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Harnessing dietary fiber from yellow passion fruit peel in emulsified chicken meat model

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Abstract

This study investigated the extraction and application of dietary fiber (DF) from yellow passion fruit peel (YPFP) to enhance the nutritional and functional properties of meat products. The experiments focused on analyzing the physicochemical and functional properties of DF-rich powders extracted using different methods: water bath heating-assisted acidic extraction, ultrasonication-assisted acidic extraction, and enzymatic extraction. The results showed that the total dietary fiber (TDF) content increased by 15.25–22.33% compared to whole peel powder, with the highest TDF content observed in the 2% citric acid-treated powder. The DF-rich powders exhibited higher water- and oil-holding capacities than the commercial binder (wheat flour) in the emulsion meat model, enhancing their potential as functional food ingredients. Incorporating 2% and 4% DF-rich powders into meat models improved cooking yield and reduced expressible fluid and fat percentages. However, the addition of DF-rich powders affected the color, reducing L* and a* values, which may impact consumer acceptability. The study concluded that YPFP-derived DF-rich powders can enhance the functional properties of meat products, offering a sustainable approach to utilizing fruit byproducts.

Keywords: Chicken emulsion model; Dietary fiber; Extraction methods; Passion fruit peel; Physicochemical properties

1. Introduction

Dietary fiber (DF) is defined as plant parts or similar carbohydrates that resist digestion and absorption in the small intestine and undergo fermentation in the large intestine. DF is classified into soluble (SDF) and insoluble (IDF) fibers, each offering distinct health benefits. SDF, such as pectin and gums, dissolve in water, prolong gastric emptying, and control glucose absorption, serum LDL cholesterol, and blood pressure, enhancing cardiovascular health. IDF, like cellulose and lignin, does not dissolve in water and aids in gut activity by increasing stool volume and reducing bowel transit time, lowering the risk of constipation and bowel diseases. Despite these benefits, there is a significant difference between actual fiber intake and recommended daily allowances. To address this, interest in the use of both conventional and nonconventional sources of dietary fiber to increase fiber intake while utilizing industrial byproducts is increasing. DF primarily comes from cereals, legumes, fruits, and vegetables [1, 2]. Byproducts from the fruit and vegetable processing industry, such as peels and pomace, are also substantial sources of dietary fiber. Recent research highlighted the potential of these byproducts in developing functional foods, offering health benefits, and reducing waste [1].

The worldwide consumption of meat is steadily increasing [3]. Although meat provides a rich source of high-quality protein, studies have linked its saturated fats to noncommunicable diseases such as coronary heart disease [4]. In response to consumer preferences for healthier eating, the meat industry is reforming products to reduce fat, sodium, and caloric contents while increasing fiber content [5]. The incorporation of DF-rich byproducts into meat products also offers technological and economic benefits, including reduced cooking loss and increased stability [6]. For example, DF from rice bran, orange albedo powder, and amorphous cellulose has shown efficacy in enhancing water-holding capacity, reducing shrinkage, and serving as a fat substitute in low-fat meat formulations [7, 8, 9].

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Passion fruit is a tropical fruit known for its juicy, seed-filled interior and many nutritional and health benefits. The passion fruit juice industry generates substantial coproducts, including seeds, pulp, and especially a large volume of peels [10]. These peels, representing 50–60% of the fruit, are a potential source of DF [11]. Additionally, the annual passionfruit production in Sri Lanka is approximately 976 metric tons [12]. While studies have explored various aspects of passion fruit peel, there is a gap in research on DF extraction and its applications in meat systems.

Current extraction methods for DF include chemical and enzymatic approaches using solvents such as water, acid, or alkali [13]. These methods and sources can significantly affect the chemical composition and physicochemical properties of dietary fibers, impacting their functionality as food ingredients [14]. This research focused on analyzing the physicochemical and functional properties of DF-rich powders extracted from yellow passion fruit (*Passiflora edulis flavicarpa)* peel (YPFP). The experiments were conducted to evaluate the effectiveness of different extraction methods to extract insoluble and soluble DF contents and explore their application in a meat model system to understand their functional properties. Extracting DF from passion fruit peel and incorporating it into meat products present promising opportunities to increase environmental sustainability and human health.

2. Materials and methods

- *Raw materials:* Peels of yellow passion fruit were collected from a fruit juice processing facility, and chicken thigh meat was purchased from a commercial supplier.
- *Chemicals:* Alpha-amylase, protease, alpha-glucosidase, cholesterol, ethanol, ammonium ferric sulfate, glacial acetic acid, phosphoric acid, 2,2-diphenyl-1-picrylhydrazyl (DPPH), gallic acid, Folin-Ciocalteu reagent, citric acid, and boric acid were purchased from Sigma–Aldrich Company Ltd. (New Delhi, India). All chemicals were of analytical grade.

3. Methodology

3.1. Passion fruit peel powder preparation

The YPFPs were washed twice with 30°C warm water and then cut into uniform pieces approximately 1 cm × 1 cm in size. These pieces were dried at 40°C for 24 hours using a tray drier (D-10/32609 model, USA). After drying, the samples were ground and sieved through a 0.475 mm sieve.

