**Addition Effect of Encapsulated Dragon Fruit Peel Extract on the Bioactivity of Yogurt**

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**Abstract.** Dragon fruit peel contains bioactive compounds, including phenolic and betacyanin. This study investigated the effect of addition of encapsulated dragon fruit peel extract using sodium alginate and maltodextrin to yogurt. The extract was obtained by maceration using demineralized water as the solvent at a ratio of 1:50 for 24 hours. Maceration was carried out at room temperature and 45 °C. The extract obtained at room temperature has the highest total phenolic content, betacyanin content, antioxidant activity (DPPH and ABTS), and antioxidant capacity, with respective values of 18.072 ± 0.004 µg AGE/g, 10,111.929 ± 28.849 µg BE/g, 63.340 ± 0.267%, 31.181 ± 0.092%, and 3.529 ± 0.011 µg TE/g. The encapsulated extract was fortified into yogurt at a ratio of 1:100 g. The results showed that Yogurt Y1 (room temperature) had the highest total phenolic content, betacyanin content, antioxidant activity (DPPH and ABTS), and antioxidant capacity, with values of 0.824 ± 0.005 µg AGE/g, 1.818 ± 0.173 µg BE/g, 21.970 ± 0.148%, 23.981 ± 0.183%, and 0.161 ± 0.001 µg TE/g, respectively. A decrease in pH was observed in all yogurt samples during the six-day storage period. Morphological observations of the encapsulated dragon fruit peel extract were carried out using FESEM to determine the particle size, which ranged from 0.479 to 1.559 mm at room temperature and from 0.658 to 2.014 mm at 45 °C.

**Keywords:** Dragon Fruit Peel, Encapsulation, Antioxidant, Yogurt, FESEM.

# INTRODUCTION

Dragon fruit, also known as *pitaya* or *pitahaya*, belongs to the genus *Hylocereus*. The *Hylocereus* species is a type of cactus originating from Mexico and Central America [1]. Dragon fruit consists of three main components, pulp (47.40–73.76%), peel (36.70–37.60%), and seed (2.70–1.67%) [2]. The total of dragon fruit peel is about one-third of the entire fruit and it become food waste after the fruit consumed. The high amount of dragon fruit peel in environment becomes breeding grounds for bacteria, pests, and rodents, which can contribute to the spread of diseases [3].

Dragon fruit peel is a rich source of bioactive compounds, including phenolic. Phenolic compounds have garnered significant attention due to their potential health benefits, including antioxidant, anticancer, and antidiabetic properties. The phenolic composition is 35–65% from the total compounds in plants. Currently, more than 23 polyphenolic compounds have been identified in the flesh and peel of red dragon fruit, including gallic acid, protocatechuic acid, vanillic acid, caffeic acid, syringic acid, p-coumaric acid, isorhamnetin triglycoside, quercetin-3-O-rutinoside, flavonol glycosides, and others. The phenolic content of *Hylocereus polyrhizus* dragon fruit peel is 11.6 mg GAE/g DW [4]. Another research also reported the phenolic content on the *H. polyrhizus* peel in ethanol and water solvents are 22.335 ± 1.229 and 22.213 ± 0.444 mg GAE/g, respectively [5].

Dragon fruit peel also contains betacyanin. Red dragon fruit (*H. polyrhizus*) has a high betacyanin content. Betacyanin is a natural red pigment with antioxidant properties. Seven betacyanin compounds are found in red dragon fruit, namely betanin, isophyllocactin, betanidin, isobetanidin, bougainvillein-RI, isobetanin, and hylocactin [6]. Based on previous research, betacyanin content of red dragon fruit peel was 35.12 ± 0.01 mg/g sample [7].

Phenolics and betacyanins are polar compounds and it can be disolved in polar solvent such as demineralized water [8,9]. The advantages of using this solvent are its ability to dissolve many substances, affordability, non-toxic, non-flammable, and high polarity [10,11]. Betacyanin is generally recognized as a heat-sensitive pigment that not stable at high temperatures. Moreover, the stability of betacyanin significantly decreases at temperatures between 50 and 60 °C [12].

Encapsulation aims to protect unstable and sensitive materials from environmental factors, thus extending their shelf life [13]. Encapsulation can also mask unpleasant tastes of bioactive compounds and preserve their bioactivity in the digestive tract [14]. One method of encapsulation is ionic gelation, that produce porous gel matrices without requiring high temperatures [16]. This method has been successfully applied to increase the stability and bioactivity of polyphenolic compounds from yerba mate extract [17].

Determining the type of wall material used is also important because it affects encapsulation efficiency and pigment stability [18]. The encapsulation of betacyanin microbeads using sodium alginate was examined in previous research [19]. Sodium alginate was chosen because it contains linear heteropolysaccharides of D-mannuronic and L-guluronic acids, derived from brown algae, which are known to be anionic, non-toxic, biodegradable, naturally occurring, and biologically safe. Maltodextrin (MD), a partial hydrolysis product of starch, is commonly used as a secondary wall material in microencapsulation. The use of maltodextrin offers several advantages, including low cost, a neutral aroma and taste, low viscosity, and good antioxidant protection properties, which allow it to combine well with other wall materials to enhance the encapsulation effect [20]. Encapsulation using sodium alginate and maltodextrin was applied to encapsulate peppermint essential oil [21].

