



Corn Stalks as a Novel Source of Functional Dietary Fiber: Process Optimization and Product Characterization

Fajriyati Mas'ud^{1*}, Vilia Darma Paramita¹, Zulman Wardi¹, Suhardi Suhardi², and Muhammad Sayuti³

¹ Department of Chemical Engineering, Politeknik Negeri Ujung Pandang, Makassar, South Sulawesi, 90245, Indonesia

² Department of Agricultural Engineering, Hasanuddin University, Makassar, South Sulawesi, 90245, Indonesia

³ Department of Animal Husbandry, Agricultural Faculty, Gorontalo State University, Gorontalo, 96128, Indonesia

* Correspondence: fajri888@poliupg.ac.id

Citation:

Mas'ud, F.; Paramita, D.V.; Wardi, Z.; Suhardi, S.; Sayuti, M. Corn stalks as a novel source of functional dietary fiber: process optimization and product characterization. *ASEAN J. Sci. Tech. Report.* **2026**, *29*(6), e262107. <https://doi.org/10.55164/ajstr.v29i6.262107>

Article history:

Received: October 25, 2025

Revised: March 22, 2026

Accepted: April 12, 2026

Available online: May 15, 2026

Publisher's Note:

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Abstract: The growing demand for dietary fiber (DF) has encouraged the exploration of sustainable and low-cost sources from agricultural by-products. Corn stalks are an abundant agricultural residue that remains underutilized as a potential source of dietary fiber. This study aimed to optimize the alkali extraction of DF from corn stalks (*Zea mays*, L.) using Response Surface Methodology (RSM) with a Central Composite Design (CCD). Three independent variables, namely temperature (70-90°C), time (50-70 min), and NaOH concentration (15-25%), were investigated for their effects on DF yield. The model showed a high significance ($p < 0.0001$) with $R^2 = 0.99$, indicating excellent predictive accuracy. The optimal extraction conditions were 82.29°C, 62.06 min, and 23.03% NaOH, resulting in a maximum DF yield of 25.75%. Verification experiments confirmed the model's reliability, with an experimental yield of $25.43 \pm 0.24\%$. The extracted DF exhibited favorable functional properties, including high water holding capacity/WHC (4.7 ± 0.08 g/g), water binding capacity/WBC (2.7 ± 0.05 g/g), swelling capacity/SW (5.12 mL/g), oil holding capacity/OHC (1.8 ± 0.07 g/g), and Fourier Transform Infrared Spectroscopy (FTIR) analysis confirmed the removal of lignin and hemicellulose. These characteristics highlight its potential as a functional ingredient in food formulations, particularly in meat- and fish-based products that require improved texture and moisture retention. This study demonstrates the valorization of corn stalk waste into a valuable DF source, supporting sustainable resource utilization and the development of clean-label, fiber-enriched food products aligned with circular economy principles.

Keywords: Corn stalks; dietary fiber extraction; alkali treatment; response surface methodology; functional properties

1. Introduction

Dietary fiber (DF) is essential to the diet, leading to increased demand for DF products in recent years, driven by growing public awareness of its numerous health benefits, including regulating intestinal transit, lowering blood cholesterol levels, and promoting glycemic control [1]. As a component of functional foods, DF plays a crucial role in preventing chronic diseases, including cardiovascular disease, type 2 diabetes, obesity, and cancer [2,3]. This has prompted studies to find sustainable and alternative sources of dietary fiber, especially those made from agro-industrial byproducts. Corn/maize is economically important, serving as the main food crop and a raw material for corn starch, corn syrup, ethanol, and corn oil products. In addition,

corn is animal feed for cattle, pigs, and poultry. Due to its wide use and high productivity, corn plays an important role in food security, agriculture, and industrial development.

Corn cultivation generates large amounts of corn stalk waste. Corn stalks are rich in lignocellulosic components, particularly cellulose, hemicellulose, and lignin, which can be processed into valuable products such as DF [4]. Utilizing corn stalks not only provides an economical source of functional ingredients for the food industry but also contributes to waste reduction and environmental sustainability. Extracting DF from corn stalks is a complex process that requires chemical breakdown of the plant cell wall matrix to release cellulose and hemicellulose while minimizing degradation. Alkali treatments, such as sodium hydroxide (NaOH), have been widely used for this purpose due to their effectiveness in delignifying biomass and increasing the accessibility of fiber components. However, optimizing the extraction process for efficiency is significantly influenced by several parameters, including extraction temperature, time, and alkali concentration. Optimizing these parameters is crucial to maximizing fiber yield while maintaining its functional qualities [5].