3.2. Preparation of DF-rich fiber powders

3.2.1. Acidic extraction

Water bath heating-assisted acidic extraction

The methodology outlined by [15] with slight modifications was used to extract two types of DF-rich powders: 1% citric acid-treated powder (AHE 1%) and 2% citric acid-treated powder (AHE 2%). Briefly, the peel powders were treated with 1% and 2% citric acid solutions at a 1:30 (w/v) ratio. The samples were then incubated in a shaking water bath (LSB-030S model) at 40°C and 80 rpm for 1.5 hours. The supernatant and pellet were separated using centrifugation (GEMMYCO PLC-025, Taiwan) at 5000 rpm for 15 minutes. The pellet was washed with 0.1% sodium carbonate solution to adjust the pH to 6–7 and then dried at 40°C for 24 hours to obtain an insoluble dietary fiber (IDF)-rich fraction. The supernatant was treated with 95% ethanol and left overnight. The mixture was then filtered, and the precipitate was washed with absolute ethanol. After drying at 40°C for 24 hours, a soluble dietary fiber (SDF)-rich fraction was obtained. Both the IDF and SDF-rich fractions were ground and sieved using a 0.60 mm sieve and then combined.

Ultrasonication-assisted acidic extraction (AUE)

Ultrasonication-assisted acidic extraction followed the same procedure outlined for water bath heating-assisted extraction except for the incubation method. Instead of water bath incubation, ultrasonic bath incubation (DCG-120H model) was performed at 40°C with an ultrasonic power of 100 W for 1.5 hours.

3.2.2. Enzymatic extraction

The methodology established by [15], with slight modifications, was applied for enzymatic extraction. Peel powders were treated with phosphate buffer (pH 8.2 ± 0.1) at a 1:30 (w/v) ratio. Heat-stable alpha-amylase (500 µL) was added to the mixture, which was subsequently incubated in a shaking water bath at 40°C and 80 rpm for 1.5 hours. The pH was then adjusted to 7.5 ± 0.1, and protease (500 µL) was added, followed by incubation in a water bath at 40°C for one

hour. The pH was subsequently adjusted to 4.5 ± 0.1, and 200 µL of amyloglucosidase enzyme was added, with another water bath incubation at 40°C for one hour. Finally, the same procedure as acidic extraction was followed to obtain enzymatically extracted DF-rich powder (EE).

3.3. Determination of the proximate composition and color of DF-rich powders

Proximate analysis of ash, protein, and crude fiber was performed according to AOAC [16] methodologies. The total carbohydrate content was calculated as the difference. The DF content of the DF-rich powders was determined according to the modified official AOAC method 991.43 [17]. The CIE L*, a*, and b* color values were evaluated with a chromometer (Konica Minolta Chroma meter CR-400). The instrument was calibrated with a standard white plate.

3.4. Determination of bulk density

The bulk density of the DF-rich powders was determined according to the method outlined by Prakongpan et al. [18]. In brief, a 5 mL measuring cylinder was filled with 1 g of sample, and the volume was recorded. The bulk density was calculated as follows:

$$\text{Bulk density} = \frac{\text{Sample weight (g)}}{\text{Sample volume (mL)}}$$

3.5. Determination of total phenolic content and DPPH free radical scavenging activity

3.5.1. Sample preparation

A 1.0 g sample of powder was combined with 20 mL of methanol and subjected to incubation in a shaking water bath (LSB-030S model) at 25°C for one hour. The mixture was subsequently centrifuged (GEMMYCO PLC-025 model) at 4000 rpm for 10 minutes. The resulting extract was then filtered through Whatman No. 1 filter paper and brought up to a volume of 25 mL with 80% methanol [19].

3.5.2. Determination of total phenol content

The total phenolic content of the DF-rich powders was measured using the Folin–Ciocalteu assay as described by Pathiraje et al. [20], with modifications. A 0.5 mL aliquot of the extract was mixed with 0.1 mL of Folin–Ciocalteu reagent and 3 mL of distilled water. After the mixture was incubated in the dark for 5 minutes, 2.5 mL of 7.5% sodium carbonate was added, followed by a 30-minute incubation in the dark. The absorbance was then measured at 760 nm using a UV/VIS spectrometer (EVOLUTION 201, China). Gallic acid was used to construct the standard curve.

3.5.3. Determination of DPPH free radical scavenging activity

The method described in Pathiraje et al. [20] with modifications was used to determine the DPPDH free radical scavenging capacity of the DF-rich powders. Briefly, 100 µL of the extract was mixed with 3.9 mL of 1 mM methanolic DPPH solution. The mixture was incubated for 30 min in the dark, and the absorbance was measured at 517 nm using a UV/IS spectrometer (EVOLUTION 201, China) against a blank (80% methanol). A control sample was prepared using 80% methanol instead of the DF-rich powder extract and DPPH radical scavenging activity was calculated as the percent inhibition.

