

VALORIZATION OF DRAGON FRUIT PEEL: EXTRACTION, STRUCTURAL ANALYSIS AND FUNCTIONAL PROPERTIES OF DIETARY FIBER

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ABSTRACT

Dragon fruit (*Hylocereus undatus*) peel, an abundant agricultural by-product in Vietnam, is rich in dietary fiber but often underutilized, leading to resource waste. This study aimed to optimize the extraction of soluble dietary fiber (SDF) from dragon fruit peel under acidic conditions and to characterize its structural and functional properties for potential food applications. The effects of solid-to-liquid ratio, pH, temperature, and extraction time on SDF yield were systematically investigated. Optimal extraction conditions were identified at a solid-to-liquid ratio of 1:37.5 (w/v), pH 2.5, 80 °C, and 60 minutes, resulting in an SDF yield of $14.54 \pm 0.50\%$. Fourier-transform infrared spectroscopy (FTIR) confirmed the polysaccharide structure of both SDF and insoluble dietary fiber (IDF), while scanning electron microscopy (SEM) revealed that SDF exhibited a porous and amorphous microstructure, in contrast to the dense, fibrous morphology of IDF. X-ray diffraction (XRD) analysis further demonstrated the amorphous nature of SDF and the partial crystallinity of IDF, indicating distinct structural functionalities. Functional assessments showed that SDF had a water-holding capacity of 21.25 ± 0.34 g/g, an oil-holding capacity of 3.85 ± 0.54 g/g, and a swelling capacity of 32.36 ± 1.06 mL/g. These findings suggest that SDF extracted from dragon fruit peel possesses favorable structural and physicochemical characteristics, making it a promising candidate for incorporation as a functional ingredient in food systems. The study also supports the valorization of agro-industrial by-products, contributing to sustainable development and waste reduction in the food industry.

Keywords: Dragon fruit peel, *Hylocereus undatus*, dietary fiber, acid extraction, structure, physicochemical properties.

1. INTRODUCTION

Dragon fruit (*Hylocereus* spp. and *Selenicereus* spp.), belonging to the Cactaceae family, is an exotic tropical fruit increasingly valued for its distinctive appearance, sensory attributes, and nutritional properties [1]. Its global production is expanding, with Vietnam recognized as a leading exporter [2]. However, commercial processing generates substantial quantities of peel waste, comprising 20–40% of the fruit weight, which is typically discarded [3]. This represents a significant economic loss and contributes to the environmental burden due to the high organic content of the waste [4, 5]. Consistent with current efforts toward sustainable resource utilization and circular economy models, dragon fruit peel (DFP) has attracted attention as a promising by-product rich in bioactive compounds, notably dietary fiber (DF),

phenolic acids, and betalains [3]. Dehydrated DFP is particularly abundant in DF, positioning it as a potential raw material for extracting functional ingredients for food and nutraceutical applications [6].

Dietary fiber is a complex group of carbohydrate polymers that resist enzymatic digestion in the human small intestine [7]. It is classified into insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) based on water solubility [8]. IDF, mainly composed of cellulose, hemicellulose, and lignin, primarily improves bowel regularity. In contrast, SDF, including pectins, β -glucans, and gums, forms viscous gels that contribute to glycemic control, cholesterol reduction, and enhanced satiety [9]. SDF is also of considerable interest for food applications due to its favorable techno-functional properties, such as water-holding capacity (WHC), oil-holding capacity (OHC), and swelling capacity (SC) [10, 11]. However, SDF's natural abundance in many plant sources is lower than IDF's, necessitating efficient extraction strategies to concentrate the SDF fraction [12]. Therefore, valorizing DFP through the selective recovery of SDF offers a strategic avenue for enhancing its functional and commercial value.

Acid extraction represents a practical and accessible method for recovering SDF, particularly pectin, from fruit peels [13, 14]. Citric acid, a mild organic acid of natural origin widely applied in food processing due to its established safety profile, is frequently selected for this purpose [13]. The mechanism involves acid-catalyzed hydrolysis of glycosidic linkages within the plant matrix, facilitating the solubilization of SDF components [14]. In this study, the optimization of extraction parameters - including acid concentration (pH), extraction temperature, extraction time, and solid-to-liquid ratio - will be systematically investigated using a One-Factor-At-a-Time (OFAT) experimental design [14], rather than multivariate approaches such as Response Surface Methodology. This approach aims to identify the most effective individual conditions to maximize SDF yield while preserving key structural features. Previous investigations have demonstrated the feasibility of SDF extraction from dragon fruit peel [6, 11, 13]; however, a focused optimization using conventional citric acid extraction specifically targeting SDF remains limited. Building upon existing studies, this research seeks to refine a practical, food-grade extraction method to valorize DFP.

After extraction under optimized conditions, the recovered SDF will be comprehensively characterized to evaluate its structural and functional attributes. Scanning Electron Microscopy (SEM) will assess surface morphology and porosity. At the same time, Fourier-Transform Infrared Spectroscopy (FTIR) will be used to identify functional groups associated with polysaccharides, such as hydroxyl and carboxyl groups [11–14]. X-ray Diffraction (XRD) will also provide insights into the crystalline or amorphous nature of the extracted fibers [11–14]. These structural analyses will be complemented by evaluating key physicochemical properties, including WHC, OHC, and SC, critical determinants of the fiber's functional performance in food systems [6, 7, 10, 14]. This integrated approach is anticipated to provide valuable data supporting the utilization of dragon fruit peel-derived SDF as a functional food ingredient, contributing to sustainable waste management and value addition in dragon fruit processing industries, particularly in high-production regions such as Vietnam.