Previous research has been conducted on other biomasses, such as rice bran, rice husk, and bagasse [6–8]. However, reports on the valorization of corn stalks as a fiber source are limited, particularly regarding systematic optimization of extraction conditions. RSM, specifically CCD, is a powerful technique for modeling and optimizing complex chemical processes by evaluating interactions between variables. The extracted DF was characterized based on its functional properties, such as water holding capacity (WHC), water binding capacity (WBC), swelling capacity (SC), and oil holding capacity (OHC), and its chemical structure using FTIR spectroscopy. The resulting data were used to evaluate its potential application as a DF source in food systems. By using corn stalks as a DF source, this study contributes to the development of cost-effective, fiber-rich ingredients for the formulation of meat- and fish-based products, such as meatballs, nuggets, and others, as well as to broader functional food innovation.

2. Materials and Methods

2.1 Materials

Corn stalks were obtained from local farms in Maros Regency, South Sulawesi, Indonesia. The stalks were cleaned, chopped into uniform particles, dried in an oven at 60 °C for 5 h, milled into flour, and sieved through a 60-80 mesh sieve before extraction. Food-grade NaOH and H₂O₂ were obtained from Sigma-Aldrich.

2.2 Experimental Design

A CCD was used to study the effects of three independent variables: temperature (A, °C), time (B, min), and NaOH concentration (C, %). The midpoint values for these variables are presented in Table 1, and the experimental results and the DF results obtained, including 6 replications at the midpoint, are shown in Table 2.

Table 1. Experimental Range and Levels (Coded and Actual)

Variable	-1.682	-1	0	+1	+1.682
Temperature (°C)	63.18	70	80	90	96.8
Time (min)	43.18	50	60	70	76.82
NaOH (%)	11.59	15	20	25	28.41

2.3 DF Extraction Procedure

Powdered corn stalks were extracted using NaOH in a stainless steel stir pan under various process conditions, as in the CCD matrix (Table 2). After the extraction process, the mixture was filtered, washed with distilled water until neutral pH (6.5-7), dried at 50°C for 12 h, bleached with 5% H₂O₂ for 1 h, filtered, washed with distilled water until neutral pH (6.5-7), and dried at 50°C for 12 h. The DF yield (%) could be calculated based on dry weight.

2.4 Determination of WHC, WBC, and SC

WHC, WBC, and SC were determined according to Qiu et al. [9]. A 1.0 g sample was mixed with 70 mL of distilled water and stirred for 4 h. The resulting cloudy liquid was then centrifuged at 3000 rpm for 15 min, and excess water was carefully removed by filtration. The sample's wet weight was recorded, and it was then dried at 105°C until a constant weight was reached. SC was expressed as the change in volume resulting from water swelling.

$$\text{WHC (g/g)} = \frac{(W_1 - W)}{W} \quad (1)$$

$$\text{WBC (g/g)} = \frac{(W_1 - W_2)}{W_1} \quad (2)$$

$$\text{SC (g/g)} = \frac{(V_2 - V_1)}{W} \quad (3)$$

Where: W_1 is the sample weight after water absorption (g), W is the sample weight before water absorption, W_2 is the sample weight after drying, V_2 is the sample volume after water absorption (mL), and V_1 is the sample volume before water absorption (mL). WHC, WBC, and SC measurements for each sample were performed in triplicate.

2.5 Determination of OHC

OHC was determined using a method adapted from Qiu et al. [9]. A 1.0 g sample was placed in a centrifuge tube and mixed with excess corn oil. The tube was stirred for 30 seconds every 5 min, and after 30 min, the tube was centrifuged at 1600 rpm for 20 min. After carefully separating the excess oil, the oil and water adhering to the inside of the tube were discarded, and the tube was weighed to calculate the OHC of the obtained DF. OHC measurements were performed in triplicate.

$$\text{OHC (g/g)} = \frac{W_1}{W_2} \quad (4)$$

Where W_1 = oil retained, W_2 = original dried sample

2.6. Structural Analysis

Structural analysis was reviewed using FTIR (Bruker Corporation, Germany). Samples were scanned in the 4000-600 cm^{-1} range with a resolution of 4 cm^{-1} . Each sample was scanned 32 times.