3.6. Determination of water holding capacity (WHC) and oil holding capacity (OHC)

The WHC of the DF-rich powders was determined following the method described by Robertson et al. [21] with modifications. A sample of 1.0 g was placed into a preweighed 15-mL centrifuge tube, and 12 mL of distilled water was added. The mixture was vortexed at high speed for 5 minutes and allowed to stand for 1 hour. The sample was then centrifuged (GEMMYCO PLC-025 model) at 4000 rpm for 15 minutes. The supernatant was discarded, and the weight of the precipitate was measured. The procedure for determining the WHC was adapted to measure the oil holding capacity (OHC) by using coconut oil instead of distilled water. The WHC and OHC were calculated as percentages.

3.7. Determination of cholesterol absorption capacity (CAC)

To determine cholesterol absorption capacity, a series of cholesterol standard solutions (100–1000 ppm) were prepared following modified methods from Feng Hsien-wen et al. [22]. An ammonium ferric sulphate coloring reagent was prepared by dissolving 8 grams of ammonium ferric sulphate in 100 mL of 85% phosphoric acid and then mixing 50 mL with 1 M sulfuric acid. Sample preparation followed the method described by Hu and Zhao [23] with slight modifications. The egg yolk was diluted 30 times with distilled water, and 1 gram of DF-rich powder was mixed with 20

mL of this diluted egg yolk. The pH was adjusted to 2 ± 0.5 to simulate stomach conditions, and the mixture was incubated at 37 °C for 2 hours. After centrifugation at 4000 rpm for 10 minutes, the supernatant was collected. The control samples were similarly prepared without the DF-rich powder. For each test and control sample, 0.2 mL of the supernatant was mixed with 2 mL of coloring reagent and 2 mL of glacial acetic acid, and the absorbance was measured at 560 nm using a UV/VIS spectrometer.

The CAC was calculated as follows:

$$\text{CAC} = \frac{\text{Weight of cholesterol in the control sample (mg)} - \text{Weight of cholesterol in the test sample(mg)}}{\text{sample weight (g)}}$$

3.8. Application of DF-rich powder in a meat emulsion model system

Four different meat emulsion model products were formulated (Table 1). The meat was minced through a grinder with a 3 mm plate. The meat and other ingredients were added and mixed twice in a food processor for 2 minutes each time. The final temperature was less than 10 °C. Approximately 25 g portions of each sample were placed into 50 mL Falcon tubes. These tubes were then heated in a water bath at 70 °C for 30 minutes. After heating, the samples were allowed to cool to room temperature.

Table 1 Meat model formulations

Treatment	Chicken meat	Water	Spices	Salt	Wheat flour	Peel powder	DF-rich powder
No-binder Control	75%	14.5%	1%	2%	7.5%	-	-
Peel powder added (P)	75%	14.5%	1%	2%	-	7.5%	-
DF-rich powder 2% added (F-2)	75%	14.5%	1%	2%	4.0%	-	2.0%
DF-rich powder 4% added (F-4)	75%	14.5%	1%	2%	3.5%	-	4.0%

3.8.1. Determination of cooking yield

The weights of the meat emulsion model were recorded before and after cooking, and the cooking yield was calculated as the difference between the precooked sample and the cooked sample and cooking yield was expressed as a percentage [24].

3.8.2. Determination of total expressible fluid and expressible fat percentage

The total expressible fat and fluid contents were determined according to the methods of Serdaroğlu et al. [24], with slight modifications. A sample (3 g) of cooked meat was centrifuged at 1000 rpm for 1 minute. The expressible fluid was then separated into a preweighed crucible. The total expressible fluid percentage was calculated on the basis of the weight difference between the raw meat sample and the cooked meat sample after the expressible fluid was removed. The crucibles with expressible fluid were oven-dried at 105 °C overnight, and the total expressible fat percentage was calculated on the basis of the weight difference before and after oven drying.

3.8.3. Determination of CIE color of cooked meat models

The color of the cooked meat samples was measured on the outer and inner surfaces by using a chromometer (CR-400 Minolta Chromameter, Japan). The color was expressed as CIE L* (lightness), CIE a* (redness), and CIE b* (yellowness). The instrument was calibrated with a standard white plate.

3.8.4. Determination of textural properties

A sample approximately 5 cm in length with a diameter of 1 cm was taken from each formulation, and triplicate measurements were taken. The hardness (N) and cutting shearing force (J) were measured using a texture analyzer (Ez-SX, China) at a constant speed of 2 mm/second, and texture profile analysis measurements were performed in terms of cohesiveness (N), gumminess (N), and chewiness (N) using a texture analyzer (TX-700, France).

3.9. Data analysis

All the experiments were conducted in triplicate, and the statistical analysis was performed using SPSS version 25. ANOVA, followed by Tukey's test for mean comparisons, was used to evaluate the treatment effects, with $P < 0.05$ considered statistically significant.

