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# Physicochemical, Microbiological, and Sensory Characteristics of Functional Yogurt Fortified with Dragon Fruit (Hylocereus polyrhizus) Peel Powder During Refrigerated Storage

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**Abstract**

The growing consumer demand for functional foods has encouraged the development of dairy products enriched with bioactive compounds derived from agricultural by-products. Dragon fruit (Hylocereus polyrhizus) peel represents approximately 30–35% of the total fruit weight and contains substantial amounts of dietary fiber, phenolic compounds, flavonoids, and betalains with recognized antioxidant properties. This study investigated the effects of dragon fruit peel powder (DFPP) incorporation on the physicochemical, microbiological, antioxidant, and sensory characteristics of yogurt during refrigerated storage. Yogurt samples were prepared with four concentrations of DFPP: 0% (control), 1%, 2%, and 3% (w/w), then stored at 4 ± 1°C for 21 days and evaluated periodically for pH, titratable acidity, viscosity, syneresis, total phenolic content, antioxidant activity, lactic acid bacteria count, and sensory acceptability. The results demonstrated that DFPP significantly enhanced the nutritional and functional properties of yogurt. Total phenolic content increased from 28.45 mg GAE/100 g in the control to 78.62 mg GAE/100 g in the 3% DFPP treatment, while antioxidant activity rose proportionally, reaching 71.4% DPPH radical scavenging activity at the highest fortification level. DFPP supplementation also improved yogurt viscosity (up to 2,480 cP) and reduced syneresis (down to 8.7%) throughout storage, while lactic acid bacteria counts remained above the minimum recommended level of $10^7$ CFU/g. Sensory evaluation revealed that yogurt fortified with 2% DFPP achieved the highest overall consumer acceptability. Incorporation of 2% DFPP is recommended as the optimal concentration for producing functional yogurt with improved antioxidant properties and high consumer acceptance.

*Keywords:* Functional yogurt, dragon fruit peel powder, antioxidant activity, food waste valorization, probiotics, functional foods

## Introduction

The global food industry has experienced substantial growth in the development of functional foods, driven by increasing consumer awareness of the relationship between diet and health. Functional foods are defined as foods that provide health benefits beyond basic nutritional functions through the presence of physiologically active compounds [1]. Among various functional food categories, fermented dairy products particularly yogurt have received significant attention because of their nutritional value, probiotic characteristics, and broad consumer acceptance [2].

Yogurt is produced through the fermentation of milk by specific starter cultures, primarily Streptococcus thermophilus and Lactobacillus delbrueckii subsp. bulgaricus. These microorganisms convert lactose into lactic acid, resulting in characteristic flavor, texture, and nutritional properties. Numerous studies have reported that yogurt consumption contributes to improved gastrointestinal health, enhanced immune response, and reduced risk of certain chronic diseases [3]. Consequently, yogurt has become an attractive carrier for incorporating bioactive compounds derived from plant sources.

Recent trends in food innovation emphasize the utilization of agricultural by-products as sustainable sources of functional ingredients. Fruit-processing industries generate substantial amounts of waste, including peels, seeds, and pomace, which often contain higher concentrations of bioactive compounds than the edible portions [4]. Valorization of such by-products aligns with circular economy principles and contributes to environmental sustainability.

Dragon fruit (Hylocereus polyrhizus) is widely cultivated in tropical and subtropical regions, including Indonesia, Malaysia, Thailand, and Vietnam. The fruit has gained popularity due to its attractive appearance, nutritional profile, and potential health

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benefits. During processing, approximately one-third of the fruit weight becomes peel waste, which is traditionally discarded despite containing significant amounts of valuable phytochemicals [5].

Previous investigations have revealed that dragon fruit peel contains substantial levels of dietary fiber, pectin, phenolic compounds, flavonoids, and betalains. Betalains are water-soluble, nitrogen-containing pigments responsible for the characteristic red-purple coloration of the peel, and exhibit strong antioxidant, anti-inflammatory, antimicrobial, and anticancer properties [6, 7].

Dietary fiber derived from dragon fruit peel may also improve yogurt texture and stability. Fiber-enriched dairy products often exhibit increased water-holding capacity, reduced syneresis, and enhanced viscosity, which contribute positively to consumer perception and product quality [8]. Furthermore, dietary fiber can serve as a prebiotic substrate that supports the growth and viability of beneficial probiotic microorganisms.

