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THE EFFECT OF DRAGON FRUIT EXTRACT CONCENTRATION AND FERMENTATION DURATION ON THE FUNTIONAL PROPERTIES OF NATA FROM PALM SAP

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ABSTRACT
Changes in modern consumption patterns show a tendency toward low daily dietary fiber intake. One potential solution to increase fiber intake while utilizing agricultural waste is through the use of red dragon fruit peel (Hylocereus polyrhizus). The objective was to analyze the effect of dragon fruit peel extract concentration and fermentation duration on the functional properties of nat a from palm sap. The study used a complete randomized design (CRD) with multiple factors. Factor x was the concentration of dragon fruit peel extract at 10%, 20%, 30%, and 40%, and factor y was the fermentation duration at 7 days, 14 days, and 21 days, with each treatment repeated three times. Data analysis was performed using Analysis of Variance (ANOVA). Significant differences between treatments were analyzed using DMRT. The results showed that the treatment with 40% dragon fruit peel extract concentration and a fermentation period of 14 days showed an increase in antioxidant response and good nutritional content with an antioxidant response of 110.5 ppm (moderate). There is an effect of concentration and fermentation duration on antioxidant response, fiber, thickness, pH, mold/yeast, and ALT, as indicated by a ρ value of 0.000 < α 0.05.

Keywords: concentration; extract; fermentation duration; nata; palm sap

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INTRODUCTION

Low fiber intake has been associated with an increased risk of various non-communicable diseases (NCDs), such as obesity and others. A global study by Khazanah et al. (2019)shows that the burden of cardiovascular disease due to low fiber consumption remains high. One potential solution to increase fiber intake while utilizing agricultural waste is through the use of red dragon fruit peel (Hylocereus polyrhizu). The problem of fiber deficiency in nata products is a challenge in developing innovative food products that can provide broader health benefits. Therefore, efforts are needed to increase the fiber content in nata products through raw material innovation or the addition of natural ingredients rich in fiber. Food ingredients that are often used are sucrose or granulated sugar.

In addition to granulated sugar, palm sap can also be used as a source of carbon in the production of nata. Palm sap is a sweet liquid obtained from tapping the male flowers of the palm tree (Arenga pinata). Palm sap contains sucrose, protein, and minerals that can be used as raw materials for the production of various food products, one of which is nata. Nata is a fermented product produced by Acetobacter Xylinum bacteria, which form a cellulose layer on the surface of a medium containing

sugar and nitrogen. Based on research by Babyonggo (2022) , Nata made from palm sap produces a product that is lacking in texture, such as elasticity and thickness, so it is necessary to add additional ingredients that can improve the texture and elasticity of Nata. One ingredient that can be used is dragon fruit peel extract.

The use of dragon fruit peel extract in food formulations is not only intended to enrich fiber content, but also to provide additional benefits in the form of anti-inflammatory, antidiabetic, and free radical scavenging effects. Therefore, the integration of dragon fruit peel extract into food products, such as nata, can be an innovation in the development of functional foods that are high in nutritional and economic value. In addition to increasing the nutritional value of nata, dragon fruit peel can improve texture thickness because the sugar contained in dragon fruit peel can be used by Acetobacter Xylinum to form cellulose fibers, thereby affecting the fiber content formed. (Nur'ain & Ramalia, 2016)

According to research conducted by Simangunsong et al.(2014) , the chemical content of red dragon fruit peel produces 25.56% fiber, 2.6% fat, 9.98% protein, and 18.76% ash. The potential nutritional value and high bioactive content of red dragon fruit peel waste is a distinct advantage for processing into food products (Utami et al., 2022) so that the functional properties of dragon fruit peel can be fortified in the manufacture of nata. The most abundant nutrients in Nata are water (95%) and fiber (2.5%), where the average recommended fiber intake per person (per day) is 22–28 grams (Hidayat et al., 2006) . This composition of Nata results in suboptimal functional value for health. The functional value of Nata, which is already popular among the public, needs to be enhanced to provide greater health benefits. Based on the above, research on the development of antioxidant-rich Nata products is necessary. This study aims to determine the optimal concentration of dragon fruit extract in the production of antioxidant-rich Nata and the optimal fermentation time for Nata de palma that does not damage the antioxidants.

METHOD

This research is a laboratory experiment with a Post Test-Only Control Group design. It uses Nata made from palm sap and dragon fruit peel extract as the research subjects. The experiment was conducted using a completely randomized design (CRD) factorial with two factors, namely the extract concentration factor (x) and the fermentation duration factor (y), which consisted of two treatment levels, namely the % concentration of dragon fruit peel extract (X): X1 = 10%, X2 = 20%, X3 = 30%, and X4 = 40% and Fermentation Duration (Y), namely: Y1 = 7, Y2 = 14, Y3 = 21 (days), with each factor replicated three times as a validation test for the data produced. The research data will be analyzed using Analysis of Variance (ANOVA) and Duncan's post-hoc test at a confidence level of $\alpha = 0.05$. Data analysis will be performed using the SPSS version (Ghozali, 2016) statistical analysis application. The test parameters in this study consist of physical, chemical, and microbiological tests. Physical testing includes the thickness and elasticity of Nata, chemical testing includes moisture content, crude fiber, pH, and antioxidant activity, and microbiological testing includes lactic acid bacteria, total plate count, and mold/yeast.