4. Results and discussion

4.1. Proximate composition of YPFP

The proximate analysis of YPFP revealed that carbohydrates were the most abundant component, accounting for 77.04 ± 0.17 g/100 g. The protein and fat contents were relatively low at 1.49 ± 0.07 g/100g and 1.24 ± 0.20 g/100g respectively, while the ash content was 8.08 ± 0.11 g/100 g and having 12.15 ± 0.42 g/100g moisture content. In a separate study conducted in Brazil, the fat, protein, ash, and total carbohydrate contents of YPFP powder were reported to be 1.24 ± 0.20, 2.13 ± 0.16, 7.28 ± 0.11, and 89.33 ± 2.66 g/100 g, respectively which are comparable to the results of the present study [25]. In comparison, dragon fruit peel and mango peel presented relatively high fat contents of 2.34 ± 0.18 g/100 g and 5.9 ± 0.05 g/100 g, respectively [26]. Similar fat contents were observed in pineapple and guava peels [26]. In terms of ash content, the YPFP of the present study was 8.08 ± 0.11 g/100 g, which was higher than those reported for mango and pineapple peels. Furthermore, the protein level in YPFP powder was lower than that in pineapple and mango, which contain 4.0 g and 8.0 g of protein per 100 g, respectively [26]. Moreover, Ajila et al. [27] reported more protein in mango peel powder (3.6 ± 0.6 g/100 g) than in YPFP.

4.2. Effect of extraction method on the IDF, SDF, and TDF contents in DF-rich powders

This study revealed that the IDF, SDF, and TDF contents of YPFP powder were 44.12±3.22%, 10.57±1.10%, and 54.69±2.91%, respectively (Table 2). Similarly, a study conducted in Mexico reported comparable values for YPFP, with IDF, SDF, and TDF contents of 46.18 ± 3.76%, 11.75 ± 1.21%, and 57.93 ± 2.72%, respectively [28]. In contrast, a study from Abidjan reported higher values, with IDF at 60.8 ± 0.5%, SDF at 11.6 ± 0.2%, and TDF at 73.5 ± 1.2% in alcohol-insoluble material from YPFP [11].

Table 2 Dietary fiber contents of yellow passion fruit peel powders

Sample	Insoluble Dietary Fiber (%)	Soluble Dietary Fiber (%)	Total Dietary Fiber (%)
Whole peel powder	44.12 ± 3.22 ^{c}	10.57 ± 1.10 ^{c}	54.69 ± 2.91 ^{c}
AHE – 2%	54.67 ± 0.36 ^{b}	22.35 ± 1.84 ^{ab}	77.02 ± 1.83 ^{a}
AHE - 1%	56.59 ± 0.55 ^{ab}	13.35 ± 0.52 ^{c}	69.94 ± 1.03 ^{b}
AUE – 2%	45.23 ± 0.98 ^{c}	26.72 ± 2.71 ^{a}	71.95 ± 2.47 ^{b}
AUE - 1%	58.89 ± 0.16^{a}	10.9 ± 1.48 ^{c}	69.79 ± 1.62 ^{b}
EE	53.03 ± 0.16^{b}	18.20 ± 0.19 ^{b}	71.23 ± 0.19^{b}

^{a,b,c} Means with different superscripts within the same column are significantly different ($p<0.05$). Values are expressed as mean ± Standard deviation (n=3). AHE 2%: Water bath heating- assisted 2% acid extracted powder, AHE 1%: Water bath heating- assisted 1% acid extracted powder , AUE 2% : Ultrasonication - assisted 2% acid extracted powder; AUE 1%: Ultrasonication- assisted 1% acid extracted powder, EE: Enzymatic extracted.

The results of the present study indicated that, compared with whole peel flour, both acidic and enzymatic extraction methods increased the TDF content by 15.25–22.33%. The AHE 2% powder resulted in the highest TDF content, whereas the AUE 2% powder resulted in the highest SDF content. IDF was highest in the AHE 1% powder. Conversely, Wang et al. [29] reported that acidic extraction of dietary fiber from Rubus chingii Hu. Fruit extraction resulted in lower SDF yields compared to enzymatic extraction. This difference could be due to the acidic medium breaking down polysaccharides and hydrolyzing SDF into oligosaccharides and monosaccharides, which are not precipitated by ethanol. Additionally, they noted that enzymatically extracted SDF contains high amounts of protein due to residual enzymes, potentially affecting the SDF content.

Table 3 shows that both acid concentration and physical treatment significantly affected the contents of IDF, SDF, and TDF. The acid concentration had a notable effect on all three fiber types ($p<0.05$), whereas the physical treatment significantly influenced the IDF and TDF contents ($p<0.05$). The interaction between these factors also affected the fiber

contents. Abboud et al. [30] reported that approximately 92% of the SDF in YPFP is pectin. Studies by Kulkarni & Vijayanand [31] indicated that lowering the pH increased the pectin yield, suggesting that increasing the acid concentration from 1% to 2% increases the SDF yield. However, research on the combined effects of acid concentration and physical treatments is limited. To further investigate these effects, 2% AHE and 2% AUE powders were selected for their physicochemical and functional properties.