Encapsulated dragon fruit peel extract can be used as a food additive, such as in yogurt. Yogurt is a milk product that undergoes fermentation and is popular across all age groups. The primary active components in yogurt are probiotic bacteria, such as *Lactobacillus bulgaricus* and *Streptococcus thermophilus*, which are responsible for fermenting lactose into lactic acid, contributing to the characteristic texture and sour taste of yogurt [22]. Additionally, yogurt is a rich source of unsaturated fatty acids, protein, calcium, vitamin B12, riboflavin, phosphorus, and potassium. To improve its nutritional, sensory, physicochemical, and rheological properties, yogurt can be enriched with synbiotic or bioactive additives [23], such as the addition of grape seed extract [24].

Based on the explanation above, this research aims to utilize dragon fruit peel, which is rich in phenolics and betacyanins, through the maceration extraction method. The obtained extract will be encapsulated using sodium alginate and maltodextrin. The encapsulated dragon fruit peel extract will be applied as a food additive in yogurt. This addition is expected to develop yogurt as a functional food rich in natural bioactive (phenolics and betacyanins), possessing high antioxidant activity and providing health benefits. Moreover, the addition of encapsulated dragon fruit peel extract is also expected to enhance the market value of yogurt and support the development of functional food products.

# EXPERIMENTAL

## Research Methods

The extract was encapsulated using sodium alginate and maltodextrin, and dried using freeze dryer. The encapsulated extract added to yogurt with ratio of 1:100. Fortified yogurt was tested for total phenolic content, betacyanin, and antioxidants. The granules resulting from freeze drying were subjected to morphological testing using the FESEM (Field-Emission Scanning Electron Microscope).

## Tools and Materials

### Tools

The instruments used are UV-Vis spectrophotometer (Genesys 10S) and Field Emission Scanning Electron Microscope (Hitachi Regulus 8220).

### Materials

The materials used in this research include dragon fruit peel obtained from dragon fruit sellers in Keputih, Surabaya, demineralized water (OneMed), Folin–Ciocalteu reagent (Supelco), sodium carbonate (Na₂CO₃) (Merck), gallic acid (Sigma-Aldrich), methanol (Merck), betanin (Sigma-Aldrich), DPPH (2,2-diphenyl-1-picrylhydrazyl) (Sigma-Aldrich), sodium alginate (Sigma-Aldrich), maltodextrin, calcium chloride (CaCl₂) (Sigma-Aldrich), potassium persulfate (K₂S₂O₈) (Sigma-Aldrich), ABTS (2,2′-Azino-bis(3-ethylbenzthiazoline-6-sulfonic acid)) (Merck Millipore), Trolox acid (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylate), pasteurized fresh milk (Diamond), and *Lactobacillus bulgaricus* yogurt seeds.

## Procedure

### Extraction of Dragon Fruit Peel

Dragon fruit peel is washed using water, cuted into small pieces and dried in an oven at 50°C for 42 hours [25]. The dried dragon fruit peel is then ground using a blender until it forms a powder. The powder is sifted using a sieve until a fine powder is obtained. The resulting fine powder is stored in a plastic clip and placed in the refrigerator until the next procedure. Dragon fruit peel powder was extracted in demineralized water with a ratio of 1:50. Extraction was carried out at room temperature and 45°C and stirred using magnetic stirrer at 700 rpm for 24 hours. After that, the sample was separated by centrifugation for 25 minutes at a speed of 1500 rpm. The filtrate was then filtered using Whatman filter paper No. 1. The extract was stored in a dark glass bottle and placed in the refrigerator for further processing.

### Determination of Total Phenolic Compounds Using the UV-Vis Spectrophotometer Method

Total phenolic compounds from dragon fruit peel were measured using the Folin–Ciocalteu method [26]. Gallic acid was used as a standard with varying concentrations of 20, 40, 60, 80, and 100 ppm, which were measured at a wavelength of 716 nm using a UV-Vis spectrophotometer. A total of 1 mL of sample was placed in a dark vial and mixed with 5 mL of Folin–Ciocalteu reagent which had been diluted using demineralized water (1:50) for 5 minutes. After incubation, the solution was added with 4 mL of 0.04 M Na₂CO₃ and incubated again for 2 hours in the dark. The sample was measured at a wavelength of 716 nm using a spectrophotometer UV-Vis measurements were carried out in triplicate, and the results were expressed in units of μg Gallic Acid Equivalent (AGE)/g dry dragon fruit peel.