2. MATERIAL AND METHODS

Fresh white-fleshed dragon fruits (*Hylocereus undatus*) were sourced from a local agricultural market in Ho Chi Minh City, Vietnam, with origins traced to major growing regions such as Bình Thuận and Long An province. Only commercially mature fruits (600–800 g), with firm texture and no visible defects, were selected. Peels were separated and processed within 6 hours of purchase to minimize degradation. The peels were washed, sliced, and oven-dried at 60 °C for 18 hours or until constant weight. Dried peels were ground and passed through a 100 mesh sieve (approx. 150 μ m opening) to produce a uniform dragon fruit

peel powder (DFPP). The powder was stored in sealed polyethylene bags at room temperature, protected from moisture and light until use. This preparation procedure, adapted from Corimayhua-Silva *et al.* [15], ensured material consistency across experimental batches and met quality standards suitable for food-grade functional ingredient extraction.

2.1. Dietary fiber extraction preparation

Dietary fiber extraction was conducted using an aqueous solvent under varying conditions of solid-to-liquid ratio (15–45 g/mL), pH (1.5–5.5) adjusted with 5% citric acid solution, extraction temperature (50–90 °C), and extraction time (30–90 minutes). A One-Factor-At-a-Time (OFAT) experimental approach was employed to evaluate the effect of each parameter individually on the yield of soluble dietary fiber (SDF). In each trial, only one factor was modified within its specified range while the remaining parameters were held constant at baseline values. This strategy enabled the systematic assessment of the isolated impact of each factor on extraction efficiency. Although OFAT does not capture potential interactions among variables, it provides clear and practical insights into the optimal level of each parameter. This design aimed to identify extraction conditions that maximize SDF yield, owing to its well-documented health benefits and favorable techno-functional properties in food applications [16–19]. Following SDF recovery under the established conditions, the insoluble dietary fiber (IDF) fraction was also collected and subjected to comparative structural and functional characterization alongside DFPP and SDF.

Specifically, one gram of DFPP was dispersed in distilled water, and the pH was carefully adjusted with a 5% citric acid solution. The mixture was then extracted in a temperature-controlled water bath for the duration. After extraction, the mixture was cooled to room temperature and vacuum-filtered to separate the filtrate from the residue. The residue was then washed three times with 96% ethanol to remove impurities and dried at 60 °C until a constant weight was reached to obtain IDF, following a modified method by Wang *et al.* [20]. Meanwhile, the filtrate was followed by a technique of Lin *et al.* [21] by continuing to precipitate with 96% ethanol at a ratio of 1:2 (v/v) and incubating overnight at 4 °C. The obtained precipitate was then separated by centrifugation at 6000 rpm for 15 minutes and washed three times with 96% ethanol to eliminate impurities. Afterward, it was dried at 60 °C until a constant weight was reached to obtain SDF. Finally, the SDF yield (%) was determined by dividing the weight of SDF (g) by the weight of the sample (g) and multiplying by 100.

2.2. Characterization analysis of dietary fiber structure

2.2.1. Microstructure analysis by Scanning Electron Microscopy (SEM)

The microstructure of DFPP, IDF, and SDF samples was examined using a scanning electron microscope (SEM) (JSM-IT200 InTouchScope™, JEOL, Japan). Microstructural images were captured at magnifications of ×1000 and ×10000.

2.2.2. Chemical structure analysis by Fourier-Transform Infrared (FT-IR) Spectroscopy

The DFPP, IDF, and SDF samples were analyzed using a Fourier transform infrared (FT-IR) spectrometer (FT/IR-6X, JASCO, Japan). The near-infrared spectrum was recorded in the 500 - 4000 cm⁻¹ wavenumber range with a resolution set at 2 cm⁻¹.

2.2.3. Crystal structure analysis by X-ray Diffraction (XRD)

The DFPP, IDF, and SDF samples were analyzed using an X-ray diffraction (XRD) spectrometer (D2 Phaser, Bruker, Germany) to evaluate the crystalline structure. The diffraction scan (2θ) was performed in the 5 - 80° range with a step size of 0.02°, a tube current of 10 mA, and a voltage of 30 kV, utilizing a Lynxeye detector in 1D mode.

2.3. Techno-functional properties analysis

The water-holding, oil-holding, and swelling capacity were evaluated according to the method of He *et al.* [22].

2.3.1. Water holding capacity (WHC)

Firstly, a 0.50 g sample was precisely weighed and dispersed in distilled water at a 1:100 (w/w) ratio, then incubated in a centrifuge tube at room temperature for 1 hour. The mixture was subsequently centrifuged at 5000 rpm for 15 minutes. After decanting to remove the liquid, the weight of the remaining residue was recorded. The WHC was expressed as the weight of the residue (g) per weight of the sample (g).

2.3.2. Oil holding capacity (OHC)

A 0.50 g sample was weighed and mixed with 10 g of soybean oil, then incubated in a centrifuge tube at room temperature for 1 hour. The mixture was subsequently centrifuged at 5000 rpm for 20 minutes. After decanting to remove any free oil, the weight of the residue was recorded. The OHC was expressed as the weight of residue (g) per weight of the sample (g)

2.3.3. Swelling capacity (SC)

A 0.50 g sample is placed in a 25 mL graduated cylinder for SC analysis. The initial volume is recorded before adding 20 mL of distilled water. The mixture is then shaken for 5 minutes and allowed to stand at room temperature for 24 hours. After the standing period, the final volume is measured. The SC was expressed as the volumetric change of dry samples relative to the sample's weight.

2.4. Statistical analysis

All experiments were conducted in triplicate. Then, using Excel (Office 365) and Minitab (version 19.2) software, the data will be statistically analyzed using one-way ANOVA to test for differences according to Turkey's test at a 5% significance level. Data are reported as mean \pm standard deviation, and statistical significance was defined as $p < 0.05$.