Table 3 Effects of acid concentration, physical treatment, and their interaction on insoluble, soluble and total dietary fiber content

Dietary fiber	**P values**		
	Physical Treatment (PT)	**Acid Concentration (AC)**	**PT * AC**
Insoluble dietary fiber	P = 0.000	P = 0.000	P = 0.000
Soluble dietary fiber	P = 0.319	P = 0.000	P = 0.005
Total dietary fiber	P = 0.014	P = 0.001	P = 0.019

4.3. Physical and chemical properties of DF- rich powders

Bulk density is influenced primarily by particle shape and size, with higher bulk density indicating smaller particle sizes. It is also affected by the air volume within the sample, the drying technique used, and the material integrity [32]. As shown in Table 4, the DF-rich powders presented a significantly greater bulk density than the whole peel powder, suggesting that the DF-rich powders have smaller particle sizes. The notable decrease in the bulk density of the ultrasonic bath-incubated powder compared with that of the water bath-incubated powder indicates increased porosity and surface area due to ultrasonication. Furthermore, bulk density is linked to the functional properties of meat products, where higher bulk density enhances water and fat retention, thereby improving moisture and juiciness in products such as sausages [10, 33].

The color of a powder is an important parameter, especially when it is incorporated into food products, as it affects appearance and consumer acceptability. For example, Zaini et al. [34] reported that adding banana peel powder to sausages resulted in a darker color, which negatively impacted consumer acceptability. Similarly, Sánchez-Zapata et al. [35] reported that incorporating date paste into meat products led to a darker color, reduced brightness, and a pink hue due to decreased lightness and increased redness values. Conversely, López-Vargas et al. [10] reported that adding passion fruit albedo powder to pork burgers caused only slight color changes, with no significant differences compared with the control.

The CIE L*, a*, and b* color values revealed that the DF-rich powders had higher L* values than did the whole peel powder, indicating greater lightness. However, the redness (a*) and yellowness (b*) values were significantly lower than those of the whole peel powder. YPFP is rich in carotenoid pigments, with oven-dried peel containing 2.21 mg/100 g of powder [28]. Carotenoids are unstable because of their unsaturated nature and are susceptible to oxidation, which is accelerated by heat, light, and oxygen, leading to autoxidation during processing [36]. These observations suggest that the DF extraction process can lead to carotenoid degradation.

There was a significant difference in the total phenol content among the three types of DF-rich powders. Sonication, which is primarily attributed to cavitation, involves the formation and collapse of bubbles, inducing physical, chemical, and mechanical effects. This process facilitates the extraction of polyphenolic compounds from the material matrix into the solvent by breaking down the material structure [37]. The results revealed that the total phenolic content of the ultrasonication-assisted DF-rich powder was lower than that of the water bath-assisted DF-rich powder, suggesting that more phenolic compounds were removed from the peel powder during ultrasonication. The enzymatically extracted powder had the lowest total phenolic content. Escribano-Bailon [38] reported that higher temperatures result in more extraction of polyphenols, but temperatures above 25°C cause the degradation of phenolic compounds. Therefore, in this study, high temperatures and fluctuations in the acidic and basic environment during enzymatic extraction might have caused more degradation or removal of polyphenol compounds from the DF-rich powder compared with acid extraction methods.

Table 4 Bulk density, color, total phenolic content and antioxidant activity of yellow passion fruit peel powders

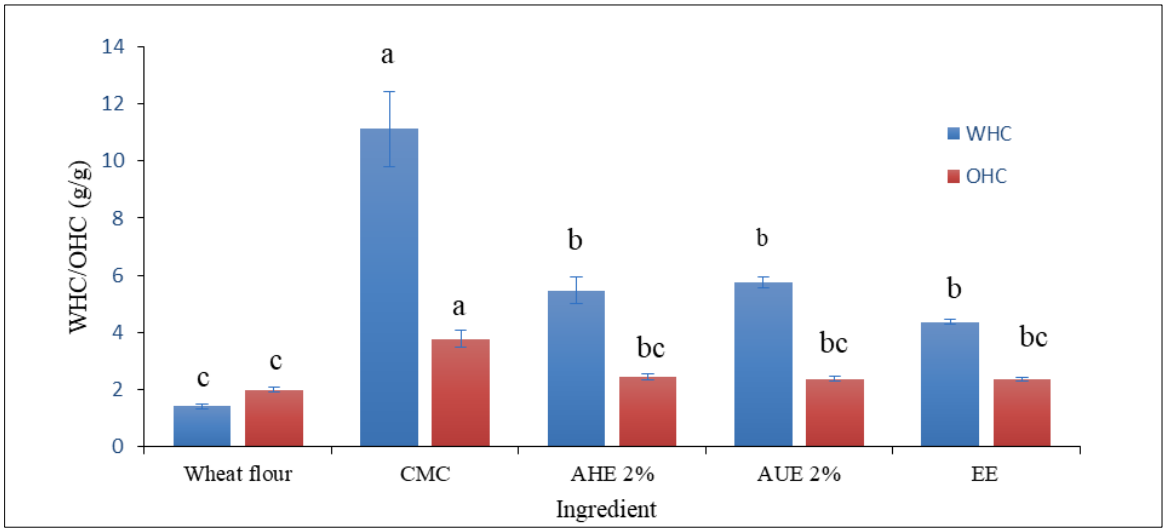
Parameter	Peel flour	AHE 2%	AUE 2%	EE
Bulk density (g/mL)	0.35 ± 0.01 ^{c}	0.74 ± 0.01 ^{a}	0.68 ± 0.01 ^{b}	0.75 ± 0.01^{a}
Color				
L*	70.8 ± 0.60^{c}	72.8 ± 0.75^{b}	72.5 ± 0.15^{b}	75.9 ± 0.17^{a}
a*	3.2 ± 0.38^{a}	0.27 ± 0.01^{b}	0.33 ± 0.06^{b}	0.33 ± 0.02^{b}
b*	22.9 ± 0.16^{a}	19.3 ± 0.44^{c}	20.6 ± 0.06^{b}	20.5 ± 0.06^{b}
TPC content	ND	1.149 ± 0.01^{a}	0.95 ± 0.02^{b}	0.75 ± 0.03^{c}
DPPH scavenging activity	ND	33.6 ± 0.97^{a}	30.1 ± 1.01^{b}	27.4 ± 0.77^{c}