### Determination of Total Betacyanin Compounds Using the UV-Vis Spectrophotometer Method

The total content of betacyanin compounds was determined using the UV-Vis spectrophotometer method [27]. In the procedure, a standard curve was used which was made from a plot between betanin concentration and absorbance at a wavelength of 533 nm. Concentrations of betanin were prepared with varying values of 1500, 2000, 2500, 3000, and 3500 (µg/mL). The sample’s absorbance was measured at 533 nm with a dilution factor of 5 at room temperature and a dilution factor of 1 at 45°C. Sample measurements were repeated three times (triplicate). The results of the total betacyanin content are expressed in units of µg Betanin Equivalent (BE)/g dry dragon fruit peel.

### Measurement of Antioxidant Activity Using the DPPH Method

Antioxidant activity was determined based on the DPPH (2,2-diphenyl-1-picrylhydrazyl) method by [28] with modifications. A total of 3 mL of sample was added with 2 mL of methanol. Samples were separated by centrifugation for 10 minutes at a speed of 1800 rpm. The filtrate obtained was placed in a vial and added with 6 mL of 50 ppm DPPH. The mixed solution was incubated for 30 minutes in the dark. Absorbance was measured using a UV-Vis spectrophotometer at a wavelength of 518 nm with three repetitions (triplicate). Antioxidant activity is expressed in % decolorization. % Decolorization value of free radical inhibitory activity is calculated using the radical inhibition equation in Equation 3.1

(3.1)

### Measurement of Antioxidant Activity Using the ABTS Method

Measurement of antioxidant activity using the ABTS method with modifications [29]. The radical solution was made using 2.4 mmol/L potassium persulfate and 3.3 M ABTS in a ratio of 1:10, then incubated for 1 hour in the dark. The radical solution diluted with methanol and measured the absorbance at 745 nm. Trolox was used as the standard, with concentrations of 0, 20, 40, 60, 80, and 100 ppm. A total of 150 µL sample was added to 1.0 mL of radical solution. The mixture was incubated for 5 minutes. The absorbance is measured using a UV-Vis spectrophotometer at 734 nm. The results obtained are expressed in two units, namely µg Trolox Equivalent (TE)/g dry dragon fruit peel to determine the antioxidant content in the sample, and (%) decolorization to determine antioxidant activity, which represents the % free radical inhibitory activity expressed in Equation 3.1.

### Encapsulation of Dragon Fruit Peel Extract

Encapsulation of dragon fruit peel extract was carried out using the ionic gelation method based on literature from [30] with modifications. A total of 1.5 g of sodium alginate was added to a 250 mL beaker containing 100 mL of sample and stirred using a magnetic stirrer at a speed of 900 rpm for 6 hours at room temperature. Next, 0.6 g of maltodextrin was added to the mixture and stirred using a magnetic stirrer at a speed of 900 rpm for 4 hours. The mixed solution was dripped using a 26 G syringe at a distance of 30 cm into 100 mL of 3.5% calcium chloride solution. The granules formed are filtered using a sieve and washed using demineralized water . Next, the granules were dried using a freeze dryer at -50 °C. The powder resulting from freeze drying is stored in the refrigerator before being used for the next process.

### Fortification of Yogurt

A total of 1 L of pasteurized fresh milk was heated to 85°C for 10 minutes [31]. The temperature of the milk is lowered to 40°C and then added with 1 g of yogurt starter. The yogurt is incubated at 43°C for 6–8 hours until the yogurt becomes thick [32]. A total of 100 g of yogurt was fortified with 1 g of encapsulated dragon fruit peel extract and stirred using a magnetic stirrer for 2 minutes. Next, the fortified yogurt is stored for further processing.

### FESEM Testing

Testing the morphology of the encapsulated dragon fruit peel extract granules was observed using a Field-Emission Scanning Electron Microscope (FESEM), starting with the preparation of the samples that had been made. The sample was placed in the holder, then placed on the coating tool and coated for approximately 1 minute. After the sample is coated, the next steps follow standard FESEM procedures, including setting operational parameters, adjusting the focus and stigmata, image capture, image analysis, and morphological interpretation.

### Yogurt Extraction

Fifty grams of yogurt sample was mixed with 12.5 mL of demineralized water , and the pH was adjusted to 4.0 using 1 M HCl [33][34]. The yogurt sample was incubated at 45 °C for 10 minutes. The incubated yogurt samples were then separated by centrifugation at a speed of 2000 rpm for 40 minutes. The obtained supernatant was adjusted to pH 7.0 using 1% NaOH [35]. The supernatant was centrifuged again at a speed of 2000 rpm for 40 minutes. The final supernatant obtained can be used for further analysis.

# RESULTS AND DISCUSSION

## Dragon Fruit Peel Extraction

In this research, dragon fruit was obtained from traders in the Keputih area, Surabaya. The dragon fruit was washed with clean water, and the peel was peeled to separate the fruit from the peel. The dragon fruit peel was cut into 2 cm pieces and dried in an oven at 50 °C for 42 hours. The dried peel was then ground using a blender until it formed a powder. The powder was sieved to obtain a uniform fine powder. The finer the particle size used, the greater the extraction yield achieved because it can increase solvent penetration and solute diffusion [36].