3. RESULTS/DISCUSSION

3.1. Effect of extraction conditions on SDF yield

3.1.1. Effect of solid-to-liquid ratio

As shown in Figure 1, increasing the solid-to-liquid ratio from 1:15 to 1:37.5 significantly enhanced SDF yield from $6.04 \pm 0.07\%$ to $12.18 \pm 0.28\%$. However, further increasing the ratio to 1:45 resulted in a slight decline to $11.77 \pm 0.15\%$, indicating that extraction efficiency had reached saturation. Therefore, a ratio of 1:37.5 was identified as the optimal condition for SDF yield. This result closely aligns with the optimal solvent-to-solid ratios reported by Lin

et al. [21] and Tran [23], which were 1:35 g/mL and 1:34.24 g/mL, respectively. The rationale is that a lower solvent ratio may not provide sufficient diffusion into the material's micropores, reducing extraction efficiency. Conversely, an excessively high solvent ratio can increase processing costs without yielding additional benefits. Based on these findings, a solid-to-liquid ratio of 1:37.5 was selected as a fixed parameter for subsequent optimization experiments.

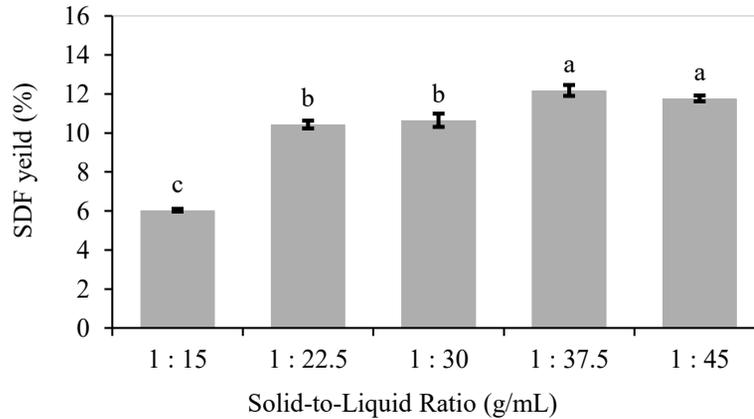


Figure 1. Effect of Solid-to-Liquid Ratio on SDF yield
(Different lowercase letters above the bars indicate statistically significant differences ($p < 0.05$))

3.1.2. Effect of pH

Figure 2 shows that the lowest SDF yield ($4.41 \pm 0.10\%$) was observed at pH 1.5. However, as the pH increased to 3.5, SDF yield significantly improved, reaching $12.18 \pm 0.28\%$. According to Tran [23], pH 3.5 is the optimal condition for extracting pectin (soluble dietary fiber) from red dragon fruit peel, as the acidic environment facilitates the breakdown of polysaccharide linkages in the cell wall, allowing pectin to diffuse into the solvent. However, further increasing the pH to 5.5 led to a decline in SDF yield to $9.19 \pm 0.20\%$. Therefore, pH 3.5 was the most suitable condition for maximizing SDF extraction and was selected as a fixed parameter for subsequent experiments.

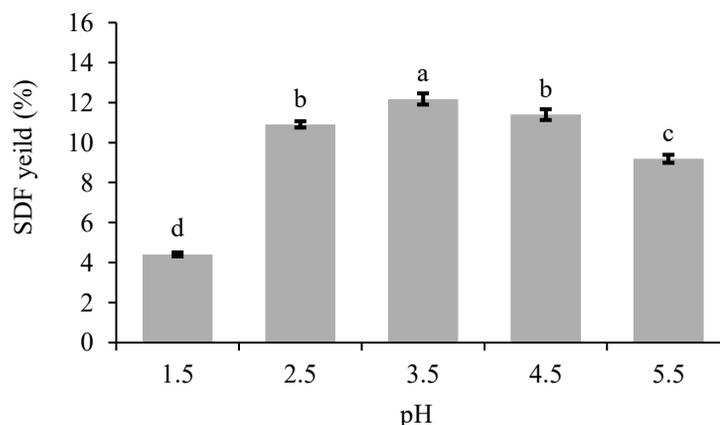


Figure 2. Effect of pH on SDF yield
(Different lowercase letters above the bars indicate statistically significant differences ($p < 0.05$))

3.1.3. Effect of extraction temperature

As shown in Figure 3, SDF yield increased from $9.18 \pm 0.10\%$ at $50\text{ }^{\circ}\text{C}$ to a peak of $14.54 \pm 0.50\%$ at $80\text{ }^{\circ}\text{C}$ before decreasing to $11.97 \pm 0.89\%$ at $90\text{ }^{\circ}\text{C}$. According to Tran [23], a temperature of $90\text{ }^{\circ}\text{C}$ is considered excessive, as it can lead to pectin degradation, the primary component of soluble fiber SDF. Elevated temperatures accelerate the breakdown of glycosidic and ester linkages in the pectin structure, deteriorating SDF integrity. Consequently, $80\text{ }^{\circ}\text{C}$ was identified as the optimal temperature for SDF extraction and was selected as a fixed parameter for further experiments.