RESULT

Nata de coco is a fermented product made from the sweet sap of the sugar palm tree, fermented with Acetobacter xylinum bacteria. Sugar palm sap is rich in natural sugars, making it a good source of carbon for the growth of cellulose-producing bacteria. Red dragon fruit peel (Hylocereus polyrhizus), an agricultural waste rich in bioactive compounds such as anthocyanins, flavonoids, betacyanins, tannins, and vitamin C, has high antioxidant and antimicrobial activity and can be used as a natural dye. Dragon fruit peel extract increases nutritional value, provides attractive color, and extends product shelf life through antimicrobial activity.

1. The Effect of Red Dragon Fruit Skin Extract Concentration and Fermentation Duration on the Antioxidant Response of Nata from Palm Sap

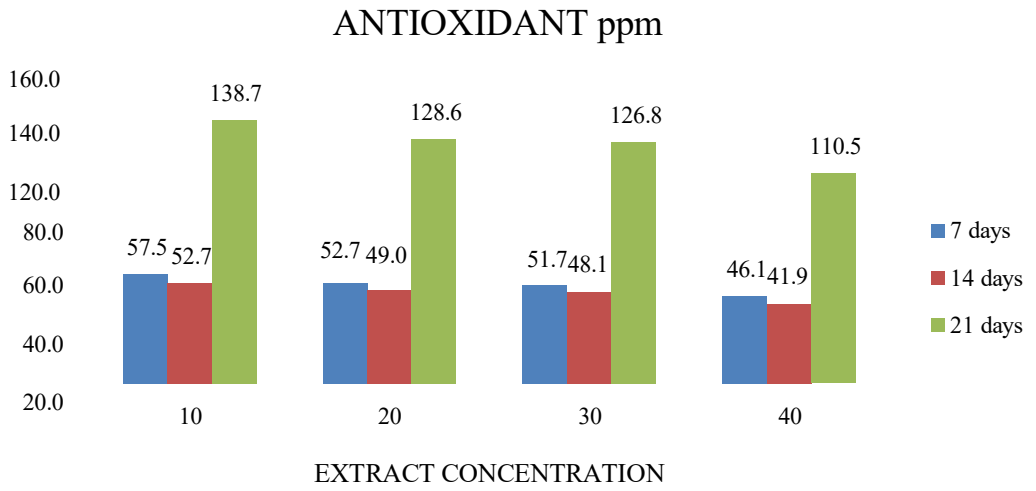

Figure 1.
Analysis of Antioxidant Activity of Nata from Palm Sap and Dragon Fruit Peel Extract

IC50 Range:
IC50 < 50 µg/mL = Very strong
IC50 50-100 µg/mL = Strong
IC50 101–150 µg/mL = Moderate
IC50 >150 µg/mL = Weak

The results of the study show an increase in antioxidant activity values along with increasing concentrations of bark extract and fermentation duration. Soaking the skin extract at 10% and fermenting for 7 days produced an IC50 value of 57.5 (strong), fermenting for 14 days produced an IC50 value of 52.7 ppm (strong), while fermenting for 21 days produced an IC50 value of 138.7 ppm (moderate). When treating palm sap with a 20% skin extract concentration and a fermentation period of 7 days, the IC50 value produced was 52.7 ppm (strong). with a fermentation period of 14 days, the IC50 value produced was 49.0 ppm (very strong), while with a fermentation period of 21 days, the IC50 value produced was 126.8 ppm (moderate). The treatment of palm sap with a 30% skin extract concentration and a fermentation period of 7 days produced an IC50 value of 51.7 ppm (strong), while a fermentation period of 14 days produced an IC50 value of 48.1 ppm (very strong), and a fermentation period of 21 days produced an IC50 value of 126.8 ppm (moderate). In the treatment of palm sap nata with an extract concentration of 40% and a fermentation period of 7 days, the IC50 value produced was 46.1 ppm (very strong). with a fermentation period of 14 days, the IC50 value produced was 41.9 ppm (very strong), while with a fermentation period of 21 days, the IC50 value produced was 110.5 ppm (moderate).

Table 1.
Antioxidant Activity Results

Fat Concentration	Antioxidant		
	Fermentation Duration		
	7 Days	14 Days	21 Days
10	57.5^{a}± 36.67	52.7 ^{ab}± 9.07	138. 7bc^{bc}± 539.8
20	52.7^{ab}± 9.07	49.0^{bc}± 15.87	128.6^{b}± 15.0
30	51.7^{c}± 191.5	48.1^{cd}± 91.6	126.8^{de}± 17.08
40	46.1^{d}± 151.5	41.9^{ed}± 49.12	110.5^{f}± 770.60

Source: Primary Data 2025

The results of the study indicate that variations in concentration and fermentation time affect the increase in antioxidant response in palm sugar nata. The higher the concentration variation of 10%, 20%, and 30% with fermentation times of 7 days and 21 days, the better the antioxidant response in palm sugar nata. 10% 20% 30% 40% 7 days 57.48 52.75 51.66 46.05 s 14 days 52.75 48.98 41.87 21 days 138.74 128.63 128.63 110.52. The highest antioxidant response was obtained in the combination of 40% peel extract with a fermentation period of 14 days, namely 41.87 ppm (very strong), while the lowest antioxidant response was obtained in the combination of 10% peel extract with a fermentation period of 21 days, namely 138.74 ppm (moderate).