The dragon fruit peel powder was extracted using the maceration method. This method was chosen because it is quite simple and only involves soaking plant raw materials in powder form in a solvent under certain conditions [37]. Extraction was performed in demineralized water (demineralized water) solvent at a ratio of 1:50. Demineralized water was chosen because it is the most polar solvent and is widely used for extracting various polar compounds. The advantages of using this solvent include its ability to dissolve various substances, being economical, non-toxic, non-flammable, and highly polar [38]; [37]. Demineralized water is also recommended for the food industry because the resulting extract does not contain residues, making it safe for consumption [39].

Extraction was carried out at room temperature and at 45 °C. During extraction, stirring was performed using a magnetic stirrer at 700 rpm for 24 hours. The temperature variation was applied to determine the optimal temperature for the maceration process. Room temperature and 45 °C were chosen because increasing temperature can enhance solubility and diffusion. However, excessively high temperatures can cause solvent loss and decomposition of thermolabile compounds such as betacyanin [36]. For example, betacyanin stability was observed to decrease at temperatures between 50 and 60 °C [40]. Stirring was done using a magnetic stirrer because the extraction rate can be increased by thoroughly homogenizing the plant tissue [41].

The extraction process lasted for 24 hours because extraction efficiency increases with a longer extraction time within a certain period. Increasing the maceration time beyond this does not affect the extract yield once solute equilibrium has been reached inside and outside the material [36]. After maceration, the sample was centrifuged for 25 minutes at 1500 rpm. The filtrate was then filtered using Whatman No. 1 filter paper. The filtrate obtained was red at room temperature and yellow at 45 °C. Betacyanin is a red pigment belonging to the betalain group [42].

## Total Phenolic and Betacyanin Content of Dragon Fruit Peel

The results of the maceration of dragon fruit peel extract at varying temperatures were used to test the total phenolic and betacyanin contents. Qualitative analysis was performed using a UV-Vis spectrophotometer. Before testing, a standard calibration curve was prepared. The calibration curve consists of the x-axis representing concentration and the y-axis representing absorbance. Sample measurements were conducted in triplicate to ensure accuracy. The resulting regression equation was used to determine the total phenolic and betacyanin contents of the dragon fruit peel extract based on the absorbance values.

From the measurements, the standard regression equation for gallic acid was obtained as y = 0.0044x - 0.0017 with a correlation coefficient (r) of 0.9993. Meanwhile, the regression equation for betanin was y = 0.0002x + 0.0006 with a correlation coefficient of 0.9997. The calibration curves are provided in Appendices 2 and 3.

To measure the total phenolic content, a gallic acid standard curve was used. Gallic acid was selected as the standard because it is natural, provides stable phenol measurement, and is relatively inexpensive compared to other phenolic compounds. Gallic acid belongs to the group of phenolics derived from hydroxybenzoic acid and is classified as a simple phenolic acid [43].

The total phenolic content of the dragon fruit peel extract was measured using a UV-Vis spectrophotometer at a wavelength of 716 nm. The test involved reacting the extract with Folin-Ciocalteu reagent, which is yellow in color. This reagent oxidizes the phenolics (base salts) or phenolic hydroxyl groups, reducing the heteropoly acid (phosphomolybdate-phosphotungstate) to a molybdenum-tungsten complex. The reaction requires an alkaline environment; therefore, sodium carbonate (Na2CO3) was added to dissociate protons from phenolic compounds into phenolic ions, which reduce the Folin-Ciocalteu reagent to form a blue color [44]. The results were calculated using the regression equation and expressed as µg Gallic Acid Equivalent (GAE) per gram of dry dragon fruit peel.

The total betacyanin content was measured using a betanin standard curve. Betanin was chosen because it is the most common betacyanin compound found in dragon fruit peel [19] The dragon fruit peel extract was diluted prior to measurement, with a dilution factor of 5 for the room temperature extract and a dilution factor of 1 for the extract obtained at 45 °C. This ensured absorbance values within the range of 0.2 to 0.8, complying with the Lambert-Beer law. Absorbance was measured at 533 nm using a UV-Vis spectrophotometer. The total betacyanin content was calculated using the regression equation and expressed as µg Betanin Equivalent (BE) per gram of dry dragon fruit peel. The results of this analysis are presented in Table 2.

**TABLE 2.** Test Results of Total Phenolic Content and Total Betacyanin Content of Dragon Fruit Peel Extract

|  |  |  |
| --- | --- | --- |
| Dragon Fruit Peel Extract With Temperature Variation | Total Phenolic Content (µg GAE/g dried dragon fruit peel) | Total Betacyanin Content (µg BE/g dried dragon fruit peel) |
| Room Temperature | 18.072 ± 0.004 | 10,111.929 ± 28.849 |
| 45 °C | 13.778 ± 0.004 | 1,973.273 ± 7.617 |

In this research, the total phenolic content and total betacyanin content are presented in Table 2. The highest total phenolic and betacyanin contents were obtained from dragon fruit peel extract extracted at room temperature, with total phenolic content of 18.072 ± 0.004 µg GAE/g dry dragon fruit peel and total betacyanin content of 10,111.929 ± 28.849 µg BE/g dried dragon fruit peel. As shown in Table 2, both total phenolic and betacyanin contents decreased with increasing extraction temperature. The stability of betacyanin significantly decreases at temperatures between 50 °C and 60 °C [40].