^{a,b,c} Means with different superscripts within the same raw are significantly different ($p<0.05$). Values are expressed as mean ± Standard deviation; AHE 2%: Water bath heating- assisted 2% acid extracted powder, AUE 2%: Ultrasonication - assisted 2% acid extracted powder, EE: Enzymatic extracted powder; TPC content: Total Phenolic content (GAE mg/g of dry weight), ND: Not determined

4.4. Water and oil holding capacities of DF-rich powders

As shown in Figure 1, compared with that of wheat flour, the WHC of all three DF-rich powders was significantly greater, ranging from 4.37 ± 0.09 to 5.75 ± 0.18 g/g powder. Wheat flour, which is commonly used as a binder in meat products, enhances water retention properties. A relatively high WHC is beneficial for viscosity development and freshness preservation in cooked meat products [26]. The alcohol-insoluble material in YPFP has a slightly lower WHC of 3.7–4.1 g/g [11] than the WHC of the DF-rich powders in the present study.

The OHC of the DF-rich powders ranged from 2.36 ± 0.187 to 2.45 ± 0.125 g/g, higher than those of the mango, pineapple, and guava byproducts, which were 1.6 ± 0.04, 0.7 ± 0.08, and 0.07 ± 0.05 g/g, respectively [26]. OHC is influenced by the surface characteristics of the hydrocolloid, total electrical charge density, and hydrophobicity [39], suggesting a greater proportion of hydrophobic groups in these DF-rich powders.



CMC: Carboxy Methyl Cellulose, AHE 2%: Water bath heating- assisted 2% acid extracted powder, AHE 1%: Water bath heating- assisted 1% acid extracted powder, AUE 2%: Ultrasonication - assisted 2% acid extracted powder, AUE 1%: Ultrasonication-assisted 2% acid extracted powder. ^{a,b,c} Means with different superscripts within the same column are significantly different ($p<0.05$). Values are expressed as mean ± Standard deviation (n=3)

Figure 1 Water (WHC) and oil (OHC) holding capacities of dietary fiber-rich powders compared to wheat flour and Carboxy Methyl Cellulose (CMC)

4.5. Cholesterol absorption capacity of the DF-rich powders

The DF-rich powders extracted with acid had higher cholesterol absorption capacity values (AUE 2%: 36.14 ± 0.58 mg/g and AHE 2%: 35.25 ± 1.44 mg/g) compared to the enzymatically extracted powder (32.07 ± 0.76 mg/g). Jurevičiūtė et al. [40] reported that cranberry, lingonberry, sea buckthorn, and black currant powders have cholesterol binding capacities of 23.13 ± 0.47 mg/g, 22.61 ± 0.45 mg/g, 22.75 ± 0.46 mg/g, and 21.11 ± 0.42 mg/g, respectively. Additionally, cassava DF has binding capacities of 5.27 mg/g at pH 2 and 7.16 mg/g at pH 7 [41]. These findings indicate that YPFP-derived DF-rich powders have significantly greater in vitro cholesterol absorption capacities. Furthermore, the results of the present study revealed a significant increase in SDF content in acid-extracted powders compared with that in enzymatically extracted powders, suggesting a greater cholesterol absorption capacity in the former.

The application of DF from YPFP offers a sustainable way to enhance the functional properties of food products. The resulting DF-rich powders exhibited good water- and oil-holding capacities, making them ideal for improving meat product formulations. However, further analysis is needed to optimize the integration of these powders into meat products. Therefore, this study further focused on assessing the effects of DF-rich powder on the color texture and cooking properties of meat products using a model emulsion meat system.