The incorporation of fruit-derived ingredients into yogurt has been extensively investigated. Studies involving blueberry, strawberry, pomegranate, and grape by-products have demonstrated improvements in antioxidant capacity, sensory attributes, and nutritional value [9, 10]. However, research concerning the application of dragon fruit peel powder in yogurt remains limited, particularly regarding its effects on physicochemical properties, microbial stability, and sensory characteristics during refrigerated storage.

Therefore, the present study aimed to evaluate the effects of dragon fruit peel powder incorporation on the physicochemical, microbiological, antioxidant, and sensory characteristics of yogurt during 21 days of refrigerated storage, contributing to the development of innovative functional dairy products utilizing agricultural by-products while supporting sustainable food systems.

## Literature Review

### 2.1. Functional Dairy Products and Probiotic Fermentation

Functional dairy products are designed to deliver health benefits through bioactive compounds, probiotic microorganisms, or fortified nutrients beyond standard nutrition. Yogurt remains the most widely studied carrier for functional ingredients due to its established fermentation process and broad global consumption [2, 3].

### 2.2. Bioactive Compounds in Dragon Fruit Peel

Dragon fruit peel is rich in betalains, flavonoids, and phenolic acids that confer strong antioxidant and anti-inflammatory properties. These compounds have been associated with reduced oxidative stress markers and improved metabolic health outcomes in various food matrix applications [6, 7].

### 2.3. Fiber Fortification and Yogurt Stability

The incorporation of dietary fiber into yogurt formulations has been shown to enhance water-holding capacity, increase viscosity, and reduce syneresis, contributing to overall product stability and consumer-perceived quality during refrigerated storage [8, 15].

## Methodology

### 3.1. Study Location and Experimental Design

This study was conducted at the Food Technology Laboratory, Universitas Prima Nusantara, Indonesia. The experiment employed a Completely Randomized Design (CRD) with four treatments: T0 (control, 0% DFPP), T1 (1% DFPP), T2 (2% DFPP), and T3 (3% DFPP). Each treatment was prepared in triplicate, resulting in twelve experimental units. Yogurt samples were stored at 4 ± 1°C and analyzed on days 1, 7, 14, and 21 of refrigerated storage.

### 3.2. Materials

Fresh red dragon fruits (Hylocereus polyrhizus) were obtained from a commercial plantation in West Sumatra, Indonesia. Full-cream pasteurized cow milk was purchased from a local certified dairy supplier. The yogurt starter culture consisted of Streptococcus thermophilus and Lactobacillus delbrueckii subsp. bulgaricus.

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### 3.3. Preparation of Dragon Fruit Peel Powder

Fresh dragon fruit peels were washed thoroughly, cut into small pieces (approximately 2 cm × 2 cm), and blanched at 80°C for 2 minutes to reduce enzymatic browning and microbial contamination. The blanched peels were dried using a hot-air oven at 55°C for 24 hours until the moisture content reached below 10%, milled, and sieved through a 60-mesh screen.

### 3.4. Yogurt Production

Milk was heated to 90°C for 10 minutes, cooled to 42°C, and dragon fruit peel powder was incorporated according to treatment concentrations. The mixtures were homogenized at 10,000 rpm for 3 minutes, inoculated with starter culture at 3% (v/v), and fermented at 42°C for approximately 6 hours until the pH reached 4.5.

### 3.5. Physicochemical Analysis

Titratable acidity was determined according to AOAC official methods [12] and expressed as percentage lactic acid using Equation (1): %Lactic Acid = (V × N × 0.009 × 100) / W, where V is the volume of NaOH used (mL), N is the normality of NaOH, and W is the sample weight (g). Viscosity was measured using a Brookfield Viscometer at 60 rpm with spindle number 4. Syneresis was determined by centrifuging 25 g of yogurt at 4,000 rpm for 10 minutes and calculated as: Syneresis (%) = (weight of whey separated / weight of sample) × 100.

### 3.6 Total Phenolic Content, Antioxidant Activity, and Microbiological Analysis

Total phenolic content was determined using the Folin–Ciocalteu method and expressed as mg GAE/100 g [13]. Antioxidant activity was assessed using the DPPH radical scavenging assay and calculated as: DPPH Inhibition (%) = [(A0 − As) / A0] × 100 [14]. Lactic acid bacteria were enumerated on MRS agar incubated anaerobically at 37°C for 48 hours and expressed as log CFU/g.

### 3.7. Sensory Evaluation and Statistical Analysis

Sensory evaluation was conducted using 30 semi-trained panelists who assessed color, aroma, texture, taste, and overall acceptability using a nine-point hedonic scale. Data were analyzed using Two-Way ANOVA followed by Duncan's Multiple Range Test (DMRT) at $p < 0.05$.