The previous study showed temperature variations at 10, 20, 30, 40, 50, and 60 °C to extract betacyanin from *Basella alba* over 5 days [45]. Their results showed a decrease in betacyanin copigmentation at temperatures between 40 °C and 60 °C, while stability increased at temperatures between 10 °C and 30 °C. Furthermore, demonstrated that both maceration time and temperature can reduce betacyanin levels. Heating at 80 °C for 20 minutes caused a significant reduction in betacyanin content from 0.75 ± 0.06 to 0.62 ± 0.07 mg GAE/g [46].

Research on total phenolic content showed different results, where the phenolic content of cocoa fruit was higher when extracted at 60 °C for 36 hours compared to 30 °C for 24 hours, with values of 168.16 ± 0.061 and 36.3 ± 0.94 mg GAE/g, respectively [47]. Similar research by [48] investigated methanol extracts of *E. spinosum* at different temperatures: 170.02 ± 15.37 mg GAE/g at 55 °C, 158.30 ± 17.16 mg GAE/g at 65 °C, and 95.71 ± 8.35 mg GAE/g at 75 °C. The total phenolic content increased between 55 °C and 65 °C but decreased between 65 °C and 75 °C.

Phenolics are thermosensitive compounds that can undergo hydrolysis and degradation at high temperatures, leading to decreased phenol levels. Extraction time also affects phenolic content because prolonged extraction increases the opportunity for oxidation reactions of phenolic compounds due to exposure to oxygen, which causes a decrease in total phenolics.

## Antioxidant Activity of Dragon Fruit Peel Extract

The antioxidant activity of dragon fruit peel extract with variations in maceration temperature was determined based on the percentage (%) of decolorization. This value was calculated using the DPPH and ABTS methods. The DPPH method was chosen because it is associated with the presence of phenolic acids and most water-soluble compounds. Meanwhile, the ABTS method is related to flavonoid compounds and fatty acids, which have the ability to scavenge lipophilic compounds [49].

Antioxidant activity was measured using the DPPH (2,2-diphenyl-1-picrylhydrazyl) method by adding 3 mL of methanol to the sample in a 15 mL Eppendorf tube. The sample was then centrifuged for 10 minutes at 1800 rpm. The addition of methanol to the demineralized water extract causes the filtrate to become cloudy; therefore, centrifugation is necessary to precipitate solids. The resulting filtrate was placed in a dark vial and mixed with 50 ppm DPPH solution. The mixture was incubated in the dark for 30 minutes. Absorbance was measured using a UV-Vis spectrophotometer at a wavelength of 518 nm, with three replicates (triplicate).

The DPPH reagent obtains hydrogen atoms from antioxidant compounds [50]. The greater the ability of the fruit peel extract to donate electrons, the more it changes the color of DPPH from purple to yellow, due to the formation of 1,1-diphenyl-2-picrylhydrazine, which indicates higher antioxidant power [51].

Measurement of antioxidant activity using the ABTS method (2,2'-azinobis-(3-ethylbenzothiazoline)-6-sulfonic acid) was carried out by preparing a radical solution from potassium persulfate (K2S2O8) and ABTS, which was incubated for 1 hour in the dark. The radical solution was then diluted with methanol. Afterward, the sample was reacted with the radical solution, and absorbance was measured at a wavelength of 734 nm.

The determination of antioxidant activity is based on the oxidation of potassium persulfate and diammonium salt (ABTS). The disappearance of the blue color in the ABTS reagent indicates the presence of antioxidant activity [52]. ABTS radicals are produced from the reaction between ABTS and potassium persulfate, resulting in an ABTS chromophore with a blue-green color. When the unstable ABTS- + radical receives electrons from antioxidants, the blue-green color fades to pale blue, indicating the regeneration of ABTS to its stable form [53].

**TABLE 3.** Results of Percentage Decolorization of DPPH and ABTS in Dragon Fruit Peel Extract

|  |  |  |
| --- | --- | --- |
| **Dragon Fruit Peel Extract with Temperature Variations** | **% DPPH Decolorization** | **% ABTS Decolorization** |
| Room Temperature | 63.340 ± 0.267 | 31.181 ± 0.092 |
| 45 °C | 56.745 ± 0.196 | 23.822 ± 0.234 |

Table 3. shows the percentage of antioxidant decolorization results using the DPPH and ABTS methods. Based on these data, it can be observed that increasing the extraction temperature reduces the percentage of decolorization in all antioxidant assays. The highest percentage of decolorization was obtained at room temperature using the DPPH and ABTS methods, with values of 63.340 ± 0.267% and 31.181 ± 0.092%, respectively. These results are consistent with the findings for total phenolic and total betacyanin contents.