4.6. Effect of DF-rich powder on the CIE color of the cooked meat model

Compared with the control sample with 7.5% wheat flour, the addition of 4% DF-rich powder significantly reduced the L* value of both the internal and external surfaces of the meat model ($p<0.05$). This reduction in lightness could be due to the yellowish color of the DF-rich powder. In contrast, adding 2% DF-rich powder did not affect the L* value. The L* value of meat is strongly influenced by its pH and water-holding capacity (WHC), which are associated with structural changes such as protein denaturation or aggregation, shrinkage of muscle fibers, and changes in the osmolarity of the sarcoplasm and extracellular space [42]. Several other studies have shown that the application of DF-rich plant ingredients decreases the L* value of meat products [35, 43].

The CIE a* values, which indicate redness, revealed that the application of the DF-rich powder reduced the CIE a* value compared with that of the control samples. These findings are in agreement with those of previous studies. Yilmaz [44] reported a reduction in redness with increasing levels of wheat bran, whereas a 5–20% increase in oat bran resulted in decreased redness in Turkish meatballs [45].

The b* value, which indicates yellowness, was not significantly different among the inner surfaces of the cooked meat samples. However, there was a significant difference in the yellowness of the outer surfaces between the DF-rich powder-added samples and the control samples. The fiber percentage did not affect the yellowness value. WHC also influences differences in yellowness. For example, a study on chicken sausages revealed that yellowness decreases as the percentage of banana peel powder increases due to its high water-retaining capacity [34].

4.7. Emulsion stability and cooking yield of the meat model

The whole peel powder-treated sample had the lowest amount of expressible fluid after cooking, and the amount of expressible fluid decreased as the amount of DF-rich powder increased (Table 5). Similar results were obtained when pomegranate seed powder was added to chicken meat emulsions [24]. Additionally, the cooking yield increased with the addition of the DF-rich powder. Compared with those containing 5% fiber, chicken nuggets containing 10% fiber from orange albedo and eggplant pulp presented significantly greater cooking yields [7]. Yilmaz [44] reported the lowest weight loss in meatballs containing 20% wheat bran. In contrast, low-fat, low-salt chicken nuggets with apple pulp presented significantly lower cooking yields than the control samples [46]. Emulsion stability is related to the expressible moisture content. The expressible moisture percentage of the control sample (7.5% wheat flour included) was not significantly different from that of the DF-rich powder-added samples. Therefore, these results suggest that the addition of 2% or 4% DF-rich powder to the meat model has no significant effect on the expressible moisture. Shand [47] reported that the addition of carrageenan and soy protein concentrate into pork bologna resulted in the highest expressible moisture, whereas the lowest expressible moisture accounted for the waxy barley meal-added burger.

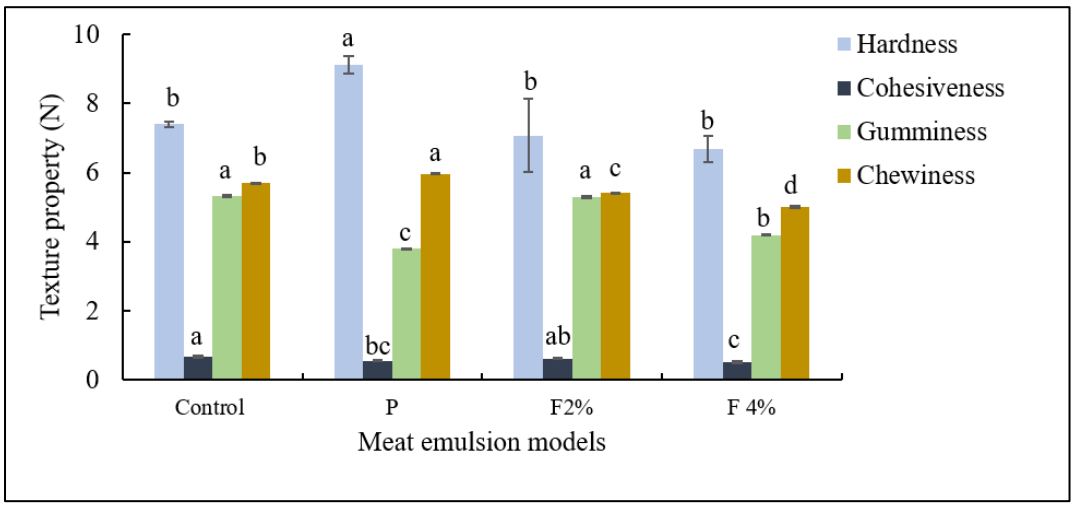
Table 5 Effect of dietary fiber rich powders from yellow passion fruit peel on color, fluid holding and cooking attributs of emulsified chicken meat models

