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Enhancing Functional Foods with Plant Extracts: A Study on Gummy Candies Containing Sungkai Leaf Extract

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Abstract. Gummy candy is a popular food product, but it is generally high in calories and low in functional content. Sungkai leaves (Peronema canescens Jack) are known to contain antioxidant compounds that have the potential to be developed as functional food ingredients. To overcome the high calorie content of gummy candy, this study developed a low-calorie gummy candy formulation with the addition of encapsulated sungkai leaf extract and a low-calorie sweetener. This study aims to determine the optimal concentration of encapsulated sungkai leaf extract that produces gummy candy with optimal physicochemical, texture, antioxidant activity, and organoleptic characteristics. The study used an experimental method with Randomized Group Design (RAK), consisting of seven treatments of sweetener combination (xylitol and sucralose) and microcapsule concentration (3-7%). The results showed that the best formulation was a combination of 75% xylitol and 3% sungkai leaf extract microcapsules. This formulation produced good antioxidant activity (total phenolics 1,843 mg GAE/g; IC_{50} of 597.878 mg/L), favorable texture (hardness 26.12 N; chewiness 42.99 Nmm), and good consumer acceptability (overall acceptability 3.71 out of 5). In addition, the caloric value was only 2.76 kcal/g, lower than conventional candy. The implications of the results of this study indicate a great opportunity for diversification of healthy food products based on local plants, as well as encouraging the development of functional food innovations that support a healthy lifestyle and prevention of degenerative diseases through the daily diet.

Keywords: Antioxidant, bioactive compound, functional food, gummy candy, low calorie, microencapsulation, sungkai leaf.

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1. Introduction

The utilization of natural materials containing bioactive compounds is now increasingly widespread. Traditional plants with potential health benefits have been widely researched and utilized in Indonesia as a source of functional food ingredients (Nurdyansyah & Widyastuti, 2020). One of these plants is sungkai leaves (Peronema canescens Jack), which grow in tropical climates and hilly areas, especially in provinces such as Central Kalimantan, South Kalimantan, West Kalimantan, West Sumatra, South Sumatra, Bengkulu, and Jambi (Dista et al., 2022). Natural compounds derived from plants have various health benefits and have been widely studied, especially regarding the activity of bioactive compounds as antibacterial agents (Nurafifah et al., 2021).

Sungkai leaves are known to have good medicinal properties because they contain a variety of bioactive compounds, including phenolics, flavonoids, tannins, alkaloids, steroids, and saponins (Rahmi et al., 2023). These compounds serve as natural antioxidants and exhibit antipyretic, antidiabetic, antibacterial, immunostimulatory, and cytotoxic properties (Yani & Putranto, 2014). The sungkai leaves extract possesses a very strong antioxidant activity (IC50) ranging from 50.78 µg/mL to 53.50 µg/mL (Nurfauziyah et al., 2024). The chemical composition of sungkai leaf extract presents significant potential as a source of nutritional and functional components that may be incorporated into food products. The Dayak tribe has employed the sungkai (Albertisia papuana Becc.) leaf powder as a natural flavoring enhancer due to its umami taste profile (Purwayantie et al., 2019). This practice provides great opportunities for the advancement of sungkai leaves as functional food ingredients.

Gummy candy, a popular confectionery, is favored by many consumers due to its unique shape, chewy texture, and sweet taste. However, the sugar content in gummy candy is very high, leading to a high-calorie content (351 kcal/100g) (Teixeira-Lemos et al., 2021). Continuous consumption of high-sugar foods is associated with an increase in various health risks, particularly diabetes mellitus. This trend has driven demand for alternative sweeteners within the food production industry, such as xylitol and sucralose. Xylitol, classified as a sugar alcohol, possesses the same sweetness level as sucrose, but its calorie content is 40% lower than sucrose (Rehman et al., 2016). Mäkinen (2014) explained that xylitol does not raise blood sugar levels and is safe for diabetics. Another alternative sweetener is sucralose, which is characterized as a non-calorie artificial sweetener with a sweetness level 600 times greater than sucrose, thereby allowing for a reduced quantity of sugar usage. Sucralose is known for its lack of a bitter aftertaste and does not influence the sensory attributes of food products (Rana et al., 2021).

