanjuntak et al. [28], which was 56.25-59.09. The higher L* and DoW and lower in a* and b* in DSF-WK than CDSF were also correlated with the particle size distribution (Figure 2) in both samples. The DSF-WK has a smaller particle size distribution in the 5.43 to 121.60 µm range than the CDSF one, which has a particle size range of 11.27 to 308.80 µm [13]. Thereby, the smaller particles are more uniform and have fine pores, decreasing the ability to absorb light and increasing the ability to reflect light, making the DSF more light and whiter [29]. Overall, the color quality of DSF is influenced by some factors, such as cultivar, fruit maturity, planting location, and processing methods [3, 16, 30, 31].

Table 1 also summarizes the functional properties of flour, such as WS, swelling power (SP), water absorption capacity (WAC), and oil absorption capacity (OAC). The WS and SP show the extent of interaction between starch chains in the amorphous and crystalline domains of the starch granule, which can be influenced by amylose and amylopectin characteristics [15]. The WS of DSF-WK and CDSF were insignificant to each sample. In this study, the WS was higher than that of DSF reported by Kumoro dan Hidayat [6] (6.95-8.35%) and Siti Farida et al. [16] (0.75 – 3.00%). However, the data from this study fell within the range of WS of DSF from Thailand (approximately 18-35%). Sindhu et al. [15] claimed the higher WS in DSF could be attributed to the high interaction of protein and fat in flour with the amylose to form protein/fat-amylose complexes. Chumsri et al. [32] added that the higher complex index between the starch-fat complex produces higher swelling power and solubility. Moreover, heating process at high temperatures, the starch granule, including the amylose, was fully swollen and gelatinized, resulting in high solubility. Permatasari et al. [13] stated that the DSF-WK has lower protein content (6.26%) and fat content (0.57%) than the CDSF's protein content (7.49%) and fat content (1.03%). Moreover, the WS is also influenced by the particle size of DSF. The small particle size needs a short time to dissolve in water into matrix samples, thus increasing the WS. However, coarse and larger particles take longer to process, which affects WS reduction [33].

In the other parameter, the SP of DSF-WK was recorded higher than CDSF's. Researchers believe that the lower SP of CDSF was correlated with the larger granules of flour [34], which was confirmed by the morphology in the following explanation. Flour's low swelling power suggests stronger bonding forces within the interiors of starch granules and more amylose-lipid complex [15]. Compared with earlier references, the SP in this study was higher than the SP of DSF from Sabah, Malaysia (approximately 2-4 g/g) [16] and native DSF from Java, Indonesia (8.03 g/g) [6]. However, the SP in this study fell within the SP of DSF from Thailand, which is approximately 10-25 g/g [1,2]. The bonding strength interaction between the protein and amylose in the DSF itself might cause the WS and SP of DSF [16]. Furthermore, the differences in amylose content, viscosity patterns, and weak internal organization resulting from negatively charged phosphate groups within the starch granules may also explain the swelling power and solubility differences [35].

Table 1 also provides that the WAC of DSF-WK was higher than that of CDSF. This variance might be due to DSF-WK's lower protein and fat content and higher amylose content, contributing to its greater capacity to absorb water. Our previous study confirmed this observation through the protein, fat, and starch content of both samples. Specifically, DSF-WK had lower protein (6.26%) and fat (0.57%) content than CDSF but similar starch content [13]. Klunklin and Savage [36] stated that low WAC is associated with high amylopectin in rice samples. Furthermore, the higher WAC in DSF-WK could be attributed to the loose association of amylopectin and amylose molecules in the samples [37,38]. The lower WAC of CDSF might also be due to its lower hydrophilic components [15]. Additionally, the variation in the granule structure of different types of flour or starch contributed to the WAC [35]. The bigger particle size in CDSF also contributed to lowering its WAC, which aligns with the study reported by Nabil et al. [39]. Surprisingly, the WAC in this study is higher than that reported in the previous study, which found that the WAC of native DSF ranged from 1.1 -1.5 g/g [1, 6, 17].