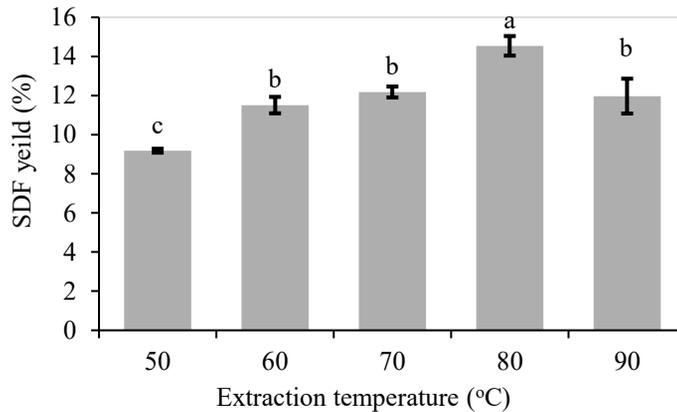


Figure 3. Effect of Extraction temperature on SDF yield
(Different lowercase letters above the bars indicate statistically significant differences ($p < 0.05$))

3.1.4. Effect of extraction time

The relationship between extraction duration and Soluble Dietary Fiber (SDF) yield is depicted in Figure 4. Initially, SDF yield demonstrated an upward trend, rising from $12.2 \pm 0.12\%$ at 30 minutes to a peak of $14.54 \pm 0.50\%$ when the extraction time reached 60 minutes. Subsequently, prolonging the extraction process led to a progressive decrease in yield, registering $12.05 \pm 0.73\%$ at 90 minutes. This reduction is postulated to result from enhanced pectin degradation during extended exposure to the acidic environment. Such conditions can promote the hydrolysis of crucial glycosidic and ester bonds within pectin molecules [24], lowering the efficiency of SDF isolation. Based on these results, 60 minutes was the optimal extraction time to achieve the maximal SDF yield.

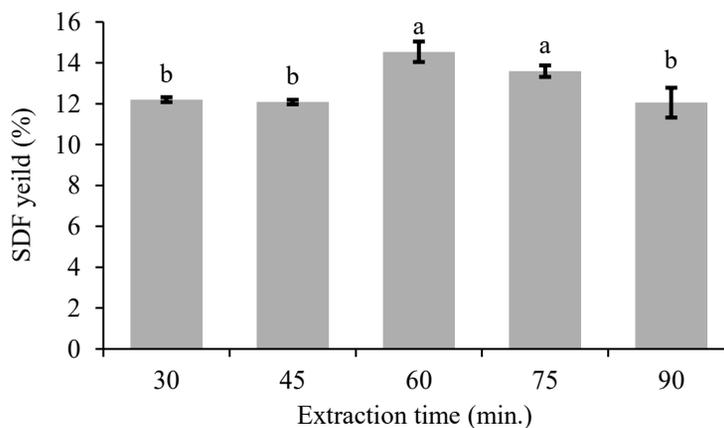


Figure 4. Effect of Extraction time on SDF yield
(Different lowercase letters above the bars indicate statistically significant differences ($p < 0.05$))

3.2. Structural characterization of dietary fibers

3.2.1. SEM

SEM analysis reveals that dragon fruit peel powder (Figure 5A, 5B) features a heterogeneous structure with cellulose fibers and a pectin network, supporting its multifunctional role in food applications. Insoluble fiber (Figure 5C, 5D) displays a thick, porous structure that aids digestion. In contrast, soluble fiber (Figure 5E, 5F) forms a fine mesh-like network, making it ideal for gel formation and cholesterol reduction. These structural differences highlight the distinct functions of each fiber type, with dragon fruit peel powder standing out for its balanced combination of both. However, further chemical analysis and processing evaluations are necessary to understand the relationship between microstructure and functional properties.

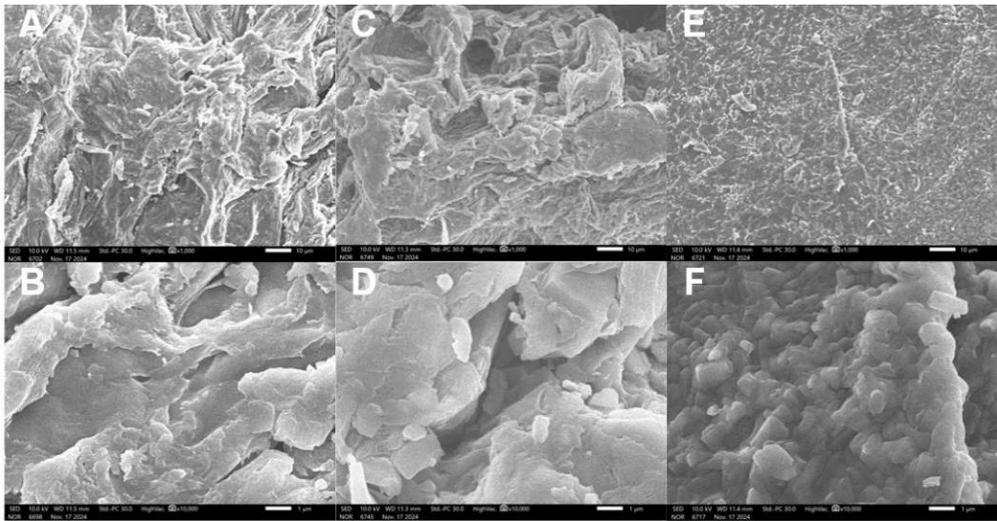


Figure 5. SEM images of DFPP (A and B), IDF (C and D), and SDF (E and F) ((A, C, E): $\times 1000$; (B, D, F): $\times 10000$)

3.2.2. FT-IR

The FT-IR spectra of the samples display characteristic vibrations within the 4000-500 cm^{-1} range, indicating the presence of polysaccharide structures (Figure 6). Absorption peaks around 3300, 2900, 1700, and 1200-800 cm^{-1} highlight distinct differences among the samples. The broad peak at 3300 cm^{-1} corresponds to hydroxyl (-OH) groups, while the peak at 2900 cm^{-1} relates to various methyl (-CH, -CH₂, -CH₃) functional groups [25]. DFPP and IDF exhibit absorption at these wavelengths, whereas SDF does not. This absence in SDF likely results from stretching vibrations of -OH in cellulose and hemicellulose, which are characteristic of insoluble fiber fractions [14]. DFPP shows the lowest absorption intensity at 1700 cm^{-1} compared to IDF and SDF, likely due to its unprocessed nature and higher impurity content. This difference suggests a lower fiber concentration in DFPP than the extracted fiber fractions [11]. In the 1200-800 cm^{-1} region, SDF exhibits the most distinct absorption peaks, representing the fingerprint region of pectic polymers, a key characteristic of soluble fiber fractions [26]. These findings confirm the successful separation of dietary fiber components and highlight structural differences between soluble and insoluble fiber fractions.