Low-calorie gummy candy is expected to be developed with sungkai leaf extract as a source of functional substances. According to the previous research, gummy candy formulated with sungkai leaf extract and forest honey exhibits strong antioxidant activity (IC50) of 51.1 mg/L, but results in an astringent aftertaste that leads to bitterness, thus affecting its organoleptic attributes (Faisal et al., 2023). Therefore, it is imperative to implement encapsulation techniques for the sungkai leaf extract. Encapsulation through the spray drying method with various coating materials can protect active compounds from environmental influences and conceal undesirable bitter flavors (Pop et al., 2022). The encapsulated sungkai leaf extract could optimize the functional properties and sensory profile of gummy candy.

However, until now, there are still research gaps, especially in the utilization of encapsulated sungkai leaf extract in low-calorie functional food products such as gummy candies. Most studies still focus on the utilization of herbal extracts in direct form or in functional beverages, while applications in gelatin-based solid systems with a combination of low-calorie sweeteners, such as xylitol, are still limited. In addition, public awareness of the potential health benefits of sungkai leaves is still low, so an innovative approach is needed to increase its acceptance and utilization in everyday food products.

This research contributes to the development of food science and technology by presenting innovations in the formulation of low-calorie gummy candies that combine microencapsulation techniques of local herbal extracts with considerations of sensory and functional value. The main focus is to determine the optimal concentration of encapsulated sungkai leaf extract to produce products with the best physical, chemical, and organoleptic qualities. This research is expected to make a real contribution to the diversification of functional food products by utilizing local potential, namely, sungkai leaves. The results prove that encapsulated sungkai leaf extract can be formulated into low-calorie gummy candies without significantly compromising sensory characteristics. This opens up opportunities for the commercialization of products based on Indonesian natural ingredients that have added health value. For the industry, the results of this study provide practical insights into the formulation and production strategies of functional products that can be adapted in small to medium-scale industries (SMEs) as well as large industries.

2. Methods

2.1. Materials

The main ingredients used in the encapsulation process of sungkai leaf extract are distilled water, crude sungkai leaf extract, maltodextrin DE-10 (Brand: Lihua Starch), and Whey Protein Isolate (WPI) 90 (Brand: Puro). The ingredients used in making gummy candy are water, sucrose, sucralose, xylitol, gelatin bloom 150, glucose syrup brix 82, and vanilla flavor.

2.2. Microencapsulation of Sungkai Leaf Extract

The microencapsulation of sungkai leaf extract was conducted with a spray drying method, as modified from the research of [1]. The coating material utilized was a combination of WPI and maltodextrin, formulated in a ratio of 3:1 (w/w). The coating material was subsequently prepared into a solution containing a concentration of 20% soluble solids (w/v). Weights of WPI and maltodextrin were measured and dissolved separately in 750 ml of distilled water for WPI and 250 ml for maltodextrin. Each solution was homogenized using a magnetic stirrer for about 15 minutes. Following this process, the two homogenized coating solutions were combined, and crude sungkai leaf extract at 5% of the total coating material was added to the coating solution. Then, the mixture was stirred again using a magnetic stirrer for 60 minutes, until an emulsion was formed. The microcapsule emulsion was subsequently dried using a spray dryer, with an inlet temperature of 125°C and an outlet temperature of 60°C. However, although this method is considered effective for producing microcapsules with good antioxidant stability, there are some potential limitations, including the sensitivity of proteins to high heat, which may affect encapsulation efficiency as well as possible aggregation of coating materials during drying. Therefore, controlling the temperature and air flow rate is a crucial aspect in maintaining the quality of the microcapsules produced.