The texture and flavor retention of products are determined by the interactions between nonpolar amino acid side chains and hydrocarbon chains of lipids, which result in OAC. According to Table 1, CDSF has a higher OAC than DSF-WK, positively correlated with the protein and fat content confirmed by previous studies. The studies found that the CDSF has higher protein and fat content than DSF-WK [13], with parameters described in WAC. Siti Faridah et al. [16] reported a positive correlation between OAC and protein content, with a correlation coefficient of 0.921. The increase in OAC in DSF may be due to its higher protein and fat content, which can entrap more oil [34]. Additionally, the OAC is influenced by surface properties, charge density, hydrophilic nature [37], and particle size [40]. Compared to earlier studies, both samples have a lower OAC than DSF from Thailand (4.1-4.8 g/g) [1] but a higher OAC than DSF from Sabah, Malaysia, and Central Java, Indonesia, which is 0.24-0.77 g/g [6, 16, 17].

Table 1 Amylose content, functional properties, and colors of DSF-WK and CDSF.

Parameter	Unit	DSF-WK	CDSF	*p-value*
Amylose	%	19.64 ± 0.41^b	14.63 ± 0.19^a	0.003^s
Water solubility	%	27.18 ± 1.51^a	28.93 ± 1.88^a	0.371^{ns}
Swelling power	g/g	19.87 ± 1.12^b	12.85 ± 0.49^a	0.010^s
WAC	g/g	3.36 ± 0.11^b	2.61 ± 0.12^a	0.029^s
OAC	g/g	0.82 ± 0.04^b	1.04 ± 0.01^a	0.014^s
L	*	85.17 ± 0.15^b	68.87 ± 0.15^a	0.000^s
a	**	$+4.77 \pm 0.12^a$	$+5.40 \pm 0.10^b$	0.034^s
b	***	$+12.23 \pm 0.06^a$	$+15.13 \pm 0.06^b$	0.000^s
Degree of Whiteness	****	80.19 ± 0.12^b	64.96 ± 0.13^a	0.000^s

Note: Data averages from 3 replications ± standard deviation, *dark to light (0 to 100), **redness (+)/greenness (-), ***yellowness (+)/ blueness (-), ****no unit (100 as assumed as 'pure' white), WAC: water absorption capacity, OAC: oil absorption capacity. The different letters in the same column indicate a significant difference by paired t-test, s: significant and ns: not significant.

(A) (B)

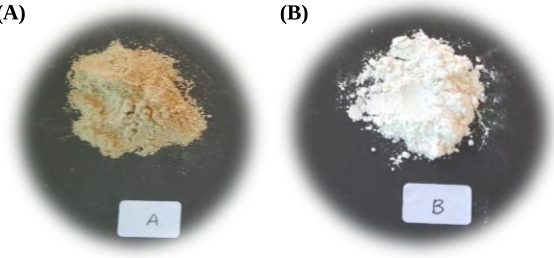

Figure 1 The visual appearance of CDSF (A) and DSF-WK (B).

3.1 Morphology and Elemental Composition of DSF

The granule shapes of DSF-WK and CDSF were polygonal with rough surfaces, either agglomerated or non-agglomerated with various particle sizes, as shown in Figure 2. This result aligns with the microstructure description of Thailand's DSF reported by Leemud et al. [2], which also reported that DSF granules have a rough surface with a polygonal shape, agglomerated and covered by a thin layer on its surface that is claimed to be gum in DSF.

In addition, Figure 2 (D) shows that CDSF appears to have more granules agglomerated and tends to have larger particle sizes than DSF-WK (Figure 2 (A)). DSF granules agglomerated due to the presence of proteins and fats, which can form complexes with starch [14]. Our previous study reported that the protein content in DSF-WK and CDSF was 6.26% and 7.49%, respectively, while fat content was 0.57% in DSF-WK and 1.03% in CDSF [13]. Furthermore, Permatasari et al. [13] reported that DSF-WK had smaller particle sizes than CDSF. The DSF-WK had the smallest particle size diameter of 5.43 μm and the largest of 121.60 μm with an average diameter of 52.11 μm. In contrast, the CDSF had an average diameter of 120.04 μm, with the smallest particle size diameter of 11.27 μm and the largest diameter of 308.80 μm. Another study reported that the smallest DSF particle size was 1.01905 μm, and the largest was 10.908 μm, with an average size of 7.03723 μm [12].