3. Results and Discussion

3.1 Alkali Extraction Mechanism

Dietary fiber extraction using alkali aims to dissolve components that coat the polysaccharide structural framework, dissolve lignin and some hemicellulose, making cellulose more accessible for extraction, and release soluble fiber by breaking cross-links between polysaccharides and proteins, or between hemicellulose and lignin [10, 11].

NaOH solutions at specific concentrations, along with temperature and time settings, as shown in Table 2, are used to produce dietary fiber. In this process, the alkali penetrates the corn stalk cell walls, causing a saponification reaction of esters, such as pectin esters and hemicellulose esters, breaking the ester and ether bonds between lignin and polysaccharides to form carboxylates and methanol. Hemicellulose and lignin dissolve. At this stage, the more amorphous hemicellulose with lignin and some of the hemicellulose bound to lignin dissolve in alkali, resulting in a purer cellulose structure. The phenolic and aliphatic lignin are hydrolyzed, and the hemicellulose is also partially hydrolyzed, disrupting ester and hydrogen bonds [12], with a high glucan content and virtually no hemicellulose/ferulate bound in the residue [13].

In the washing stage, residual alkali and dissolved products are washed with distilled water until the pH is near neutral. The washing stage is crucial, as residual alkali can damage the product and allow the reaction to continue if free OH^- remains. The use of NaOH and H_2O_2 helps remove residual hemicellulose and lignin, increasing the purity of cellulose to glucan > 90% [14].

3.2 DF Yield

The DF extraction yield from corn stalks in this study ranged from 22.19% to 25.75%, depending on the extraction conditions (Table 2). This result is slightly higher than the value reported by another study [15], which was 19.56% SDF (soluble fiber fraction) from *Cistanche deserticola* residues. Other reports state that an SDF yield of 21-22% from *Trigonella foenum graecum* L. seeds [16], and from mango peels of $22.98 \pm 0.62\%$ [17].

The best results were recorded at the midpoint, indicating high reproducibility and model fit. Using RSM, the effects of three variables: A, B, and C, were systematically studied. The statistical model shows that all three factors, including linear, quadratic, and their interactions, significantly affect the DF results ($p < 0.05$). Based on the ANOVA (Table 3), the model was highly significant ($p < 0.0001$) with an F-value of 570.57. The three linear terms of the independent variables (A, B, and C), their quadratic terms (A^2 , B^2 , C^2), and their interaction terms (AB, AC, BC) significantly affected DF yield ($p < 0.05$). The misfit was not significant ($p = 0.0515$), indicating good model fit. The model $R^2 = 0.99$ and the predicted $R^2 = 0.98$, indicating excellent predictive ability.

Table 2. Experiment and Observed Results (%)

No.	Temperature (°C)	Time (min)	NaOH (%)	DF yield (%)
1	70	50	15	22.53
2	90	50	15	22.19
3	70	70	15	22.38
4	90	70	15	23.35
5	70	50	25	23.22
6	90	50	25	23.42
7	70	70	25	23.32
8	90	70	25	24.91
9	63.2	60	20	22.56
10	96.8	60	20	23.45
11	80	43.2	20	22.23
12	80	76.8	20	23.15
13	80	60	11.6	23.05
14	80	60	28.4	24.79
15	80	60	20	25.62
16	80	60	20	25.69
17	80	60	20	25.66
18	80	60	20	25.75
19	80	60	20	25.71
20	80	60	20	25.64

Table 3. ANOVA Summary for Quadratic Model

Response: DF extraction yield from corn stalks
 ANOVA for Response Surface Quadratic Model
 Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F-Value	Prob > F	
Model	35.22578	9	3.913976	570.5657	< 0.0001	significant
A	1.12334	1	1.12334	163.7566	< 0.0001	
B	1.259417	1	1.259417	183.5935	< 0.0001	
C	3.951745	1	3.951745	576.0717	< 0.0001	
A ²	12.24939	1	12.24939	1785.673	< 0.0001	
B ²	15.38753	1	15.38753	2243.141	< 0.0001	
C ²	5.16121	1	5.16121	752.3833	< 0.0001	
AB	0.91125	1	0.91125	132.8388	< 0.0001	
AC	0.1682	1	0.1682	24.51961	0.0006	
BC	0.04205	1	0.04205	6.129902	0.0328	
Residual	0.068598	10	0.00686			
Lack of Fit	0.057115	5	0.011423	4.973715	0.0515	not significant
Pure Error	0.011483	5	0.002297			
Cor Total	35.29438	19				