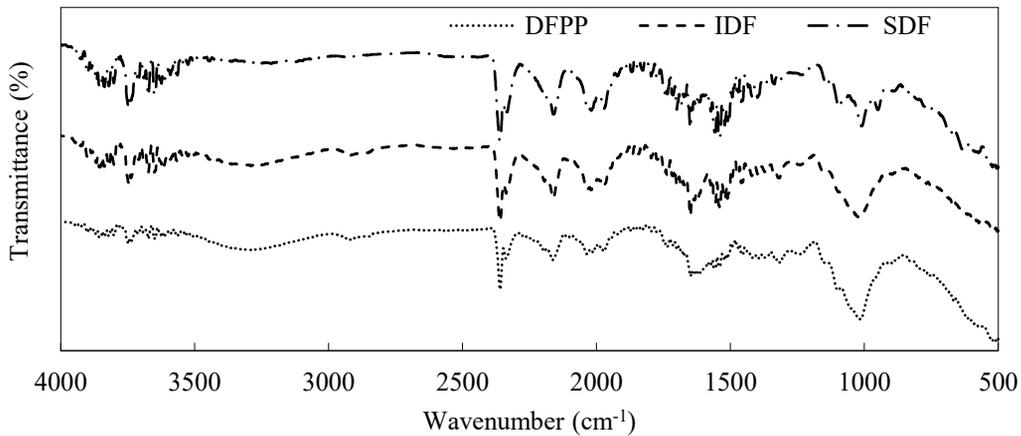


Figure 6. FTIR of DFPP, IDF, and SDF

3.2.3. XRD

The X-ray diffraction (XRD) analysis provided insights into the crystallinity of dietary fibers [27]. The samples' crystallinity, or the degree of crystalline order, was assessed by analyzing diffraction peaks' shape, intensity, and width. DFPP and IDF exhibited broad diffraction patterns with weak crystalline reflections centered around $2\theta = 20^\circ$, indicative of a predominantly amorphous structure within the crystalline domains (Figure 7). This broad peak is characteristic of cellulose type I, which typically displays a paracrystalline structure [28]. Additionally, DFPP displayed sharper reflections at $2\theta = 14.226^\circ$ and 32.146° . These peak positions are consistent with those reported by Taharuddin *et al.* [29] for cellulose type I crystals, suggesting the presence of regions with higher crystalline order within the predominantly amorphous DFPP.

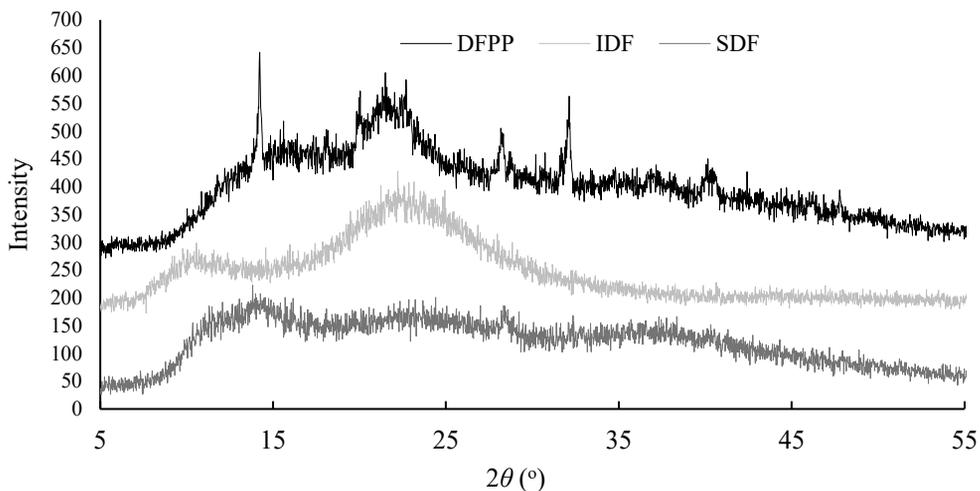


Figure 7. XRD of DFPP, IDF, and SDF

In contrast, SDF showed a broad halo extending from 14° to 25° , lacking sharp, well-defined peaks. This feature is characteristic of a highly disordered, amorphous, or semi-crystalline structure [30]. The increased amorphous character of SDF can be attributed to the acid treatment process, which disrupts the inter- and intra-molecular hydrogen bonding

network of cellulose, leading to chain fragmentation and a reduction in crystalline order. This process also hydrolyzes starch and hemicellulose components, further contributing to the overall amorphous nature of the material, and results in the solubilization of protein content [31].