2. The Effect of Red Dragon Fruit Skin Extract Concentration and Fermentation Duration on Nata Fiber from Palm Sap

The results of the analysis of crude nata fiber from palm sap and dragon fruit peel extract can be seen in Figure 2

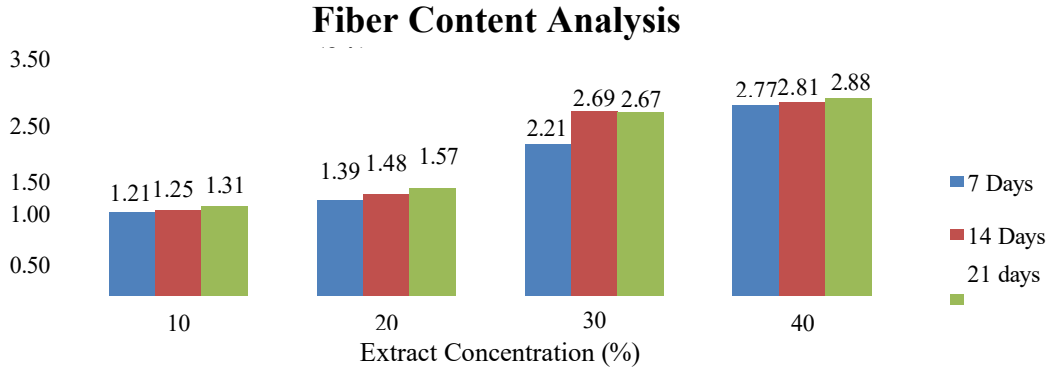

Figure 2.
Analysis of Crude Fiber in Nata from Palm Sap

The results of the study show an increase in fiber content with increasing concentrations of extract and fermentation time of palm sap nata. An extract concentration of 10% and a fermentation time of 7 days resulted in a fiber content of 1.2%, a fermentation time of 14 days resulted in a fiber content of 1.24%, and a fermentation time of 21 days resulted in a fiber content of 1.3%. When the fruit rind extract concentration was increased to 20% and the fermentation time was 7 days, the fiber content was 1.39%; when the fermentation time was 14 days, the fiber content was 1.48%; and when the fermentation time was 21 days, the fiber content was 1.57%. For the treatment with a 30% concentration addition and a fermentation period of 7 days, the crude fiber content in nata was 2.21%. A fermentation period of 14 days resulted in a fiber content of 2.68%, but there was a slight decrease in fiber content with a fermentation period of 21 days, which was 2.67%. For the treatment with a 40% extract concentration addition and a fermentation period of 7 days resulted in a crude fiber content in nata of 2.76%, a fermentation period of 14 days resulted in a fiber content of 8.43% ( ), and a fermentation period of 21 days resulted in a fiber content of 2.87%.

Table 2.
Fiber Content Analysis

Fat Concentration	Antioxidants		
	Fermentation Duration		
	7 Days	14 Days	21 Days
10	1.21^{a}± 4.50	1.25^{a}± 9.07	1.31^{ab}± 5.50
20	1.39^{b}±5.56	1.48^{bc}± 15.6.55	1.57^{c}± 11.53
30	2.21^{cd}± 126.4	2.69^{d}± 13.57	2.67^{d}± 24.94
40	2.77^{e}± 5.68	2.81^{e}±146.5	2.88^{ef}± 4.04

Source: Primary Data 2025

Figure 2 shows no significant effect on the combination of treatments involving variations in dragon fruit peel extract concentration and nata fermentation time. The fiber content analysis results show

an increase in line with increasing concentration and nata fermentation time. The highest fiber content was obtained in the treatment combination of 40% dragon fruit peel extract with a fermentation period of 14 days, namely 8.43%, while the lowest fiber content was obtained in the treatment combination of 10% extract concentration and a fermentation period of 7 days, with a value of 1.2%.

3. The effect of red dragon fruit peel extract concentration and fermentation duration on the acidity level (pH) of nata from palm sap

The results of the pH analysis of palm sap and dragon fruit peel extract are presented in Figure 3.