3.3 Optimization and Model Equation

The following regression model (in actual values) represents the response surface for DF yield:

$$Y (\%) = -63.79243 + 1.24329A + 0.97135B + 0.74610C - 0.00922A^2 - 0.01033B^2 - 0.02394C^2 + 0.00338AB + 0.00290AC + 0.00145BC \quad (5)$$

Where: Y = DF yield (%), A = Temperature (°C), B = Time (min), C = NaOH concentration (%)

Among the three variables, NaOH concentration has the most significant effect on DF yield, followed by extraction time and extraction temperature ($C > B > A$). This is in accordance with the known mechanism of alkali treatment, where NaOH acts as a chemical process agent, namely, breaking the ester and ether bonds between lignin and hemicellulose, thereby releasing cellulose fibers. Increasing the NaOH concentration to an optimal level increases the cleavage of hemicellulose and lignin bonds, thereby increasing fiber yield. However, excessive NaOH concentration can cause cellulose hydrolysis, resulting in partial degradation and reducing fiber quality [18, 19]. Along with this process, extraction time is crucial for ensuring adequate contact between NaOH and the corn stalk matrix. Longer extraction times increase the rates of delignification and hemicellulose solubilization. However, beyond the optimal point, prolonged alkali exposure can degrade fiber products, particularly amorphous cellulose, resulting in decreased yield [5, 20]. The 3D curves of the relationship between variables A and B, A and C, and B and C can be seen in Figure 1.

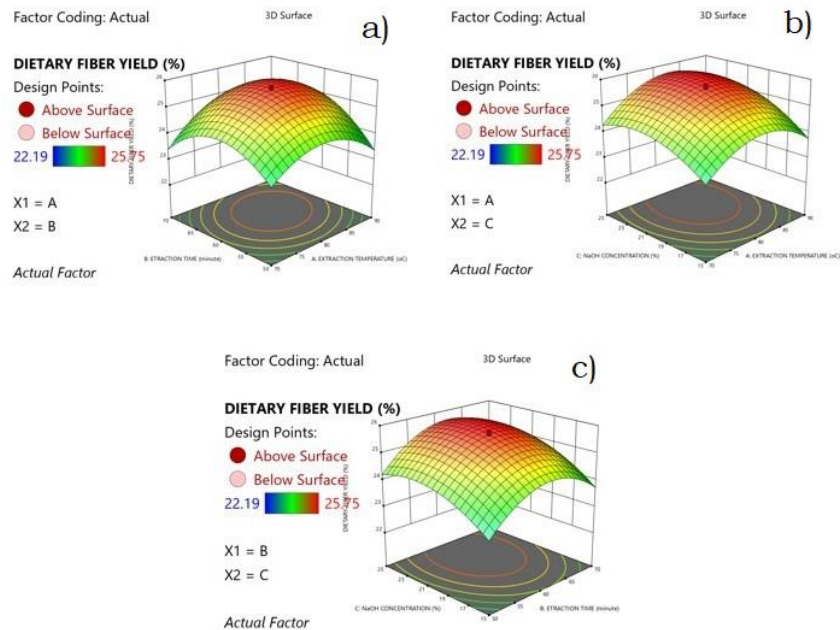


Figure 1. 3D response surface of variables A and B (a), A and C (b), and B and C (c)

In Figure 1a, the X-axis (A, °C), Y-axis (B, min), and Z-axis (vertical, percentage of DF yield). Surface color and shape: Blue-green-yellow-red indicates an increase in the value of DF yield: blue $\approx$, the lowest value (22.19%), red $\approx$, the highest value (25.75%). The curved surface (concave) indicates a significant interaction between A and B on the Z. Interpretation of the 3D curve: Increasing the A from low to high increases the Z up to the optimum point, after which it can decrease because high temperatures can damage the fiber; Increasing the B also increases the yield up to a certain point; too long a B can cause degradation. The red peak in the middle of the graph indicates the optimal condition for the combination of A and B, where the highest yield of dietary fiber is achieved; the smooth, symmetrical surface shape indicates that the response is quite stable around the optimum point. Main result: there is an optimal point (red zone) that yields a maximum result of around 25.75%.