Attribute	No-binder control	P	F2	F4
Inner color				
L*	58.91± 0.066^{a}	55.85 ± 1.01^{c}	57.98 ± 0.194^{ab}	56.79 ± 0.066^{bc}
a*	5.05 ± 0.064^{a}	3.91 ± 0.165^{b}	2.06 ± 0.066^{c}	1.95 ± 0.030^{c}
b*	16.61 ± 0.152^{a}	17.61 ± 0.548^{a}	16.75 ± 0.115^{a}	16.79 ± 0.061^{a}
Outer color				
L*	53.57 ± 0.170^{a}	49.77± 0.803^{b}	50.77± 0.106^{b}	49.75 ± 0.536^{b}
a*	3.44 ± 0.135^{a}	3.79 ± 0.221^{a}	2.57 ± 0.080^{b}	1.90 ± 0.032^{c}
b*	14.99 ± 0.116^{c}	14.46 ± 0.068^{d}	15.60 ± 0.030^{b}	15.74 ± 0.090^{b}
Expressible fluid (%)	3.50 ± 0.42^{a}	0.077 ± 0.02^{d}	2.47 ± 0.38^{b}	1.67 ± 0.59^{c}
Expressible fat (%)	0.67 ± 0.05^{a}	0.098 ± 0.01^{b}	0.57 ± 0.07^{a}	0.29 ± 0.1^{b}
Cooking yield (%)	96.49 ± 0.42^{d}	99.55 ± 0.06^{a}	97.53 ± 0.38^{c}	98.55 ± 0.44^{b}

^{a,b,c} Means with different superscripts within the same rows are significantly different ($p<0.05$). Values are expressed as mean ± Standard deviation.; P: 7.5% Yellow Passion fruit peel powder added, F 2: 2% Water bath heating- assisted 2% acid extracted fiber- rich powder + 5.5% wheat flour added, F 4: 4% Water bath heating- assisted 2% acid extracted fiber-rich powder + 2.5% wheat flour added

4.8. Texture

Texture plays a crucial role in the sensory experience of emulsified meat products such as bologna. Figure 2 shows the hardness, gumminess, cohesiveness, and chewiness values of the meat model systems. Compared with the no-binder control, there was no significant difference in hardness values with increasing DF-rich powder content from 2% to 4%.



^{a,b,c} Means with different superscripts are significantly different ($p<0.05$). Control: 7.5% wheat flour added, P : 7.5% Yellow Passion fruit peel powder added, F 2: 2% Water bath heating- assisted 2% acid extracted fiber- rich powder + 5.5% wheat flour added , F 4: 4% Water bath heating-assisted 2% acid extracted fiber-rich powder + 2.5% wheat flour added

Figure 2 Texture properties of chicken meat emulsion models formulated with dietary fiber rich powders from yellow passion fruit peel

The highest shearing energy value was observed in the whole peel powder-added sample (0.09 ± 0.001 J), while the addition of DF-rich powder did not significantly affect the shearing energy values, which were 0.06 ± 0.004 J, 0.06 ± 0.003 J, and 0.06 ± 0.002 J in the control, 2%, and 4% DF-rich powder-added samples, respectively. In emulsified meat products, increased hardness is caused by a decrease in bound water within the batter when cooked [48]. The sample with added peel flour had the highest hardness value. Similarly, López-Vargas et al. [10] reported that adding passion

fruit albedo powder to pork burgers increased hardness due to particle incorporation in the protein matrix, as noted by Viuda-Martos et al. [49].

Gumminess, chewiness, and cohesiveness decreased as the percentage of DF-rich powder increased from 2% to 4%. In contrast, gumminess, chewiness, and cohesiveness improved with the addition of 4% makgeolli leaf fiber [50] and apple pulp in low-fat chicken nuggets [46]. Mendoza et al. [51] reported that adding dietary inulin to low-fat sausages made them harder, gummier, and chewier, whereas springiness, cohesiveness, and adhesiveness decreased. Overall, the results of the texture profile analysis revealed that while the addition of DF-rich powder can influence the texture of meat products, the specific effects depend on the type and amount of fiber added.

The application of DF-rich powders derived from YPFP in meat products presents a promising avenue for enhancing both nutritional value and functional properties. These powders not only increase the DF content but also improve the water- and oil-holding capacities, leading to better cooking yields and reduced expressible fluids and fats in meat formulations. This innovation aligns with the growing consumer demand for healthier, fiber-enriched foods and offers a sustainable solution by utilizing fruit byproducts that would otherwise contribute to waste. While the impact on color and potential consumer acceptability needs further exploration, integrating YPFP-derived DF-rich powders into meat products holds significant potential for the food industry. Future research should focus on optimizing formulations and conducting sensory evaluations to ensure that these functional benefits translate into products that meet consumer preferences and market demands

5. Conclusion

The results demonstrated that YPFP can be effectively utilized to extract DF through various methods, enhancing its application in meat products. The extracted DF-rich powders significantly increased total DF content and exhibited superior water and oil holding capacities compared to conventional binders like wheat flour. Incorporating these powders into meat models improved cooking yield and reduced expressible fluid and fat percentages, indicating enhanced product stability and quality. However, the addition of DF-rich powders affected the color, reducing lightness and redness, which could influence consumer acceptability. Overall, YPFP-derived DF-rich powders offer a promising, sustainable approach to improving the nutritional and functional properties of meat products while reducing agricultural waste. Future research should focus on sensory analysis to evaluate consumer acceptance and optimize formulations for commercial applications.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest in this manuscript.

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