The EDX analysis (energy dispersive X-ray) showed that the constituents of the DSF, including C, O, Mg, P, and K, with a percentage of 52.71 % w.t, 44.54 % w.t, 00.55 % w.t, 00.73 % w.t, and 01.45 % w.t, respectively (Figure 2 (B)). In contrast, CDSF was only composed of three elements: C (57.46% w.t), O (40.67% w.t), and K (01.87% w.t), as shown in Figure 2 (C). These findings align with earlier studies on the constituent elements of durian seed starch and durian seed gum. Ginting [23] reported that the constituent elements of durian seed starch were C and CuO. Furthermore, the durian seed gum elements were C, O, K, Cl, and Mg [38].

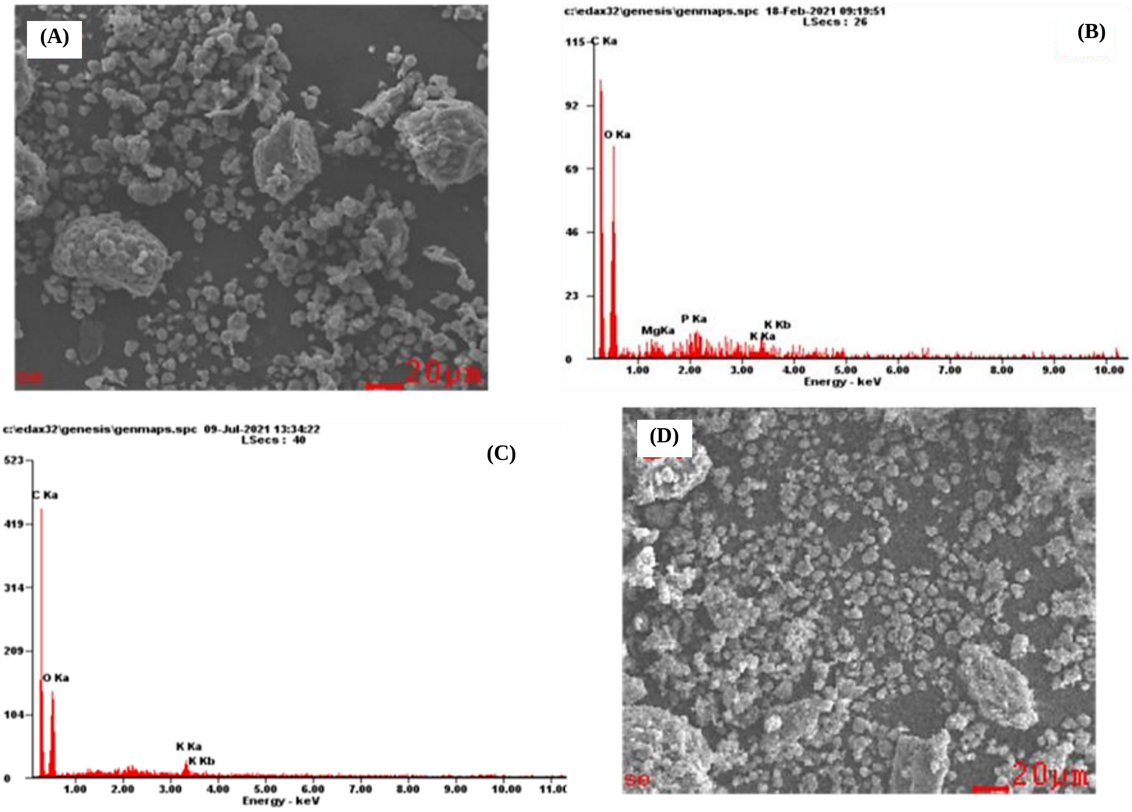

Figure 2 The microstructure of DSF-WK (A1) and CDSF (A2) at an observation area of 20 μm features with the constituent elements of DSF-WK (B1) and CDSF (B2).