In Figure 1b, it can be seen that B is kept constant at the midpoint or optimum. X-axis (A, °C), Y-axis (C, %), Z-axis (vertical, percentage of DF yield). Surface colors: Blue-green-yellow-red indicate an increase in yield, with low values $\approx$ 22.19% and high values $\approx$ 25.75%. Graph interpretation: A has a positive effect up to the optimum point. As the A increases from low to medium, the Z increases. After passing the optimum A, the Z begins to decline (indicating DF degradation or excessive dissolution). C also shows a similar pattern: low concentrations result in less effective dissolution of non-fiber materials, optimal concentrations result in maximum Z, and excessive C can degrade the DF structure, thereby reducing yield. The red zone (surface peak) shows the optimum combination of A and C to produce the highest yield ($\sim$ 25.75%). The elliptical contour below the graph indicates a significant interaction between A and C, meaning that the effect of one factor depends on the value of the other.

Figure 1c, X-axis (B, min), Y-axis (C, %), Z-axis (vertical, percentage of DF yield). Surface color: Blue, low value ($\sim$ 22.19%); red, high value ($\sim$ 25.75%). Increasing B from low to medium increases Z because more DF is extracted; once the optimal B is reached, Z begins to decrease due to possible DF degradation or dissolution of other components. Increasing C from low to medium also increases Z, because the base helps dissolve lignin and hemicellulose that bind the fiber. However, a C that is too high can damage the fiber structure, so the Z decreases again. The smooth, curved surface and the red peak indicate a significant interaction between B and C, meaning the effect of one factor depends on the value of the other. The optimum zone (red) shows the combination of B and C that yields the highest yield, similar to the 25-26% range. Both factors have a significant effect on the yield, which shows a quadratic pattern (increasing then decreasing). Real interaction means the optimum B depends on C, and vice versa. The extraction temperature affects the

reaction kinetics and the diffusion capacity of chemicals within the material matrix. Higher temperatures enhance the hydrolytic cleavage of lignocellulosic bonds and accelerate alkali penetration, thereby increasing fiber product yield. However, excessively high temperatures lead to cellulose depolymerization, thereby reducing the structural integrity of the extracted fiber. This is consistent with findings from other research [21].

The NaOH concentration, extraction temperature, and extraction time variables affect fiber yield [21]. Another study tested the NaOH concentration, extraction temperature, and extraction duration (time) for corn stalks; the results showed that higher NaOH concentrations (up to a certain limit) increased yield. At the same time, too high concentrations damaged the fiber, and too short a time did not fully open it [22]. The effects of NaOH concentration, temperature, and reaction time on the extraction of hemicellulose (xylan) from wheat straw and corn stalk were investigated; the results showed that increasing NaOH concentration, temperature, and reaction time together increased the hemicellulose yield from wheat and corn straw [5]. However, after the optimum point, increasing time or too high a temperature caused the yield to decrease (degradation).

3.4 Model Adequacy and Predictive Performance

The model's statistical strength is demonstrated by an Adjusted R^2 of 0.99 and a Predicted R^2 of 0.98, indicating excellent agreement between the experimental and predicted results. The high R^2 value of 0.99 and the insignificant non-conformity test confirmed the model's accuracy and reliability in predicting DF yield based on the studied variables. The Adequate Precision value of 60.07, well above the minimum value of 4.0, indicates a high signal-to-noise ratio and the model's ability to navigate the design space. The derived regression equation (Equation 5) in terms of actual values provides quantitative predictions of DF yield under various extraction conditions (Table 2).

3.5 Verification of optimal extraction conditions

Verification of optimal conditions in RSM is a crucial step after predicting optimal conditions to ensure the reliability and applicability of the developed model. Although RSM predicts optimal conditions based on an appropriate mathematical model, these predictions may not fully represent actual experimental results due to inherent variability and model limitations. Therefore, experimental verification is necessary to ensure that the predicted optimum conditions indeed produce the desired maximum or minimum response. This step also serves to evaluate the model's adequacy and robustness, particularly in the presence of experimental noise and complex interactions among variables. Furthermore, verification helps distinguish whether the identified optimum corresponds to the true global optimum or merely a local optimum within the studied design space. In practical applications, particularly in industrial and scientific research settings, the reproducibility and consistency of optimized conditions are crucial. Verification experiments provide confidence that the optimized parameters can be reliably implemented under real-world conditions. Furthermore, this process can reveal the influence of uncontrolled or unmodeled factors not included in the original design. Therefore, verification is crucial to validate RSM's predictive capabilities and ensure that the optimized conditions are accurate and applicable in practice [23, 24].