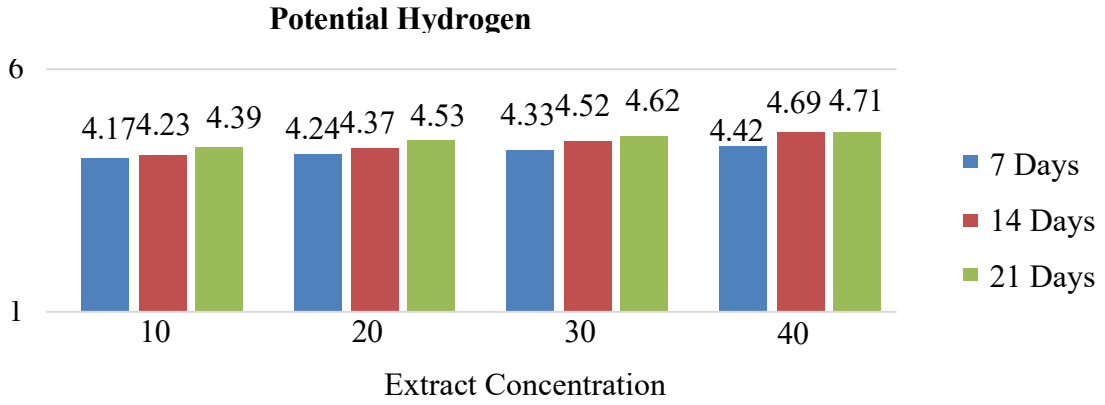

Figure 3.
Analysis Potential Hydrogen

The results of study 3 show that there is an increase in pH as the concentration of peel extract and fermentation time increase. The treatment with 10% dragon fruit peel extract and a fermentation period of 7 days resulted in a pH of 4.17% in the palm sap nata, while the treatment with a fermentation period of 14 days resulted in a pH of 4.23% and a fermentation period of 21 days resulted in a pH of 4.39%. For the treatment of adding 20% bark extract concentration and a fermentation period of 7 days, the pH was 4.24, for a fermentation period of 14 days, the pH was 4.37, and for a fermentation period of 21 days, the pH was 4.53. For the treatment of adding 30% extract concentration and a fermentation period of 7 days, the pH level was 4.33, while a fermentation period of 14 days resulted in a pH of 4.52 and 4.62 for a fermentation period of 21 days. For the treatment with the addition of 40% extract concentration and a fermentation period of 7 days, the pH level was 4.42, for a fermentation period of 14 days it was 4.69, and for a fermentation period of 21 days it was 4.71

Table 3.
Ph Analysis Result
Potential Hydrogen

Extract Concentration	Fermentation Duration		
	7 Days	14 Days	21 Days
10	4.17a ± 0.02	4.23ab ± 0.05	4.39b ± 0.01
20%	4.24bc ± 0.01	4.37c ± 0.01	4.53cb ± 0.01
30%	4.33cd ± 0.01	4.52d ± 0.03	4.62d ± 0.02
40%	4.42de ± 0.03	4.69e ± 0.03	4.71e ± 0.02

Source: Primary Data 2025

Table 3 shows a significant effect on the combination of treatments involving variations in dragon fruit peel extract concentration and nata fermentation duration. The results of the pH level analysis show an increase in line with the increase in concentration and fermentation time of nata. The highest pH level was obtained in the treatment combination of 40% dragon fruit peel extract with a fermentation time of 21 days, namely 4.71, while the lowest fiber level was obtained in the

treatment combination of 10% extract concentration and a fermentation time of 7 days with a value of 4.17.

4. Effect of Red Dragon Fruit Peel Extract Concentration and Fermentation Duration on the Thickness of Nata from Palm Sap

The results of the analysis of nata thickness from palm sap and dragon fruit peel extract can be seen in Figure 4

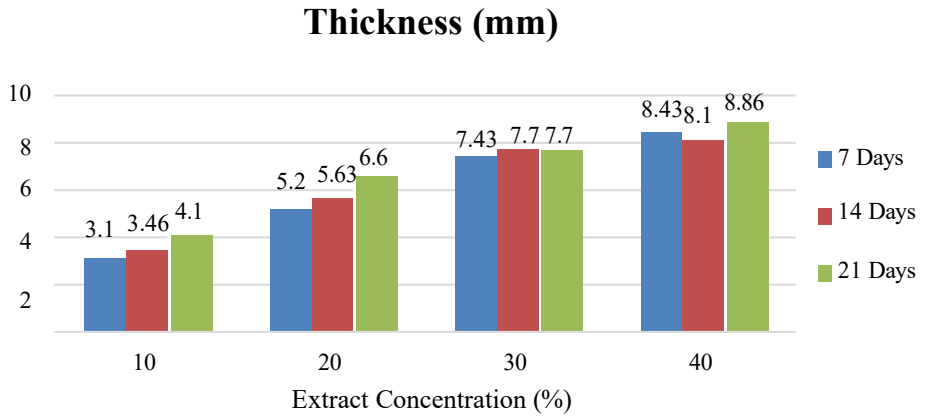

Figure 4.
Analysis of the thickness of nata from palm sap and Dragon Fruit Peel Extract

The results of the study in Figure 4 show that there is an increase in thickness with the addition of extract concentration and fermentation time. The treatment with a 10% extract concentration and a fermentation period of 7 days produced a nata thickness of 3.1 mm, while a fermentation period of 14 days produced a thickness of 3.46 mm, and a fermentation period of 21 days produced a nata thickness of 4.1 mm. Meanwhile, the treatment with a 20% concentration and a fermentation period of 7 days resulted in a nata thickness of 5.2 mm, a fermentation period of 14 days resulted in a nata thickness of 5.63 mm, and a fermentation period of 21 days resulted in a nata thickness of 6.6 mm. For the treatment of adding 30% peel extract concentration and a fermentation period of 7 days, the nata thickness was 7.43 mm, for a fermentation period of 14 days, the nata thickness was 7.7 mm, and for a fermentation period of 21 days, the nata thickness was the same, namely 7.7 mm. Meanwhile, the treatment with the addition of 40% dragon fruit peel extract and a fermentation period of 7 days produced nata with a thickness of 8.43 mm, a fermentation period of 14 days produced a thickness of 8.1 mm, and a fermentation period of 21 days produced a thickness of 8.86 mm