3.3 Functional Group of DSF

The functional group of DSF-WK and CDSF at wavenumbers 4000 – 400 cm^{-1} is shown in Figure 3. The 800 – 1500 cm^{-1} wavenumbers indicate a "fingerprint" of carbohydrates in DSF. The C-H bending was found at 1022.59 cm^{-1} in DSF-WK and 1024.02 cm^{-1} in CDSF. The wavenumbers at 1079.64 cm^{-1} and 1081.07 cm^{-1} were found sequentially in DSF-WK and CDSF, indicating C-O-H bending. The bond between C-O and C-C was found in a wavenumber of 1153.81 cm^{-1} in both DSF-WK and CDSF samples. Furthermore, the C-O bond in DSF-WK and CDSF was found at 1242.23 cm^{-1}. The C-O bond corresponded with the fat contained in DSF samples. The amine protein group was found at ~1575.96 cm^{-1} in DSF-WK and CDSF. The amine group indicated the presence of the protein in DSF. The CH_2 bending bonds, C-H stretching vibration aliphatic, and O-H stretching were found at 1655.42 cm^{-1}, 2929.44 cm^{-1}, and 3351.60 cm^{-1} in both samples. Moreover, the O-H bonds indicated the presence of amylose and amylopectin in the DSF samples. This result corresponds to the FTIR of DSF reported by Alighiri et al. [12] and the FTIR gum durian seeds reported by Zebua et al. [38]. Results from this study confirmed that the main component of DSF was carbohydrates, primarily starch. This is supported by results from our previous study, which reported that DSF contains a total carbohydrate of 80.61% for DSF-WK and 78.20% for CDSF. Moreover, the starch from total carbohydrates was 41.42% and 46.81% for DSF-WK and CDSF, respectively [13].

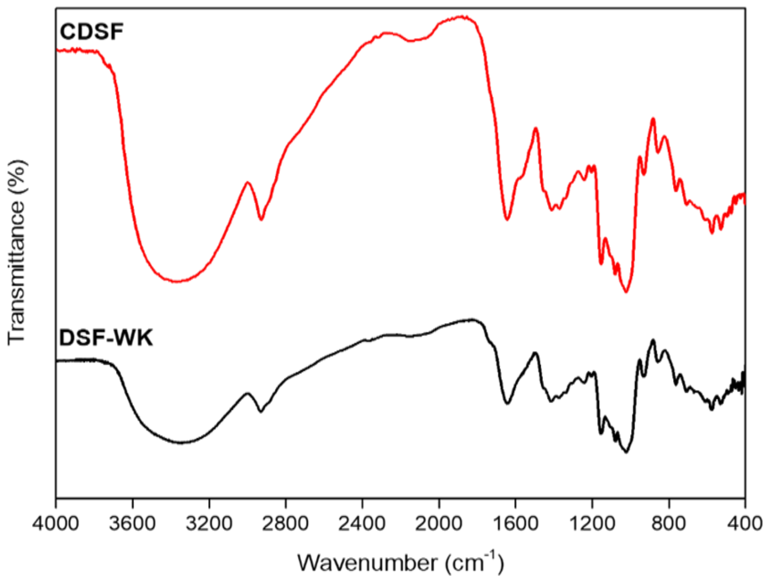

Figure 3 Functional group patterns of DSF-WK and CDSF.

3.4 X-ray Diffraction (XRD) of DSF

The X-ray diffraction (XRD) of DSF-WK and CDSF showed similar observed peaks, as shown in Figure 4. Specifically, the DSF-WK and CDSF exhibited peak at 2θ values of 15.03°, 17.02°, 18.05°, and 23.01°, while CDSF had peaks of 2θ in 14.73°, 17.05°, and 23.17°. This result corresponds to the peak of 2θ of durian flour reported by Bai-Ngew et al. [41], which has peaks of 2θ at 15.08°, 17.08°, 17.99° and 22.80°. The peak of 2θ observed in both samples indicated that DSF-WK and CDSF had the same crystallinity patterns, namely the type A-diffraction crystallinity pattern. Yan et al. [42] described that the typical pattern of type A- a crystalline pattern of brown rice starch is observed at 2θ at 15, 17, 18, and 23°. Further, Ding et al. [43] reported that type A - polymorphism in barley seed starch was observed at peak reflecting the intensity of about 15.16°, 17.23°, 18.14° and 23.11°.