This model verification step ensures that the mathematical model obtained from the experiment matches the experimental data. This stage involves comparing the model's predicted values with the experimental results. If the model accurately predicts the experimental data, it is considered representative of the DF extraction process. In this study, the verification stage involved five replicate experiments using the optimal extraction conditions identified through RSM: 82.29°C, 62.06 min, and 23.03% NaOH. This step was carried out to assess the model's accuracy and reliability in predicting DF yields under the predicted optimal conditions. The experimental results showed an average DF yield of $25.43 \pm 0.24\%$, which did not significantly differ from the RSM-predicted value of 25.75%. Although the achieved yield was slightly lower than the predicted value, the difference was not statistically significant. These results also confirmed the adequacy and predictive ability of the developed model and demonstrated that the optimal conditions for DF extraction from corn stalks can be reproduced on an industrial scale.

3.6 Functional Properties of Product

The WHC of the extracted DF product was 4.7 ± 0.08 g/g, and the OHC was 1.8 ± 0.07 g/g. These values indicate that DF derived from corn stalks exhibits superior hydration and oil retention properties compared

to flours commonly used as fillers in processed foods, such as wheat flour, which has WHC and OHC values of ≈ 1.85 g/g and ≈ 1.05 g/g, respectively. These properties are likely due to the highly porous, fibrous microstructure of the DF product, which increases surface area and allows greater water absorption. This makes it suitable as a functional ingredient in food formulations, particularly in meat and fish-based products that require enhanced moisture retention and texture stability. Previous studies have shown that DF with a high WHC can improve the juiciness, texture, and storage stability of meat-based formulations by minimizing moisture loss during cooking and storage [25]. The capacity of a substance to absorb and hold water without dissolving in it is known as WBC. This parameter describes a material's hydrophilic nature and its capacity to form a water-retaining structure. The WBC value of this product DF is 2.7 g/g, indicating that 1 gram of dry product binds an average of 2.7 grams of water. This WBC value is considered moderate to high and indicates that the product has a sufficiently large specific surface area and polar functional groups, such as hydroxyl, that can form hydrogen bonds with water molecules. This porous physical structure supports water retention, with functional implications in the food industry, in particular. A high WBC is crucial for textural stability in food products (e.g., processed meats, sausages, bread, and low-fat products), increasing tenderness and resistance to drying. Physiologically, fiber with a high WBC can slow gastric emptying, prolong the feeling of fullness, regulate blood sugar levels, and lower cholesterol by slowing nutrient absorption. Furthermore, the moderate OHC value (1.8 ± 0.07 g/g) of corn stalk fiber indicates an adequate ability to interact with lipids, which can help improve flavor retention and reduce phase separation in emulsified food products. Compared to wheat flour with an OHC of approximately 1.05 g/g, corn stalk fiber exhibits slightly better oil-binding properties, making it suitable for use in products such as emulsified meats, baked goods, or plant-based alternatives. Oil-binding ability is particularly relevant for sensory quality, as it can improve mouthfeel and flavor release [26].

The combination of high WHC and adequate OHC expands the potential applications of corn stalk DF beyond its traditional uses. This fiber can serve as a moisture-retention agent, fat replacer, or texture enhancer in low-fat or reformulated products, in line with current trends toward clean-label, high-fiber foods. From a sustainability perspective, utilizing corn stalk, a major agricultural by-product, also supports the upscaling of waste and adds economic value to the agro-industrial supply chain. SC is the maximum volume achieved by a fiber after absorbing air and expanding under certain conditions. The SC value is expressed in mL of air per gram of dry matter. The SC value of 5.12 mL/g indicates that corn stalk fiber can expand up to 5.12 mL per gram of fiber. This value indicates a fiber structure capable of holding large amounts of air and forming a swelling matrix. In its functional application, this swelling capacity is very useful in functional products such as high-fiber foods, weight loss products, or diet drinks, as it provides a faster and longer-lasting feeling of fullness. In the pharmaceutical industries, fibers with a high SC can be used as binders or slow-release agents. Physiologically, a high SC contributes to stool volume, relieves constipation, and increases the rate of fermentation by gut microbiota, thereby supporting gut health.

3.7 Structural analysis

FTIR spectroscopy is used to identify chemical functional groups in organic and inorganic compounds by measuring infrared light absorption at specific wavelengths (cm^{-1}). In this study, FTIR spectroscopy was used to examine differences in molecular structure, chemical constituents, and functional groups present in DF samples. This analytical approach provides insight into the types of molecular bonds present and facilitates the prediction of their potential interactions within a food matrix. The FTIR results are shown in Figure 2. FTIR spectroscopy results from three different samples: Raw material/corn stalks powder (purple line), product A (red line), and product B (blue line). X-axis = Wavenumber (cm^{-1}), which indicates the wavelength of infrared light; Y-axis = Absorbance, which reports how much light is absorbed at a specific wavelength—the Interpretation of Figure 2 as in Table 4.