Table 4.
Thickness Analysis Results
Thickness

Extract Concentration	Fermentation Duration		
	7 Days	14 Days	21 Days
10	$4.17^{a}\pm 0.02$	$4.23^{ab}\pm 0.05$	$4.39^{b}\pm 0.01$
20	$4.24^{bc}\pm 0.01$	$4.37^{c}\pm 0.01$	$4.53^{cd}\pm 0.01$
30	$4.33^{d}\pm 0.01$	$4.52^{de}\pm 0.03$	$4.62^{de}\pm 0.02$
40	$4.42^{e}\pm 0.03$	$4.69^{ef}\pm 0.03$	$4.71^{ef}\pm 0.02$

Source: Primary Data 2025

The results of the nata thickness analysis show an increase in line with the increase in nata concentration and fermentation time. The highest thickness was obtained in the treatment combination of 40% dragon fruit peel extract with a fermentation period of 14 days, namely 8.86 mm, while the lowest fiber content was obtained in the treatment combination of 10% extract concentration and a fermentation period of 7 days with a value of 3.1 mm

5. Effect of Red Dragon Fruit Peel Extract Concentration and Fermentation Duration on Nata Mold/Yeast from Palm Sap

The results of the analysis of total nata mold/yeast from palm sap can be seen in Figure 5

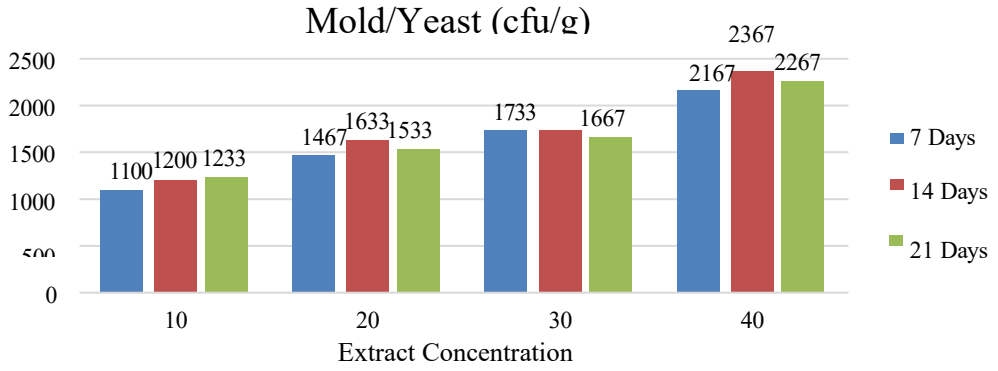

Figure 5. Total Mold/Yeast Nata from Palm Sap and Dragon Fruit Peel Extract

The total results for mold/yeast were not tested *using Analysis of Variance (ANOVA)* because the total mold/yeast test results for the samples were calculated based on the number of colonies that grew on PDA or SDA media after incubation. Data analysis was performed descriptively to describe the level of mold/yeast contamination without conducting a non- t ANOVA test because the purpose of the study was only to determine the presence and level of microbial contamination quantitatively without comparing significant differences between sample groups. The results in Figure 5 show that the total mold (mold/yeast) value increased with the addition of extract concentration and fermentation time. The treatment with the addition of 10% dragon fruit peel extract concentration and a fermentation period of 7 days produced a total of 1.1 x $10^{(1)}$ Log CFU/g fungi, while a fermentation period of 14 days produced 1 .2 x $10^{(1)}$ Log CFU/g, and a fermentation period of 21 days produced 1.2 x 10^{1}Log CFU/g. Then, in the treatment with the addition of 20% dragon fruit peel extract concentration and a fermentation period of 7 days, the total fungi produced was 1.4 x 10^{1}Log CFU/g, while a fermentation period of 14 days produced 1.6 x 10^{1}Log CFU/g, while a fermentation period of 21 days resulted in 1.5 x 10^{1}Log CFU/g. Then, in the treatment with the addition of 30% dragon fruit peel extract concentration and a fermentation period of 7 days, the total fungi produced was 1.7 x $10^{(1)}$ Log CFU/g, with a fermentation period of 14 days producing 1.7 x $10^{(1)}$ Log CFU/g, while a fermentation period of 21 days produced 1.6 x 10^{1}Log CFU/g. The treatment with 40% dragon fruit peel extract concentration and a fermentation period of 7 days resulted in a total of 2.1 x 10^{1}Log CFU/g, while a fermentation period of 14 days resulted in 2.3 x 10^{1}Log CFU/g, while a fermentation period of 21 days resulted in 2.2 x 10^{1}Log CFU/g.