2.3. Preparation of Low-Calorie Gummy Candy Formulated with Encapsulated Sungkai Leaf Extract

The gummy candy formulation and production were based on the modification of Hartel et al. (2018) and Kanpairo (2018) study. The formulation of low-calorie gummy candy formulated with encapsulated sungkai leaf extract in various treatments is illustrated in Table 1. The process of making gummy candy was divided into 2 parts. Part 1: 9 g of gelatin was dissolved into 45 ml of hot water (70°C) and left until warm. Part 2: The quantity of sugar according to the treatment was dissolved in water and subsequently heated with citric acid that had been dissolved in 2.5 g of water. The ingredients were heated at 115°C for 3 minutes, stirring continuously to prevent scorching. Subsequently, the consistency of the gummy candy was evaluated by introducing 1-2 drops of the mixture into cold water. If the gummy candy mixture has formed a thread-like consistency, the next process can be continued. The following step is to add glucose syrup to the pot, then stir and heat to a temperature of 115°C for 40 seconds. After that, the gelatin solution is added and stirred to boil for 3 seconds, then the temperature is lowered to 70°C. A flavoring agent and encapsulated sungkai leaf extract that has been dissolved in a 1:1 water ratio are added to the mixture once the temperature has sufficiently decreased. In the next step, the gummy candy mixture was poured into silicone molds and allowed to cool at room temperature (28°C) for 1 hour to obtain a solid consistency. After that, the gummy candy is refrigerated at 3°C for 24 hours until it solidifies and can be removed from the molds.

Table 1. Formulation of gummy candy in various treatments

Ingredients	Formulations (g)						
	C_0	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**
Gelatin bloom 150	9	9	9	9	9	9	9
Glucose syrup brix 82	34.5	34.5	34.5	34.5	34.5	34.5	34.5
Water	23.5	23.5	23.5	23.5	23.5	23.5	23.5
Dissolved citric acid	3	3	3	3	3	3	3
Sucrose	30	7.5	7.5	7.5	7.5	7.5	7.5
Xylitol	0	22.5	22.5	22.5	0	0	0
Sucralose	0	0	0	0	0.0375	0.0375	0.0375
Encapsulated sungkai leaf extract	0	3	5	7	3	5	7

2.4. Physicochemical Properties of Low-Calorie Gummy Candy Formulated with Encapsulated Sungkai Leaf Extract

The total phenolic content was measured based on the Folin-Ciocalteu assay by following the procedure of the Tarigan et al. (2023) Study. Antioxidant activity (IC_{50}) was estimated using the method described by Zzaman et al. (2014), based on the activity of the DPPH radical. The moisture content, ash content, and pH level of the samples were measured according to AOAC (2005) Method. The texture characteristics of the samples were determined using the Texture Profile Analysis method, following the procedure of Charoen et al. (2015). The colour parameters (L*, a*, and b*) were recorded using a colourimeter (Model CM-5 Spectrophotometer; Konica Minolta Sensing Inc., Osaka, Japan) following the procedure from Roudbari et al. (2024).

2.5. Sensory Evaluation

The sensory evaluation was conducted by 35 semi-trained panelists of Padjadjaran University of Food Technology students. The samples were evaluated based on the likeness score of their odor, colour, texture, taste, aftertaste, and overall acceptance, utilizing a hedonic 5-point scale, where a score of 5 means the highest level of likeness and a score of 1 means the lowest. [9]. Panelists have given verbal consent to take this test, and the study adhered to the ethical principles of the Declaration of Helsinki.

2.6. Total Calories of Low-Calorie Gummy Candy Formulated with Encapsulated Sungkai Leaf Extract

The total calories of the best-formulated low-calorie gummy candy with encapsulated sungkai leaf extract were compared with the control sample (without sugar substitution and extract addition). Total calorie values were calculated by multiplying the grams of carbohydrate, protein, and fat by the factors of 4, 4, and 9, respectively. The resultant values were then summed to get the total calorie content expressed as kcal per gram of gummy candy [10].

2.7. Data Analysis

This study used an experimental method with a Randomized Group Design (RAK) approach consisting of seven treatments and two replications. The data obtained were analyzed using analysis of variance (ANOVA) to test the significance between treatments. If there were significant differences ($P<0.05$), the analysis was continued with Duncan's Multiple Range Test (DMRT) to compare each treatment. All statistical analyses were performed using SPSS software version 27.0 for Windows. The best formulation of low-calorie gummy candy containing encapsulated sungkai leaf extract was determined using the DeGarmo effectiveness index method [11], which integrates various important parameters (physicochemical, texture, organoleptic, and antioxidant activity) into one total effectiveness value.