Research conducted on Hylocereus polyrhizus (dragon fruit) extract showed a strong correlation between total phenolics and DPPH (r = 0.963), as well as total phenolics and ABTS (r = 0.911), indicating that phenolic compounds in the extract significantly contribute to its antioxidant capacity [54]. Similar results were founded a correlation of r = 0.75 between dragon fruit peel betalain content and antioxidant activity [55].

In antioxidant assays, the amount of antioxidant compounds in the sample can also be quantified using a Trolox calibration curve. The antioxidant content determined by this method is presented in Table 4. The antioxidant content of dragon fruit peel extract at room temperature was higher than that at 45 °C, with values of 3.529 ± 0.011 µg/g and 2.666 ± 0.028 µg/g dried dragon fruit peel, respectively.

This method has also been applied to test xanthohumol at a concentration of 60 µmol/L, which resulted in a decolorization percentage of 40%. Calculations using the Trolox standard yielded a value of 0.32 ± 0.09 µmol/L [56].

**TABLE 4.** Results of Antioxidant Compound Mass in Dragon Fruit Peel Extract

|  |  |
| --- | --- |
| **Dragon Fruit Peel Extract with Temperature Variations** | **Mass of Antioxidant Compounds in Final Sample (µg TE/g dry dragon fruit peel)** |
| Room Temperature | 3.529 ± 0.011 |
| 45 °C | 2.666 ± 0.028 |

## Encapsulation of Dragon Fruit Peel Extract

Dragon fruit peel extract, obtained through maceration at room temperature and 45 °C, was encapsulated prior to its use in yogurt fortification. Encapsulation aims to protect sensitive compounds such as betalains and phenolics from environmental factors including pH, temperature, light, oxygen, humidity, radiation, metal content, and enzymes [57]. The encapsulation method used in this study was ionic gelation, a widely used and effective technique for protecting liquid samples within biopolymers at low temperatures. This method is simple, versatile, practical, and economical, helping to prevent color degradation and progressive nutrient loss [58].

The wall materials selected were sodium alginate and maltodextrin, both commonly employed in the encapsulation of food ingredients [59]. Sodium alginate has been used to encapsulate betacyanin compounds, achieving an encapsulation efficiency of 78.62% [19]. Similarly, maltodextrin was used to encapsulate dragon fruit peel via spray drying, resulting in an encapsulation efficiency of 79%. [58] also utilized sodium alginate and maltodextrin to encapsulate peppermint essential oil [60].

When the mixture of active compounds and wall materials is immersed in a CaCl2 solution, Ca²⁺ ions penetrate the sodium alginate matrix and undergo ion exchange with the sodium alginate groups [61]. The Ca²⁺ ions act as crosslinkers with negatively charged polymers such as alginate, forming a strong and insoluble gel [62]. The resulting granules are filtered using a sieve and washed with demineralized water. Images of the encapsulated granules are shown in Figures 1 and 2.

The granules were then freeze-dried at 50 °C for 40 hours. Freeze drying involves three main steps: (i) freezing, which solidifies the water content; (ii) primary drying, where frozen water sublimates due to reduced pressure and applied heat; and (iii) secondary drying, which removes residual water to complete the drying process[63].



**FIGURE 1.** Image of encapsulated dragon fruit peel extract granules.



(a) (b)

**FIGURE 2**. Dry granules of encapsulated dragon fruit peel extract: (a) Room temperature, (b) 45 °C.

## Yogurt Manufacturing and Fortification

In this research, yogurt was fortified with encapsulated dragon fruit peel extract. The yogurt was prepared by heating 1 L of pasteurized fresh milk to 65 °C for 10 minutes. After heating, the milk was cooled to 40 °C, and 1 g of yogurt starter culture was added. This starter culture typically contains *Streptococcus thermophilus* and *Lactobacillus bulgaricus* [64].

The mixture was incubated at 43 °C for 6–8 hours until the yogurt thickened. The optimal incubation temperature for yogurt production ranges from 36.7 to 43.4 °C. The resulting yogurt had a thick texture, a typical yogurt aroma, a white color, and a sour taste.

During fermentation, the bacteria convert lactose into lactic acid, which reacts with milk proteins. This process imparts the characteristic texture and sour flavor to the yogurt. The lactic acid decreases the pH of the milk, leading to protein coagulation, which contributes to the gel-like consistency of yogurt [64].

The produced yogurt was then fortified with encapsulated dragon fruit peel extract. A total of 100 g of yogurt was mixed with 1 g of encapsulated dragon fruit peel extract. The mixture was stirred using a magnetic stirrer for 2 minutes. Yogurt fortified with encapsulated extract at room temperature was labeled as Y1, while yogurt fortified with extract at 45 °C was labeled as Y2. The fortified yogurt samples were subsequently tested for pH under two storage conditions: room temperature and refrigeration, over a period of 6 days.

## Total Phenolic and Betacyanin Content in Yogurt

Yogurt fortified with encapsulated dragon fruit peel extract was analyzed to determine its total phenolic content and total betacyanin content. These analyses were conducted to evaluate the impact of extract fortification on yogurt. Prior to testing, the yogurt samples were extracted. A total of 50 g of yogurt was mixed with 12.5 mL of demineralized water, and the pH was adjusted to 4.0 using 1 M HCl. The mixture was incubated at 45 °C for 10 minutes.