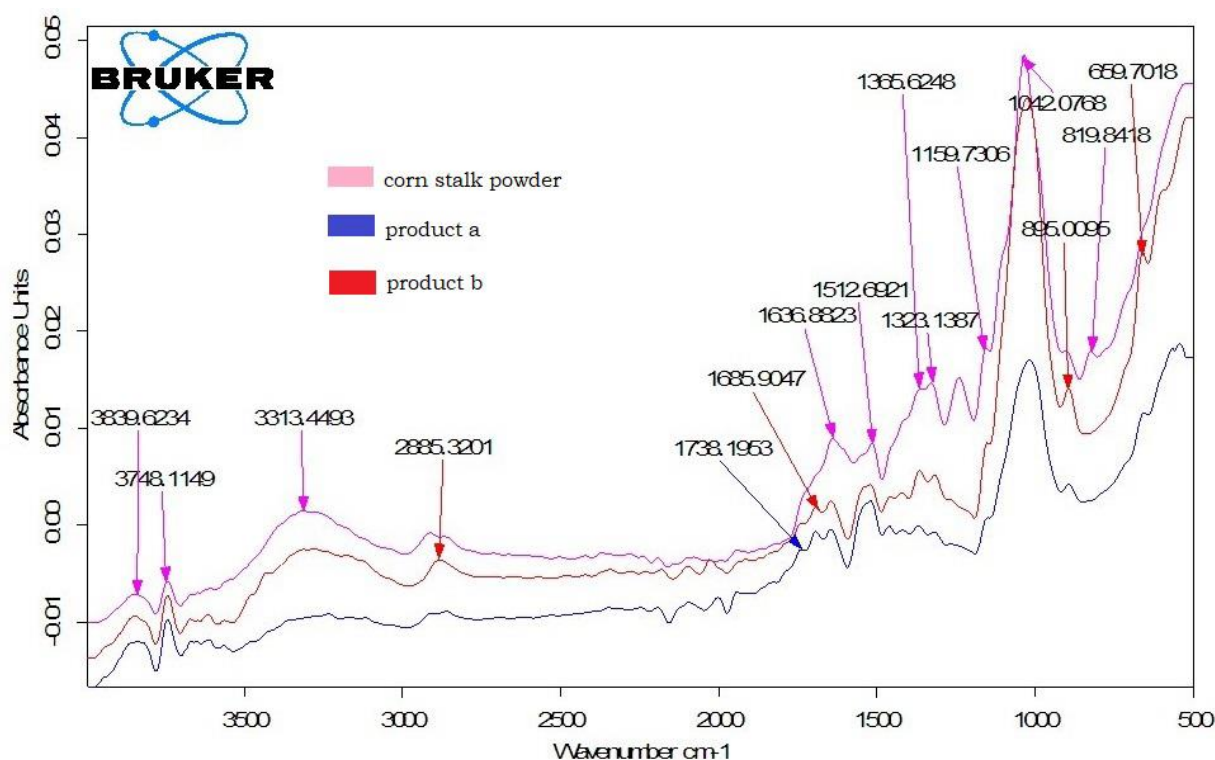


Figure 2. Infrared spectroscopy of DF from corn stalks

The FTIR spectra confirmed the presence of key functional groups such as hydroxyl (-OH), alkyl (C-H), carbonyl (C=O), and glycosidic bonds (C-O-C) in DF extracted from corn stalks. Differences in peak intensity and position between the raw material and processed products (A and B) indicated structural modifications, particularly in the removal of non-cellulosic components such as lignin and hemicellulose. These results demonstrate molecular-level cellulose enrichment in the finished fiber product and validate the efficiency of the extraction process. This chemical transformation was confirmed by FTIR spectroscopy, which showed a characteristic C=O stretching band at around 1738 cm⁻¹ and a stronger C-O-C signal in the treated samples, indicating effective removal of non-cellulosic components and potential functional group modification. The appearance of the C=O band at 1738 cm⁻¹ and the strengthening of the C-O-C signal in the processed products confirmed that extraction effectively increased the cellulose fraction, providing further molecular evidence that the final fibers were richer in cellulose and had higher functional potential. DF products derived from corn stalks exhibit high cellulose content and a chemically modified structure, leading to good water absorption. This makes them ideal candidates as fiber additives in meat and fish product formulations, such as meatballs, nuggets, and others, to increase fiber content without significantly altering flavor or texture. Furthermore, the functional properties of polysaccharide-rich DF also open up opportunities for functional food innovation, for example, in low-calorie, cholesterol-lowering, and ready-to-eat products that support digestive health, thereby expanding the application of corn DF in the modern food industry.