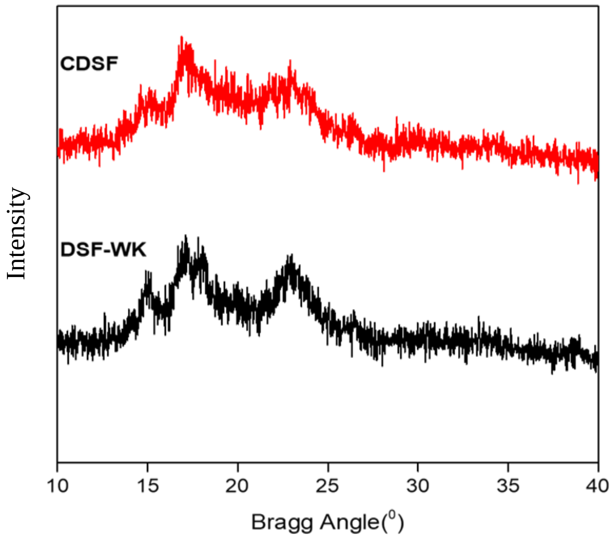

Figure 4 XRD Pattern of DSF-WK and CDSF.

3.5 Pasting Properties of DSF

The last finding is illustrated in Table 2, displaying the DSF properties, such as PV, TV, breakdown viscosity (BDV), FV, V, peak time (PK), and PT. PV represents the starch's ability to absorb water to its maximum swelling capacity [14]. In this study, DSF-WK had a higher PV than CDSF but a lower PV than reported by Baraheng and Karrila (2260 -2400 cP) [1], Leemud et al. (1918 cP) [2], and Malini et al. (1715 cP) [8]. The PV of DSF-WK was more similar to DSF from Sabah, Malaysia, as reported by Siti Faridah et al. [16] to be 1266.00 -1927.00 cP.

Meanwhile, CDSF had a lower PV than those reported in previous studies. A higher PV in DSF-WK may have resulted from its higher amylose content, as confirmed by Table 1. Zhong et al. [44] claimed that the high concentration of amylose in DSF-WK might form a rigid molecular network that stabilizes during the swelling of flour or starch granules and affects the increase in PV. Moreover, the DSF-WK had a higher TV than the CDSF. However, both DSFs in this study had a lower TV than DSF from Thailand, which was reported to be 1850 - 2100 cP [1].

Nevertheless, this study's highest amylose content results in high PV and TV in DSF-WK, which differs from several previous studies [45–47]. Therefore, further investigation is needed to understand the phenomenon in more detail. Karakelle et al. [45] reported that all viscosity parameters, such as PV, TV, BDV, FV, and setback viscosity (SV), were all negatively correlated with an amylose content of maize starch. Starch with high amylose content generally shows lower peaks and viscosities compared to starch with lower amylose content because high amylose can reduce swelling and increase retrogradation, resulting in a thinner paste [46, 47].

The BDV was used to measure the resistance of starch gels to be destroyed due to high temperature and shear stress during processing [14]. The BDV of DSF-WK was found to be lower than that of CDSF. However, the BDV in this study was lower than the BDV of DSF from Malaysia (179.00 - 357.67 cP) [16] and Thailand (320 – 400 cP) [1]. The lower values of BDV in DSF-WK than in CDSF, and previous studies indicated that DSF-WK had higher paste stability and greater resistance to shear stress and temperature during cooking [14, 34]. Next, FV represents the flour or starch's ability to form a viscous paste [14]. The FV of DSF-WK was found to be higher than that of CDSF. However, FV from DSF-WK and CDSF was lower than the TV of DSF from Thailand, which is 2090-2330 cP [1]. The higher FV in DSF-WK might be due to its higher amylose content than in CDSF, as shown in Table 1. According to Sindhu and Khatkar [14], the increase in FV from PV might be caused by the aggregation of amylose molecules during processing.