After incubation, the samples were centrifuged at 2000 rpm for 40 minutes. The pH of the resulting supernatant was adjusted to 7.0 using 1% NaOH, followed by a second centrifugation under the same conditions. The final supernatant obtained was used for further analysis.

Total phenolic and total betacyanin contents were measured using the same procedure as for the extract, with a UV-Vis spectrophotometer. Gallic acid was used as the standard for phenolic content, while betanin was used for betacyanin analysis. The Absorbance of the yogurt extract was measured at predetermined wavelengths. The results of the total phenolic and betacyanin contents in yogurt samples with added encapsulated extract are shown in Table 5.

**TABLE 5.** Test results for total phenolic and total betacyanin content in yogurt

|  |  |  |
| --- | --- | --- |
| **Fortified Yogurt Extract Encapsulated with dried dragon fruit peel** | **Total Dragon Fruit Peel Phenolic (µg AGE / g dried dragon fruit peel)** | **Total Dragon Fruit Peel Betacyanin (µg BE / g dried dragon fruit peel** |
| Control | 0.675 ± 0.012 | 0.419 ± 0.000 |
| Y1 | 0.824 ± 0.005 | 1.818 ± 0.173 |
| Y2 | 0.745 ± 0.003 | 1.019 ± 0.000 |

Based on Table 5, the addition of encapsulated dragon fruit peel extract had a clear effect on the yogurt. The highest levels of total phenolic and betacyanin content were observed in yogurt sample Y1, which was fortified with extract encapsulated at room temperature. Yogurt Y2, fortified with extract encapsulated at 45 °C, also showed higher phenolic and betacyanin content compared to the control yogurt. This indicates that fortification with encapsulated dragon fruit peel extract enhances the functional properties of yogurt.

A study in fortified yogurt with red cactus pear peel powder, also demonstrated significant increases in total phenolic compounds, flavonoids, betalains, inhibitory capacity, and reducing power—by 81.2%, 100.1%, 825.0%, 263.0%, and 635.0%, respectively [65]. Similarly, a research reported increasing in total phenolic and antioxidant content by 37.3–68.7% and 15–52%, respectively, in yogurt enriched with grape pomace [66].

However, the total phenolic and betacyanin contents in yogurt fortified with encapsulated extract were lower than those in the extract itself. This decrease may be attributed to physical processing, environmental factors, and mechanical stress during yogurt preparation. The acidic environment of yogurt (low pH) can damage the encapsulating matrix of alginate–maltodextrin, causing partial degradation of the encapsulated compounds.

Despite this, the encapsulation of dragon fruit peel extract can be considered successful, as there was still an increase in total phenolic and betacyanin content compared to the control yogurt. It is also important to note that extract encapsulated at higher temperatures showed slightly lower levels of these compounds, suggesting that thermal processing during encapsulation may negatively impact bioactive compound retention.

## Antioxidant Activity of Fortified Yogurt

The antioxidant activity of yogurt was evaluated to assess the impact of adding encapsulated dragon fruit peel extract. The antioxidant analysis was conducted using two methods: DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2-azinobis-(3-ethylbenzothiazoline)-6-sulfonic acid), both measured with a UV-Vis spectrophotometer. The testing procedures followed were the same as those used for the dragon fruit peel extract.

The antioxidant activity results are presented in Table 6. The data showed that yogurt fortified with encapsulated dragon fruit peel extract (samples Y1 and Y2) exhibited higher antioxidant activity compared to the control yogurt. The highest antioxidant activity was found in yogurt sample Y1, which was fortified with extract encapsulated at room temperature, showing percent decolorization values of 21.970 ± 0.148 for DPPH and 23.981 ± 0.183 for ABTS. In comparison, sample Y2, which was fortified with extract encapsulated at 45 °C, showed slightly lower values: 21.328 ± 0.074 for DPPH and 22.816 ± 0.159 for ABTS.

These results align with the findings for total phenolic and betacyanin content, suggesting a strong correlation between these bioactive compounds and antioxidant activity. Antioxidant content was further quantified using the Trolox calibration curve, as shown in Table 7. The antioxidant capacity of the room-temperature fortified yogurt (Y1) was 0.161 ± 0.001 µg TE/g dry dragon fruit peel, while the 45 °C-fortified yogurt (Y2) yielded 0.153 ± 0.001 µg TE/g. These results indicate that the addition of encapsulated dragon fruit peel extract contributes to the antioxidant potential of yogurt.

However, the antioxidant activity in fortified yogurt was lower than in the pure extract. This reduction is likely due to the small amount of encapsulated extract added to the yogurt. Despite this, the presence of measurable antioxidant activity in the yogurt confirms that encapsulation helps preserve the bioactive compounds, providing stability against external factors such as pH changes.