3.3. Techno-functional properties

Soluble dietary fiber (SDF) demonstrates exceptional functional properties, including a water-holding capacity (WHC) of 21.25 ± 0.34 g/g, an oil-holding capacity (OHC) of 3.85 ± 0.54 g/g, and a swelling capacity (SC) of 32.36 ± 1.06 mL/g. These characteristics render SDF highly effective as a gelling agent, stabilizer, and emulsifier in food applications. These results are consistent with findings reported by Sang *et al.* [32] in a study on dietary fiber (DF) extraction from Newhall Navel Orange by-products, highlighting the potential of these DF fractions as valuable raw materials for the functional food industry. Specifically, the elevated WHC of SDF enhances sensory attributes and reduces calorie content in food products [33]. Furthermore, its substantial OHC improves the stability of fat-rich and emulsion-based foods by facilitating the dispersion of immiscible liquids [34]. Additionally, the pronounced SC of SDF proves advantageous in the frozen food sector, where it promotes hydrodynamic volume expansion, sustains moisture retention in cooked meat and fish products, and minimizes drip loss [26]. In contrast, insoluble dietary fiber (IDF), with a moderate WHC of 17.90 ± 0.46 g/g and SC of 18.19 ± 0.13 mL/g, is better suited for enhancing the texture of solid foods and promoting digestive health.

Table 1. Techno-functional properties of DFPP, IDF, and SDF

Sample	WHC (g/g)	OHC (g/g)	SC (mL/g)
DFPP	11.92 ± 0.24^c	2.41 ± 0.03^b	17.15 ± 0.42^b
IDF	17.90 ± 0.46^b	2.92 ± 0.01^b	18.19 ± 0.13^b
SDF	21.25 ± 0.34^a	3.85 ± 0.54^a	32.36 ± 1.06^a

*Data labeled with different letters represent statistically significant differences ($p < 0.05$)

4. CONCLUSION

This study optimized dietary fiber extraction from dragon fruit peel, yielding $14.54 \pm 0.50\%$ soluble dietary fiber (SDF) under a 1:37.5 g/mL solid-to-liquid ratio, pH 3.5, 80 °C, and 60 minutes. SDF showcased superior functional properties, including high water-holding capacity (WHC), oil-holding capacity (OHC), swelling capacity (SC), and solubility, making it an excellent gelling agent, stabilizer, and emulsifier for applications like jams, dressings, and beverages. Conversely, insoluble dietary fiber (IDF) exhibited a dense structure ideal for enhancing texture in solid foods. Scanning electron microscopy (SEM) revealed IDF's compact form and SDF's porous surface, Fourier-transform infrared spectroscopy (FTIR) confirmed their polysaccharide nature, and X-ray diffraction (XRD) highlighted IDF's crystallinity versus SDF's amorphous structure. These properties position SDF as a versatile ingredient while promoting sustainable valorization of agricultural by-products, turning waste into an eco-friendly, innovative food resource.

REFERENCES

1. Bhadauria, S., Choudhary, T., & Chaurasia, S. - Exploring the therapeutic potential of dragon fruit: An insightful review, *International Journal of Pharmacognosy* **11** (6) (2024) 222-234. [https://doi.org/10.13040/IJPSR.0975-8232.IJP.11\(6\).222-34](https://doi.org/10.13040/IJPSR.0975-8232.IJP.11(6).222-34)
2. Mercado-Silva, E.M. - Pitaya-*Hylocereus undatus* (Haw), In *Exotic Fruits Reference Guide* (2018) 339–349. <https://doi.org/10.1016/B978-0-12-803138-4.00045-9>
3. Thi Thuy Hai Luu, Truc Linh Le, Nga Huynh, & Quintela-Alonso, P. - Dragon fruit: A review of health benefits and nutrients and its sustainable development under climate changes in Vietnam, *Czech Academy of Agricultural Sciences* **39** (2) (2021) 71-94. <https://doi.org/10.17221/139/2020-CJFS>
4. Teshome, E., Teka, T.A., Nandasiri, R., Rout, J.R., Harouna, D.V., Astatkie, T., & Urugo, M.M. - Fruit by-products and their industrial applications for nutritional benefits and health promotion: A Comprehensive Review, *Sustainability* **15** (10) (2023) 7840. <https://doi.org/10.3390/su15107840>
5. Hasan, M. M., Islam, M. R., Haque, A. R., Kabir, M. R., Khushe, K. J., & Hasan, S. M. K. - Trends and challenges of fruit by-products utilization: insights into safety, sensory, and benefits of the use for the development of innovative healthy food: a review, *Bioresource and Bioprocessing* **11** (10) (2024). <https://doi.org/10.1186/s40643-023-00722-8>
6. Madane, P., Das, A.K., Nanda, P.K., Bandyopadhyay, S., Jagtap, P., Shewalkar, A., & Maity, B. - Dragon fruit (*Hylocereus undatus*) peel as antioxidant dietary fibre on quality and lipid oxidation of chicken nuggets, *Journal of Food Science and Technology* **57** (4) (2020) 1449-1461. <https://doi.org/10.1007/s13197-019-04180-z>
7. Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C., & Attia, H. - Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review, *Food Chemistry* **124** (2) (2011) 411-421. <https://doi.org/10.1016/j.foodchem.2010.06.077>
8. Plakantonaki, S., Roussis, I., Bilalis, D., & Priniotakis, G. - Dietary Fiber from Plant-Based Food Wastes: A Comprehensive Approach to Cereal, Fruit, and Vegetable Waste Valorization, *Processes* **11** (5) (2023) 1580. <https://doi.org/10.3390/pr11051580>
9. Buljeta, I., Šubarić, D., Babić, J., Pichler, A., Šimunović, J., and Kopjar, M. - Extraction of Dietary Fibers from Plant-Based Industry Waste: A Comprehensive Review, *Applied Sciences* **13** (16) (2023) 9309. <https://doi.org/10.3390/app13169309>
10. Mudgil, D., & Barak, S. - Classification, Technological Properties, and Sustainable Sources in Dietary Fiber: Properties, Recovery and Applications, Elsevier (2019) 27-58. <https://doi.org/10.1016/B978-0-12-816495-2.00002-2>
11. Vilcapoma, W., de Bruijin, J., Elías-Peñafiel, C., Espinoza, C., Farfán-Rodríguez, L., López, J., & Encina-Zelada, C.R. - Optimization of Ultrasound-Assisted Extraction of Dietary Fiber from Yellow Dragon Fruit Peels and Its Application in Low-Fat Alpaca-Based Sausages, *Foods* **12** (15) (2023) 2945. <https://doi.org/10.3390/foods12152945>
12. Xiao, Q., Yang, L., Guo, J., Zhang, X., Huang, Y., & Fu, Q. - Preparation, Structural Characterization, and Hypoglycemic Activity of Dietary Fiber from Sea Buckthorn Pomace, *Foods* **13** (22) (2024) 3665. <https://doi.org/10.3390/foods13223665>