6. The effect of red dragon fruit peel extract concentration and fermentation duration on the total plate count (TPC) of nata from palm sap

The results of the analysis of the Total Plate Count of nata from palm sap and dragon fruit peel extract can be seen in figure 6.

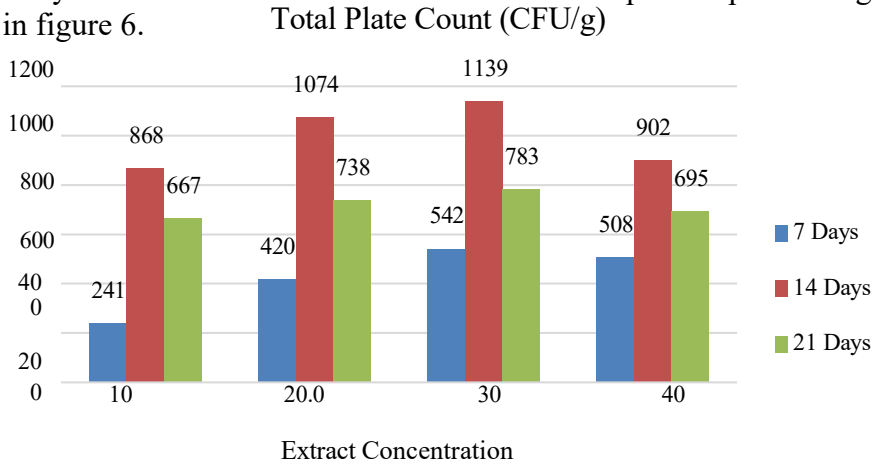

Figure 6. Total Plate Count Nata from Palm Sap and Dragon Fruit Peel Extract

The Total Plate Count (TPC) test results show the number of bacterial colonies that grow on the medium after the incubation period, where the calculation is done on a petri dish with a number of colonies between 30-300 and multiplied by the dilution factor to obtain the total number of microbes in the sample. Data analysis was performed descriptively to describe the level of microbial contamination without using ANOVA statistical tests, so that the discussion focused only on the quantitative description of the number of microbes in the sample based on the TPC calculation standard. The results of the study (Figure 6) showed that the Total Plate Count value increased with the addition of extract concentration and fermentation time. The treatment with the addition of 10% dragon fruit peel extract concentration and a fermentation period of 7 days produced a total plate count of 2.4 x $10^{(2)}$ Log CFU/g, while a fermentation period of 14 days produced 8.6 x $10^{(2)}$ Log CFU/g, and a fermentation period of 21 days produced 6.6 x 10^2Log CFU/g. Then, in the treatment with the addition of 20% dragon fruit peel extract and a fermentation period of 7 days, the total number of fungi was 4.1 x 10^2Log CFU/g, while a fermentation period of 14 days resulted in 1.0 x 10^2Log CFU/g, while a fermentation period of 21 days resulted in 7.3 x 10^2Log CFU/g. Then, in the treatment with the addition of 30% dragon fruit peel extract concentration and a fermentation period of 7 days, the total fungus produced was 5.4 x $10^{(2)}$ Log CFU/g, while a fermentation period of 14 days produced 1.1 x 10^2Log CFU/g, while a fermentation period of 21 days resulted in 7.8 x 10^2Log CFU/g. The treatment with 40% dragon fruit peel extract concentration and a fermentation period of 7 days resulted in a total of 5.0 x 10^2Log CFU/g, while a fermentation period of 14 days resulted in 9.1 x 10^2Log CFU/g, and a fermentation period of 21 days resulted in 6.9 x 10^2Log CFU/g.

DISCUSSION

The Effect of Red Dragon Fruit Skin Extract Concentration and Fermentation Duration on the Antioxidant Response of Nata from Palm Sap

Antioxidant activity tended to increase with increasing extract concentration and fermentation duration until reaching optimal conditions at a fermentation duration of 14 days, before then decreasing at the highest fermentation duration of 21 days. Antioxidant activity in this study was determined by measuring the IC_{50} (Inhibitory Concentration 50) value, which is the concentration required to inhibit 50% of DPPH free radicals. Fermentation, especially fermentation by microorganisms such as Acetobacter Xylinum, has the potential to increase the antioxidant activity of a substrate because microbes are able to break down complex compounds into simpler compounds that have higher bioactivity, such as free phenols, flavonoids, and organic acids. Fermentation can increase the total phenolic content (TPC), which is directly related to increased antioxidant capacity. However, in fermentation that is too long (e.g., 21 days), the antioxidant compounds formed can be degraded due to exposure to oxidation, enzyme activity from microorganisms, or changes in pH and the environment that no longer support the stability of these bioactive compounds. This explains the decrease in antioxidant activity on the 21st day of fermentation even though the concentration of the peel extract is high. Meanwhile, in the extract treatment, the higher the extract concentration, the more bioactive compounds such as tannins, flavonoids, and polyphenols are extracted and have the potential to act as antioxidants. However, as seen in the 40% concentration at 21 days of fermentation, increasing the concentration alone is not sufficient if it is not balanced with proper fermentation time control. Antioxidant activity is not only determined by the amount of phenolic compounds, but also by their active form and stability in the system, highlighting the importance of optimizing fermentation duration and substrate concentration in the development of food-based functional products.