Furthermore, SV measured the syneresis level since the cooling of the hot paste [14]. Based on Table 2, the SV of DSF-WK was lower than CDSF's. The SV of DSF and CDSF was higher than the SV of DSF from Thailand (240 - 250 cP) [1]. However, the SV of CDSF was in the range of SV of DSF from Sabah, Malaysia (530.67 – 810.67 cP) [16]. According to Ahmed et al. [24], the high SV was associated with the high amylose content and the molecular weight of soluble amylose from granules and remnants of the gelatinized starch. The higher SV indicated a higher resistance to retrogradation during cooling [34]. Interestingly, the opposite fact was found in this study, DSF-WK, which had higher amylose content than CDSF, as shown in Table 1, but had a lower SV as in Table 2.

In terms of PK, CDSF had a shorter duration than DSF-WK. However, CDSF still fell within the range of PK for DSF from Thailand, typically between 5.9 - 7 minutes [1]. In contrast, DSF-WK and CDSF had a lower PK than DSF from Palembang, which lasted 8 minutes [8]. The shorter PK in DSF-WK may be attributed to its lower fat content, which was only 0.57% compared to CDSF's 1.03% [13]. Baraheng and Karrila [1] found that a high-fat content in DSF can form lipid-amylose complexes during starch gelatinization, hindering the binding of starch molecules to water and resulting in a longer PK and lower FV. Additionally, Liu et al. [48] reported that increased protein quantity can lead to protein-starch interactions, reducing the swelling power of starch and increasing PT.

A minimum temperature is required to cook flour, represented as PT [14]. Comparing DSF-WK to CDSF, it was found that the PT of DSF-WK was lower. However, when compared to DSF from Malaysia, Thailand, and Palembang, Indonesia, both DSF-WK and CDSF had higher PTs than the range of 54.90 – 81.00 °C [1, 2, 8, 16]. The PT correlated with the protein content and swelling [14], confirmed in a previous study that DSF-WK contained a protein content of 6.26% and 7.49% of CDSF [13]. The disparity might be attributed to the lower PT found in DSF-WK compared to CDSF.

Table 2 Pasting properties of DSF-WK and CDSF.

Parameter	Unit	DSF-WK	CDSF
Peak Viscosity (PV)	cP	1288.00	580.00
Trough Viscosity (TV)	cP	1134.00	407.00
Breakdown Viscosity (BDV)	cP	154.00	173.00
Final Viscosity (FV)	cP	1463.00	959.00
Setback Viscosity (SV)	cP	329.00	552.00
Peak Time (PK)	min	4.87	7.00
Pasting Temperature (PT)	˚C	82.90	94.65

3. Conclusion

Extensive research has been conducted to analyze the physical, functional, structural, and pasting properties of DSF. Compared to DSF-WK, CDSF exhibited significantly lower L*, b*, swelling power, and water absorption capacity (WAC). However, no significant differences were observed in water solubility (WS) between DSF-WK and CDSF. CDSF, on the other hand, had notably higher a*, b*, and OAC. The microstructure of both DSF-WK and CDSF was observed to have polygonal shapes. DSF-WK was found to consist of C, O, Mg, P, and K elements, while CDSF only contained C, O, and K. Infrared spectra revealed the constituent bonds of DSF to be C-H, C-O-H, C-O, C-C, CH_2, and O-H. DSF-WK and CDSF exhibited the same Type A diffraction pattern in XRD analysis.

Pasting properties assessed using RVA revealed that CDSF had higher BV, SV, PT, and TP when compared to DSF-WK. However, CDSF showed lower PV, TV, and FV. In general, the DSF-WK exhibited higher white color, functional characteristics, particularly in water, and distinctive pasting properties that made it suitable for use in food products that need color and high viscosity, like cookies, noodles, or related products, and other applications like as a raw material for edible films.

4. Acknowledgments

We would like to extend our deepest gratitude to the Politeknik Tonggak Equator Foundation in Pontianak, Indonesia, for providing full financial assistance for this research.

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