13. Muhammad, K., Zahari, N.I.M., Gannasin, S. P., Adzahan, N. M., & Bakar, J. - High methoxyl pectin from dragon fruit (*Hylocereus polyrhizus*) peel, *Food Hydrocolloids* **42** (P2) (2014) 289–297. <https://doi.org/10.1016/j.foodhyd.2014.03.021>
14. Sun, Z., Zhao, Y., Zhang, Z., Wang, L., Du, J., & Zhang, S. - Optimization of chemical extraction conditions of dietary fiber from *Cistanche deserticola* residues and its structural characteristics and physicochemical and functional properties, *Molecules* **28** (22) (2023) 7604. <https://doi.org/10.3390/molecules28227604>
15. Corimayhua-Silva, A.A., Elías-Peñañiel, C., Rojas-Ayerve, T., Guevara-Pérez, A., Farfán-Rodríguez, L., & Encina-Zelada, C.R. - Red dragon fruit peels: effect of two species ratio and particle size on fibre quality and its application in reduced-fat alpaca-based sausages, *Foods* **13** (3) (2024) 386. <https://doi.org/10.3390/foods13030386>
16. Freitas, C.M.P., Coimbra, J.S.R., Souza, V.G.L., & Sousa, R.C.S. - Structure and applications of pectin in food, biomedical, and pharmaceutical industry: A review, *Coatings* **11** (8) (2021) 922. <https://doi.org/10.3390/coatings11080922>
17. Chang, C., Li, J., Li, X., Wang, C., Zhou, B., Su, Y., & Yang, Y. - Effect of protein microparticle and pectin on properties of light mayonnaise, *LWT - Food Science and Technology* **82** (2017) 8-14. <https://doi.org/10.1016/j.lwt.2017.04.013>
18. Donkor-Boateng, N.A., Agbenorhevi, J.K., & Anim-Jnr, A.S. - Physicochemical, textural and sensory attributes of beef sausage emulsified with okra pectin, *Journal of Science and Technology (Ghana)* **40** (3) (2022) 67-76. <https://www.ajol.info/index.php/just/article/view/239763>
19. Zeeb, B., Schöck, V., Schmid, N., Majer, L., Herrmann, K., Hinrichs, J., & Weiss, J. - Mixing behaviour of WPI-pectin-complexes in meat dispersions: Impact of biopolymer ratios, *Food and Function* **8** (2017) 333-340. <https://doi.org/10.1039/C6FO01436D>
20. Wang, S., Fang, Y., Xu, Y., Zhu, B., Piao, J., Zhu, L., Yao, L., Liu, K., Wang, S., Zhang, Q., Qin, L., & Wu, J. - The effects of different extraction methods on physicochemical, functional and physiological properties of soluble and insoluble dietary fiber from *Rubus chingii* Hu. fruits, *Journal of Functional Foods* **93** (2022). <https://doi.org/10.1016/j.jff.2022.105081>
21. Lin, C. B., Kai, N. Y., Ali, A. - Ultrasound assisted extraction of pectin from dragon fruit peels, *Journal of Engineering Science and Technology* **13** (Special Issue on the seventh eureka) (2016) 65-81.
22. He, Y., Li, W., Zhang, X., Li, T., Ren, D., & Lu, J. - Physicochemical, functional, and microstructural properties of modified insoluble dietary fiber extracted from rose pomace, *Journal of Food Science and Technology* **57** (4) (2020) 1421-1429. <https://doi.org/10.1007/s13197-019-04177-8>
23. Tran, Thi Dinh - Optimizing technological parameters for pectin extraction from dragon fruit peels, *Vietnam Journal of Agricultural Sciences* **14** (4) (2016) 645-653. <https://vjol.info.vn/index.php/hvnn/article/view/29900>
24. Jubayer, M.F., Karim, R., Uddin, M.B., & Jubayer, M.F. - Optimization of pectin isolation method from pineapple (*Ananas comosus* L.) waste, *Carpathian Journal of Food Science and Technology* **6** (2) (2014) 116-122. https://chimie-biologie.ubm.ro/carpathian_journal/index.html
25. Oliveira, T.Í.S., Rosa, M.F., Cavalcante, F.L., Pereira, P.H.F., Moates, G.K., Wellner, N., Mazzetto, S.E., Waldron, K.W., & Azeredo, H.M.C. - Optimization of pectin extraction