Therefore, the concentration of the peel extract and the fermentation time influence the increase in the antioxidant activity of palm sugar nata de coco. The combination of a 40% extract concentration and a 14-day fermentation time showed the best results with an IC_{50} value of 41.9 ppm, which is classified as "very strong." However, fermentation longer than 14 days, even at high concentrations,

tends to decrease antioxidant activity, indicating an optimal fermentation point that must be considered in the development of fermentation-based functional products. This is in line with the research(Puspitasari et al., 2017; Sukmawati et al., 2013) which explains that a decrease in antioxidant activity after a long fermentation period causes phenolic compounds to become more stable and difficult to release protons that can bind to DPPH, thereby decreasing antioxidant activity.

The Effect of Red Dragon Fruit Skin Extract Concentration and Fermentation Duration on the Acidity Level (pH) of Nata from Palm Sap

This increase in pH can be explained through two main aspects, namely the effect of the compound content in the peel extract and the activity of microorganisms during the fermentation process. The peel extract used contains various bioactive compounds, especially phenolic and flavonoid compounds, which have antioxidant and antimicrobial properties. As reported by(Nurjannah et al., 2022), flavonoids can inhibit the growth of certain microorganisms, including acid-producing bacteria, so that peel extract added to palm sap has the potential to suppress acid production by microorganisms such as Acetobacter xylinum, which is the main bacterium in the nata formation process.

Higher concentrations of extract cause a decrease in fermentative activity that produces organic acids, especially acetic acid. This is in line with the findings of Susanti and(Mulyani et al., 2022) , who stated that the addition of polyphenol compounds in the fermentation medium can neutralize acids and shift the pH to a more neutral level. Therefore, increasing the concentration of peel extract from 10% to 40% in this study contributed to a gradual increase in the pH of nata. In addition to the effect of concentration, fermentation time also plays an important role in pH changes. In the early stages of fermentation (day 7), microorganisms are in the log phase (rapid growth), where acid production is active, so the pH is still relatively low. However, as fermentation time increased to day 21, microbial activity began to enter a stationary phase or even decline. At this stage, the amount of substrate (glucose) decreased, and acid production tended to decline.

The increase in pH during this longer fermentation process can also be attributed to enzymatic activity and changes in metabolite compounds. According to the secondary fermentation theory proposed by(Prescott & Dunn, 1959) in the final phase of fermentation, some acidic compounds can be converted into other compounds that are less acidic or even neutral through decarboxylation and reduction reactions by certain microorganisms.

The Effect of Red Dragon Fruit Peel Extract Concentration and Fermentation Duration on Nata Fiber from Palm Sap

The results showed that an increase in the concentration of dragon fruit peel extract (Hylocereus polyrhizus) and the duration of the fermentation process was directly proportional to the fiber content in the nata produced from palm sap. The higher the extract concentration and the longer the fermentation time, the higher the fiber content formed. The most significant increase occurred at an extract concentration of 40%, with a fiber content reaching 8.43% on day 14, from 2.76% (7 days) previously. However, the fiber content decreased again to 2.87% on day 21. The very high fiber content on the 14th day of fermentation indicates that there was a very active cellulose biosynthesis process at high concentrations of dragon fruit peel. The drastic decrease afterwards was caused by the accumulation of fermentation inhibitor compounds such as acetic acid or an extreme decrease in pH, which can suppress the growth of Komagataeibacter xylinus as a nata-forming microbe. Nata production involves the conversion of sugar by acetic acid bacteria (particularly Komagataeibacter xylinus) into bacterial cellulose. According to (Rosita et al., 2021) , these microorganisms convert glucose into β-1,4-glucan chains arranged in the form of cellulose microfibrils, which then form a layer of nata on the surface of the liquid substrate. This process is highly influenced by the type and availability of the substrate, including phenolic components and other bioactive compounds.

These phenolic compounds and antioxidants can enhance the metabolic activity of acetic acid bacteria in cellulose synthesis, as they have a stimulatory effect on the biosynthetic enzymes of (Sugiarti, 2020) . Additionally, these compounds can also increase pH stability in the fermentation medium, which supports bacterial growth.(Hashem et al., 2013) states that optimal nata fermentation occurs within a range of 10–14 days. Beyond this time, the media conditions tend to deteriorate (decrease in pH, decrease in nutrients, accumulation of acetic acid), resulting in decreased microbial activity. This is in line with the findings of this study, where 21-day fermentation did not produce higher fiber content compared to day 14, and there was even a decrease in some treatments.