In addition, the determination of antioxidant activity was carried out using the DPPH (2,2-diphenyl-1-picrylhydrazyl) method to measure the reduction ability of free radicals, with the results expressed as IC_{50} values (concentration required to reduce 50% of free radicals). Total phenolic content was measured by the Folin-Ciocalteu method, and the results were expressed as mg GAE/g (Gallic Acid Equivalent per gram sample). Texture measurements of gummy candies included hardness, stickiness, chewiness, and elasticity using a Texture Analyzer (Brand: TA.XT Plus) with standard probe and speed settings for gummy products. Meanwhile, color parameters (L*, a*, b*, hue°, chroma, and ΔE values) were measured using a digital colorimeter (model CR-400, Konica Minolta) to provide a visual and objective picture of the final product color characteristics. Through the addition of these analytical methods, the reliability and validity of the research results can be further guaranteed, as well as providing in-depth technical information for functional food product development.

3. Results and Discussion

3.1. A Total Phenolic and Antioxidant Activity of Gummy Candy

Table 2 shows the total phenolic content and antioxidant activity of the low-calorie gummy candy formulated with encapsulated sungkai leaf extract. The results indicated that various treatments of encapsulated sungkai leaf extract (3%, 5%, and 7%) and the substitution of low-calorie sweeteners (75% xylitol and 75% sucralose) exhibited significant differences ($p < 0.05$) towards the content of total phenolic and antioxidant activity.

The highest total phenolic content was observed in all sugar substitution treatments incorporating 7% encapsulated sungkai leaf extract (C_3 and C_6). These results suggest that an increased concentration of encapsulated sungkai leaf extract correlates with an increased total phenolic content in low-calorie gummy candy. According to Dordoni et al. (2019)The total phenolic content of wheat cocoa biscuits similarly increases with the incorporation of higher concentrations of encapsulated grape skin extract. The results indicated that the total phenolic content of wheat cocoa biscuits added with encapsulated grape skin extract at concentrations of 1.2%, 2.3%, and 3.5% increased from 385.49 mg GAE/100g to 551.96 mg GAE/100g and 715.29 mg GAE/100g.

Antioxidant activity is indicated by the value of IC_{50}. The lower IC_{50} value means stronger antioxidant activity. The lowest IC_{50} value was found by incorporating 7% encapsulated sungkai leaf extract. This indicated that the IC_{50} value decreases with increasing concentration of encapsulated sungkai leaf extract. The research by Hani et al. (2015) Also demostrated that gummy candy incorporation with red pitaya fruit puree exhibited enhanced antioxidant activity with increasing red pitaya fruit puree content. A strong antioxidant activity in food products is indicated by the higher total phenolic content, proving a direct proportionality between antioxidant activity and the content of phenolic compounds.

Table 2. Phenolic content and antioxidant activity of gummy candy

Sample	Total Phenolic (mg GAE/g sample)	IC_{50} (mg/L)
C_0	1.33 ± 0.03^a	1061.38 ± 4.74^g
C_1	1.84 ± 0.01^c	597.88 ± 2.05^e
C_2	2.27 ± 0.02^d	315.91 ± 0.10^c
C_3	2.76 ± 0.03^f	250.70 ± 0.35^a
C_4	1.66 ± 0.04^b	648.17 ± 1.42^f
C_5	2.20 ± 0.02^d	351.35 ± 0.30^d
C_6	2.52 ± 0.04^e	263.80 ± 0.24^b

Note: Values are means ± SD. Different lower-case letters in the same column indicate significant differences ($p < 0.05$).

3.2. Moisture Content of Gummy Candy

The moisture content of low-calorie gummy candy formulated with encapsulated sungkai leaf extract demonstrated that various treatments provide significant differences ($p < 0.05$) in the moisture content of the samples. The results reveal that an increased addition of encapsulated sungkai leaf extract results in increased moisture content of low-calorie gummy candy, as seen in Table 3. This was caused by the use of water to dissolve the encapsulated sungkai leaf extract. The water content in the extract cannot evaporate alongside the water in the mixture because the addition of encapsulated sungkai leaf extract occurs post-cooling. Similar results were obtained in the research of Rahmawati & Adi (2016), who reported that the initial dissolution of moringa leaf powder in water at a ratio of 1:5 leads to an increase in the moisture content of moringa leaf jelly candy.