Table 4. The Interpretation of infrared spectroscopy of DF from corn stalks

No.	Picture	Assignment	Interpretation
1	Broadband at 3748.11-3313.45 cm ⁻¹	O-H stretching vibration	This broad region is typically associated with the hydroxyl groups (-OH) of polysaccharides and cellulose, indicating hydrogen bonding within the fiber matrix. The intensity and shape suggest strong intra- and intermolecular interactions among hydroxyl groups.
2	Peak at 2885.32 cm ⁻¹	C-H stretching vibration of aliphatic -CH ₂ groups	This band is characteristic of cellulose and hemicellulose structures and reflects the alkyl chains present in the carbohydrate backbone.
3	Peak at 1738.19 cm ⁻¹	C=O stretching of ester or carboxylic acid groups	This absorption band suggests the presence of acetyl or uronic ester groups, often attributed to hemicellulose or pectin components. The reduced intensity in processed products may indicate partial removal of non-cellulosic fractions during extraction.
4	Peak at 1638.88 cm ⁻¹	Adsorbed water or -OH bending vibration	Associated with moisture or bound water within the fiber matrix, often observed in hydrophilic materials like cellulose.
5	Peaks at 1512.69 cm ⁻¹ and 1323.14 cm ⁻¹	Aromatic C=C stretching or CH ₂ bending	These peaks may reflect residual lignin components in the raw material, indicating partial lignin removal after treatment.
6	Peak at 1364.62 cm ⁻¹	C-H bending	Indicates the presence of polysaccharide-related skeletal vibrations, primarily associated with cellulose.
7	Peak at 1159.73 cm ⁻¹	C-O-C asymmetric stretching	Corresponds to the glycosidic linkage (β -1,4) in cellulose and hemicellulose.
8	Sharp peak at 1042.08 cm ⁻¹	C-O stretching vibrations	Strongly associated with polysaccharides, particularly cellulose and hemicellulose backbones.
9	Peaks between 856.00-659.70 cm ⁻¹	C-H deformation, ring vibrations, or out-of-plane bending	Indicative of the complex ring structures in carbohydrates and a possible fingerprint region for cellulose derivatives.

4. Conclusions

This study optimized the extraction of DF from corn stalks using RSM-CCD. The maximum DF yield of 25.75% was achieved at a temperature of 82.29°C, a time of 62.06 min, and 23.03% NaOH. The developed quadratic model demonstrated high accuracy ($R^2 = 0.99$), as confirmed by verification tests. The product exhibited good functional properties related to WHC and OHC, indicating its potential for use in food formulations as a DF source and as a filler in processed foods. FTIR analysis confirmed chemical modification, particularly the removal of lignin and hemicellulose, further validating the extraction process. This study presents compelling results for the valorization of agricultural waste, such as corn stalks, into high-value functional food ingredients. The concepts of a circular economy, sustainable agriculture, and functional food innovation align with the integration of corn stalk waste valorization and nutritional enhancement. Furthermore, as efforts to increase DF content in processed foods and reduce reliance on synthetic additives continue, these natural fiber sources can serve as clean-label alternatives with promising health benefits.

5. Acknowledgments

The authors would like to thank the smallholder corn farmers in Maros Regency, South Sulawesi, Indonesia, who have prepared the corn stalks.

Author Contributions: Conceptualization, F.M. and V.D.P.; methodology, F.M.; software, S.S.; validation, S.S.; formal analysis, S.S.; investigation, M.S.; resources, Z.W.; data curation, Z.W.; writing—original draft preparation, F.M.; writing—review and editing, V.D.P.; visualization, S.S.; supervision, Z.W.; project administration, V.D.P.; funding acquisition, F.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research and the APC were funded by the Directorate General of Research and Development - Ministry of Higher Education, Science, and Technology of the Republic of Indonesia, for the research grant number: 190/C3/DT.05.00/PL-BATCH II/2025, dated July 14, 2025, and supported by the Chemical Engineering Department of Politeknik Negeri Ujung Pandang, Makassar, Indonesia.

Conflict of interest: There is no potential conflict of interest in this study.

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