The Effect of Red Dragon Fruit Peel Extract Concentration and Fermentation Duration on the Thickness of Nata from Palm Sap

The results showed that increasing the concentration of dragon fruit peel extract and fermentation time had a significant effect on the thickness of the nata produced. The data obtained showed an increase in nata thickness as the extract concentration and fermentation time increased. Dragon fruit peel extract contains various compounds that can support the growth of nata-producing bacteria, such as sugar, phenolic compounds, vitamins, and antioxidants. The higher the concentration of extract added, the more nutrients are available to support the metabolism of Komagataeibacter xylinus in producing cellulose as the main component of nata. According to the study(Lezoul et al., 2020) , substrates containing simple sugars and light phenolic compounds can increase microbial cellulose synthesis because they provide sufficient carbon sources and improve osmotic conditions in the medium. Thus, higher extract concentrations tend to produce greater nata thickness because they support a more optimal fermentation environment for microbial activity. In addition, fermentation time also affects nata thickness. The longer the fermentation lasts, the greater the accumulation of cellulose produced, as long as environmental conditions remain supportive of bacterial activity(Putri et al., 2021) This can be seen from the increase in nata thickness from day 7 to day 21, especially in treatments with low to medium concentrations. However, at a concentration of 30%, the thickness of the nata tended to stagnate between the 14th and 21st days, remaining at a thickness of 7.7 mm. This indicates that nata production can reach a weak point where nutrients begin to run out or the accumulation of toxic substances begins to inhibit microbial activity. Fauzi et al., (2023). High concentrations are able to provide sufficient nutrient reserves to maintain microbial activity during fermentation. Overall, the results of this study indicate a mutually supportive interaction between the concentration of dragon fruit peel extract and the duration of fermentation. The combination of a 40% extract concentration and a 21-day fermentation period yielded the best results, with the highest nata thickness of 8.86 mm.

The Effect of Red Dragon Fruit Peel Extract Concentration and Fermentation Duration on Nata Mold/Yeast from Palm Sap

The results shown in figure 6 illustrate that the total number of fungi (mold/yeast) increased with increasing red dragon fruit peel extract concentration and fermentation time. This increase was consistent across all treatments, although at some points in time, the rate of increase in the number of fungi began to decline or even tended to stabilize. This indicates a significant influence of two main factors, namely extract concentration and fermentation time, on the dynamics of microbial growth in the fermentation substrate. The highest increase was at a concentration of 40%, which produced the highest total number of fungi, namely 2.3×10^1 Log CFU/g on day 14, then decreased slightly on day 21 to 2.2×10^1 Log CFU/g. The increase in the number of fungi indicates that the addition of dragon fruit peel extract has a positive effect on the growth of mold and yeast. This is related to the bioactive compounds contained in dragon fruit peel, including anthocyanins, flavonoids, phenolics, and fermented sugars. According to(Anjliany et al., 2022) , dragon fruit peel extract contains powerful antioxidants and polyphenolic compounds that not only function as functional compounds but also serve as metabolic substrates for microorganisms during fermentation.

These compounds play a role in supporting fungal cell respiration, especially in microaerobic conditions such as fermentation. Adding extract concentrations of up to 40% provided optimal nutrient conditions for fungal growth, as seen in the highest total number of fungi on day 14. In addition to nutritional factors, fermentation time also has a significant effect on the fungal population. The increase in the number of fungi occurred gradually from day 7 to day 14, but began to decline or stabilize on day 21. This is thought to be due to the accumulation of secondary metabolites resulting from fermentation, such as ethanol, acetic acid, and lactic acid, which in high concentrations can inhibit the growth of microorganisms. In a mixed fermentation system, competition occurs between mold, yeast, and bacteria. When nutrients begin to deplete and environmental conditions become unfavorable, only the most adaptable microorganisms can survive (Lestari et al., 2025).

The Effect of Red Dragon Fruit Peel Extract Concentration and Fermentation Duration on the Total Plate Count (TPC) of Nata from Palm Sap

The results of the study show the growth of microorganisms during the fermentation process, which is greatly influenced by the availability of nutrients, the antimicrobial activity of bioactive compounds in dragon fruit peel extract, and changes in environmental conditions due to fermentation. This initial increase can be attributed to the growth of fermentative microorganisms such as Acetobacter Xylinum or other microflora that utilize sugar in palm sap as an energy source. However, the decline on day 21 may be due to a decrease in substrate availability, accumulation of metabolites such as organic acids, or competition between microorganisms, resulting in an environment that is less conducive to some microbes. At the highest extract concentration, although bioactive compounds increased, they were not fully able to inhibit the growth of fermentative microorganisms in the long term because microorganisms that play a role in nata formation, such as Acetobacter spp., grow better in a slightly acidic and antioxidant-rich environment. Antimicrobial compounds such as anthocyanins, flavonoids, and phenols in dragon fruit peel can inhibit the growth of pathogenic and spoilage microorganisms through mechanisms of cell membrane damage, enzyme inhibition, and disruption of the DNA replication process. A recent study by(Siregar & Daniela, 2023) explains that dragon fruit peel extract contains betacyanin anthocyanins and phenolics that are effective as antimicrobials against various types of bacteria and fungi. However, this effectiveness is highly dependent on concentration, type of microorganism, and fermentation duration.

CONCLUSION

Based on the discussion above, it can be concluded that a 40% concentration of red dragon fruit extract is optimal for producing antioxidant-rich nata with a 14-day fermentation period. This is consistent with test results showing that antioxidant activity, fiber content, pH, thickness, fungal count, and total plate count were at their highest at a 40% concentration and a 14-day fermentation period.

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