Supporting findings were reported by [67], who fortified yogurt with encapsulated *Hibiscus sabdariffa L.* extract using pectin as the wall material (ratio 3:100 g). They observed DPPH and ABTS antioxidant activities of 22.360 ± 0.400 µmol TE/g and 30.100 ± 0.370 µmol TE/g, respectively. In the present study, the relatively lower antioxidant values may be attributed to suboptimal ratios of sodium alginate and maltodextrin used as encapsulating agents, potentially reducing their protective efficiency.

Additionally, [68] found that the incorporation of 1% encapsulated *Caesalpinia bonducella* extract significantly enhanced antioxidant activity, with DPPH and ABTS decolorization values of 86.570 ± 0.090% and 89.820 ± 0.360%, respectively. These values were substantially higher than those of the control yogurt, which recorded 65.140 ± 0.290% and 71.040 ± 0.260% for DPPH and ABTS, respectively. Overall, these findings reinforce the potential of encapsulated bioactive compounds such as those from dragon fruit peel to enhance the antioxidant properties of functional yogurt products.

**TABLE 6.** Results of measuring % decolorization of DPPH and ABTS in yogurt

|  |  |  |
| --- | --- | --- |
| **Fortified Yogurt encapsulated with Dragon Fruit Peel Extract with Temperature Variations** | **% Decolorization** | |
| **DPPH** | **ABTS** |
| Control | 17.516 ± 0.223 | 22,340 ± 0.000 |
| Y1 | 21.970 ± 0.148 | 23.981 ± 0.183 |
| Y2 | 21.328 ± 0.074 | 22.816 ± 0.159 |

**TABLE 7.** Mass test results for antioxidant content in yogurt

|  |  |
| --- | --- |
| **Fortified Yogurt encapsulated with Dragon Fruit Peel Extract with Temperature Variations** | **Antioxidant Content in Final Samples (µg TE/ g Dried Dragon Fruit)** |
| Control | 0.150 ± 0.001 |
| Y1 | 0.161 ± 0.001 |
| Y2 | 0.153 ± 0.001 |

## Field Emission Scanning Electron Microscopy (FESEM)

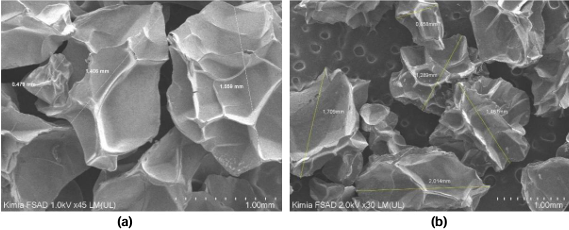
FESEM (Field Emission Scanning Electron Microscopy) analysis was conducted to observe the surface morphology and particle shape of the encapsulated dragon fruit peel extracts. Encapsulated particles can be categorized based on their size as follows: macrocapsules (>5000 µm), microcapsules (0.2–5000 µm), and nanocapsules (<0.2 µm) [69].

Based on the results, the encapsulated dragon fruit peel extract falls within the microcapsule category, with an average particle size of 1.422 µm (or 1422 nm). As shown in Figure 3 (a), sample Y1 exhibited particle sizes ranging from 0.479–1.559 µm, while Figure 3 (b) shows that sample Y2 had a particle size distribution between 0.658–2.014 µm. The particles of both samples appeared well-separated, indicating minimal agglomeration. This separation suggests that the residual moisture in the particles was effectively reduced [70].

However, the freeze-drying method used for encapsulation may have led to partial degradation of the wall structure, resulting in irregular and less spherical particle shapes. The presence of cracks in the dried granules potentially enhances oxygen permeability, which may accelerate the degradation of the encapsulated bioactive compounds.

Similar observations in encapsulated *Euterpe edulis* Martius (jussara) extract using ionic gelation and freeze-drying [71]. The resulting granules exhibited a porous surface when alginate was used alone. However, when the hydrogel granules were coated with chitosan or gelatin, the porosity was notably reduced. Corresponding findings were also observed who encapsulated chokeberry (*Aronia melanocarpa* L.) extract using alginate and alginate/inulin combinations. Particles using alginate/inulin as wall materials showed smoother, rounder, and slightly porous morphologies compared to those using alginate alone.

In this study, there was no significant difference in particle morphology between the two samples as observed via FESEM. This is likely because both samples were encapsulated using the same wall materials (alginate-maltodextrin) and the same encapsulation method. The only variation between the two was the type of extract used, which did not notably affect the morphological outcome under the given conditions.



**FIGURE 3.** FESEM results of encapsulated dry granules of dragon fruit peel extract; (a) Room temperature, (b) Temperature 45°C

# CONCLUSION

Based on the research that has been carried out, dragon fruit peel extraction was conducted using the maceration method with demineralized water at a solvent ratio of 1:50. The most effective results of dragon fruit peel extract were obtained at room temperature. To protect the extract, encapsulation was carried out using sodium alginate and maltodextrin through the ionic gelation method. The encapsulation results were considered effective based on the content in the fortified yogurt compared to the control yogurt. Morphological testing using FESEM showed particle size variations at room temperature and 45°C of 0.479–1.559 mm and 0.658–2.014 mm, respectively.

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