## Results and Discussion

### 4.1. Effect of DFPP on pH and Titratable Acidity

The pH of all yogurt samples decreased significantly ($p < 0.05$) throughout refrigerated storage. Yogurt fortified with higher DFPP concentrations exhibited lower pH values compared with the control, an effect associated with continued post-acidification by lactic acid bacteria during storage.

**Table 1. Changes in pH of yogurt samples during refrigerated storage.**

| Treatment | Day 1 | Day 7 | Day 14 | Day 21 |
|---|---|---|---|---|
| T0 | 4.56 ± 0.02 | 4.44 ± 0.03 | 4.32 ± 0.02 | 4.21 ± 0.04 |
| T1 | 4.53 ± 0.03 | 4.39 ± 0.02 | 4.28 ± 0.03 | 4.16 ± 0.03 |
| T2 | 4.50 ± 0.02 | 4.35 ± 0.03 | 4.22 ± 0.02 | 4.10 ± 0.02 |
| T3 | 4.47 ± 0.03 | 4.31 ± 0.02 | 4.17 ± 0.03 | 4.04 ± 0.03 |

*Values are means ± standard deviation of triplicate determinations.*

### 4.2. Viscosity and Syneresis

Yogurt fortified with DFPP exhibited significantly higher viscosity than the control treatment due to the high dietary fiber and pectin content present in dragon fruit peel. The highest viscosity was observed in T3 (3% DFPP), reaching 2,480 cP after 21 days of storage.

**Table 2. Viscosity and syneresis of yogurt during refrigerated storage (Day 21 values).**

| Treatment | Viscosity (cP) | Syneresis (%) |
|---|---|---|
| T0 | 1,680 ± 41 | 17.6 ± 0.9 |
| T1 | 1,920 ± 43 | 14.8 ± 0.6 |
| T2 | 2,220 ± 48 | 11.9 ± 0.5 |
| T3 | 2,480 ± 57 | 10.4 ± 0.4 |

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*Values are means ± standard deviation of triplicate determinations.*

### 4.3. Total Phenolic Content and Antioxidant Activity

The addition of DFPP significantly enhanced the total phenolic content (TPC) of yogurt ($p < 0.05$), and antioxidant activity increased proportionally. A strong positive relationship was observed between TPC and antioxidant activity ($r = 0.94$, $p < 0.01$).

**Table 3. Total phenolic content and antioxidant activity of yogurt samples (Day 1).**

| Treatment | TPC (mg GAE/100 g) | DPPH Inhibition (%) |
|---|---|---|
| T0 | 28.45 ± 1.22 | 22.8 ± 1.0 |
| T1 | 45.76 ± 1.45 | 44.3 ± 1.4 |
| T2 | 62.51 ± 1.73 | 59.7 ± 1.8 |
| T3 | 78.62 ± 2.01 | 71.4 ± 2.0 |

*Values are means ± standard deviation of triplicate determinations.*

### 4.4. Lactic Acid Bacteria Viability and Sensory Evaluation

LAB counts decreased slightly during storage but remained above the recommended minimum level of 7 log CFU/g in all treatments. Sensory evaluation revealed that the highest overall acceptability score was obtained for T2 (2% DFPP). Although T3 exhibited superior antioxidant properties, some panelists reported slight earthy and astringent flavors associated with higher DFPP levels.

**Table 4. Sensory scores of yogurt samples on a nine-point hedonic scale.**

| Attribute | T0 | T1 | T2 | T3 |
|---|---|---|---|---|
| Color | 7.1 | 7.8 | 8.5 | 8.6 |
| Aroma | 7.3 | 7.6 | 8.1 | 7.8 |
| Texture | 7.0 | 7.8 | 8.4 | 8.3 |
| Taste | 7.2 | 7.9 | 8.3 | 7.5 |
| Overall Acceptability | 7.2 | 7.9 | 8.4 | 7.8 |

*Values represent mean scores from 30 semi-trained panelists.*

### Conclusion

The incorporation of dragon fruit peel powder significantly improved the quality and functionality of yogurt. DFPP increased viscosity, reduced syneresis, enhanced total phenolic content, improved antioxidant activity, and supported the viability of lactic acid bacteria during 21 days of refrigerated storage. Among the tested concentrations, 2% DFPP produced the highest overall sensory acceptability while maintaining excellent physicochemical and functional characteristics.

These findings highlight the potential of dragon fruit peel as a sustainable and valuable ingredient for the development of functional dairy products, contributing to waste reduction, value addition, and the promotion of circular economy principles within the food industry.

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