- from banana peels with citric acid by using response surface methodology, *Food Chemistry* **198** (1) (2016) 113-118. <https://doi.org/10.1016/j.foodchem.2015.08.080>
26. Muhammad, N.W.F., Nurrulhidayah, A.F., Hamzah, M.S., Rashidi, O., & Rohman, A. - Physicochemical properties of dragon fruit peel pectin and citrus peel pectin: A comparison, *Food Research* **4** (S1) (2020) 266-273. [https://doi.org/10.26656/fr.2017.4\(S1\).S14](https://doi.org/10.26656/fr.2017.4(S1).S14)
27. Opperman, C., Majzoobi, M., Farahnaky, A., Shah, R., Van, T.T.H., Ratanpaul, V., Blanch, E.W., Brennan, C., & Eri, R. - Beyond soluble and insoluble: A comprehensive framework for classifying dietary fibre's health effects, *Food Research International* **206** (2025) 115843. <https://doi.org/10.1016/j.foodres.2025.115843>
28. Dong, Y., Li, Q., Zhao, Y., & Cao, J. - Effects of ultrasonic assisted high-temperature cooking method on the physicochemical structure characteristics and in vitro antioxidant capacities of dietary fiber from *Dendrocalamus brandisii* Munro shoots, *Ultrasonics Sonochemistry* **97** (2023). <https://doi.org/10.1016/j.ultsonch.2023.106462>
29. Taharuddin, N.H., Jumaidin, R., Mansor, M.R., Yusof, F.A.M., & Alamjuri, R.H. - Characterization of Potential Cellulose from *Hylocereus Polyrhizus* (Dragon Fruit) peel: A Study on Physicochemical and Thermal Properties, *Journal of Renewable Materials* **11** (1) (2023) 131-145. <https://doi.org/10.32604/jrm.2022.021528>
30. Chang, Y., An, R., Sun, S., Hou, M., Han, F., & Song, S. - Comparative Analysis of Structural and Functional Properties of Dietary Fiber from Four Grape Varieties, *Molecules* **29** (11) (2024) 2619. <https://doi.org/10.3390/molecules29112619>
31. Dong, W., Wang, D., Hu, R., Long, Y., & Lv, L. - Chemical composition, structural and functional properties of soluble dietary fiber obtained from coffee peel using different extraction methods, *Food Research International* **136** (2020) 109497. <https://doi.org/10.1016/j.foodres.2020.109497>
32. Sang, J., Li, L., Wen, J., Gu, Q., Wu, J., Yu, Y., Xu, Y., Fu, M., & Lin, X. - Evaluation of the structural, physicochemical and functional properties of dietary fiber extracted from Newhall navel orange by-products, *Foods* **10** (11) (2021) 2772. <https://doi.org/10.3390/foods10112772>
33. Bouaziz, M.A., Rassaoui, R., & Besbes, S. - Chemical composition, functional properties, and effect of inulin from Tunisian *Agave americana* L. leaves on textural qualities of pectin gel, *Journal of Chemistry* **2014** (2014) 758697. <https://doi.org/10.1155/2014/758697>
34. Rubio-Senent, F., Rodríguez-Gutiérrez, G., Lama-Muñoz, A., & Fernández-Bolaños, J. - Pectin extracted from thermally treated olive oil by-products: Characterization, physico-chemical properties, *in-vitro* bile acid and glucose binding, *Food Hydrocolloids* **43** (2015) 311-321. <https://doi.org/10.1016/j.foodhyd.2014.06.001>

TÓM TẮT

NÂNG CAO GIÁ TRỊ VỎ THANH LONG (*Hylocereus undatus*): TRÍCH LY CHẤT XƠ THỰC PHẨM, PHÂN TÍCH CẤU TRÚC VÀ ĐẶC TÍNH CHỨC NĂNG

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Vỏ quả thanh long (*Hylocereus undatus*) là phụ phẩm nông nghiệp dồi dào tại Việt Nam, giàu chất xơ thực phẩm nhưng thường bị bỏ phí, gây lãng phí tài nguyên. Nghiên cứu này nhằm tối ưu hóa quá trình trích ly chất xơ hòa tan (SDF) từ vỏ thanh long trong điều kiện acid, đồng thời phân tích các đặc tính cấu trúc và chức năng của SDF nhằm đánh giá tiềm năng ứng dụng trong thực phẩm. Các yếu tố ảnh hưởng đến hiệu suất thu hồi SDF (bao gồm tỷ lệ nguyên liệu/dung môi, pH, nhiệt độ và thời gian trích ly) đã được khảo sát có hệ thống. Điều kiện trích ly tối ưu được xác định ở tỷ lệ 1:37,5 (w/v), pH 2,5, nhiệt độ 80 °C trong 60 phút, cho hiệu suất SDF đạt $14,54 \pm 0,50\%$. Phổ hồng ngoại biến đổi Fourier (FT-IR) xác nhận cấu trúc polysaccharide của cả SDF và chất xơ không hòa tan (IDF). Ảnh kính hiển vi điện tử quét (SEM) cho thấy SDF có vi cấu trúc xốp và vô định hình, tương phản với hình thái sợi dày đặc của IDF. Phân tích nhiễu xạ tia X (XRD) cũng cho thấy SDF có cấu trúc vô định hình, trong khi IDF mang tính bán kết tinh, phản ánh sự khác biệt về cấu trúc và chức năng. Đánh giá các đặc tính chức năng cho thấy SDF có khả năng giữ nước đạt $21,25 \pm 0,34$ g nước/g, khả năng giữ dầu $3,85 \pm 0,54$ g dầu/g, và độ trương nở $32,36 \pm 1,06$ mL/g. Những kết quả này chứng tỏ SDF được chiết xuất từ vỏ thanh long sở hữu các đặc tính cấu trúc và hóa lý thuận lợi, khiến nó trở thành một thành phần chức năng đầy triển vọng để bổ sung vào các sản phẩm thực phẩm. Đồng thời, nghiên cứu góp phần khẳng định việc tận dụng hiệu quả các phụ phẩm nông nghiệp nhằm hướng tới phát triển bền vững và giảm thiểu lãng phí trong ngành công nghiệp thực phẩm.

Từ khóa: Vỏ thanh long, *Hylocereus undatus*, chất xơ, trích ly trong điều kiện acid, đặc tính cấu trúc, đặc tính hóa lý.