Table 3. Moisture content of gummy candy

Sample	Moisture Content (%)
C_0	18.43 ± 0.57^a
C_1	20.17 ± 0.72^b
C_2	24.47 ± 0.20^d
C_3	24.57 ± 0.51^d
C_4	23.38 ± 0.02^c
C_5	23.66 ± 0.81^c
C_6	25.00 ± 0.21^d

Note: Values are means ± SD. Different lower-case letters in the same column indicate significant differences ($p < 0.05$).

3.3. Ash Content of Gummy Candy

Table 4 shows the ash content of the low-calorie gummy candy formulated with encapsulated sungkai leaf extract. The results indicated that various treatments provide significant differences ($p < 0.05$) in the ash content of the samples. The samples exhibited an increase in ash content accompanied by an increase in the concentration of encapsulated sungkai leaf extract. A high ash content indicates that low-calorie gummy candy contains more minerals, derived from the encapsulated sungkai leaf extract. Rizal et al. (2022) Reported that the ash content of the sungkai leaf extract at 5.36%, with minerals such as magnesium (124 ± 3.0424) µg/g[16] and zinc (0.108 ± 0.003) µg/g [17] Identified in the leaves.

Table 4. Ash content of gummy candy

Sample	Ash Content (%)
C_0	0.055 ± 0.004^a
C_1	0.111 ± 0.005^b
C_2	0.173 ± 0.014^c
C_3	0.256 ± 0.016^{ef}
C_4	0.213 ± 0.021^d
C_5	0.240 ± 0.018^{de}
C_6	0.055 ± 0.004^a

Note: Values are means ± SD. Different lower-case letters in the same column indicate significant differences ($p < 0.05$).

3.4. pH Level of Gummy Candy

The results of the pH level in low-calorie gummy candy formulated with encapsulated sungkai leaf extract are presented in Table 5. The results demonstrate a significant difference ($p < 0.05$) in the pH levels of the samples. The results indicated that all samples belonged to the acidic category with a pH value of less than 7. The pH of the low-calorie gummy candy increases with higher concentrations of the encapsulated sungkai leaf extract. This phenomenon is attributed to alkaline compounds in the sungkai leaf extract, especially alkaloids. According to the study of Budiati et al. (2024)The pH level of the sungkai leaf extract is reported to be 5.25.

Table 5. pH level of gummy candy

Sample	pH
C_0	4.09 ± 0.06^a
C_1	4.25 ± 0.13^b
C_2	4.39 ± 0.12^{bc}
C_3	4.61 ± 0.03^d
C_4	4.45 ± 0.01^c
C_5	4.60 ± 0.05^d
C_6	4.72 ± 0.03^d

Note: Values are means ± SD. Different lower-case letters in the same column indicate significant differences ($p < 0.05$).

3.5. *Texture Profile of Gummy Candy*

Table 6 presents the texture profile of the low-calorie gummy candy formulated with encapsulated sungkai leaf extract. The results indicated that various treatments had no significant differences ($p > 0.05$) towards all texture profiles of the samples. This suggests that the texture attributes of the gummy candy are not affected by the substitution of low-calorie sweeteners and the incorporation of encapsulated sungkai leaf extract.

Table 6. Texture profile of gummy candy

Sample	Hardness (N)	Adhesiveness (g.sec)	Gumminess (N)	Chewiness (Nmm)
C_0	26.852 ± 0.96^a	-0.475 ± 0.24^c	25.443 ± 2.18^b	50.661 ± 4.42^b
C_1	26.117 ± 0.67^a	-1.146 ± 0.93^{bc}	23.629 ± 0.56^{ab}	42.993 ± 3.65^{ab}
C_2	25.859 ± 0.65^a	-5.011 ± 2.70^{ab}	22.939 ± 0.85^{ab}	39.986 ± 2.01^{ab}
C_3	25.613 ± 1.87^a	-5.588 ± 0.16^a	22.780 ± 1.50^{ab}	35.627 ± 5.66^{ab}
C_4	27.140 ± 0.46^a	-2.119 ± 1.57^{abc}	24.194 ± 0.11^{ab}	43.859 ± 3.72^{ab}
C_5	24.726 ± 0.22^a	-2.143 ± 1.97^{abc}	22.945 ± 0.18^{ab}	38.759 ± 10.03^{ab}
C_6	24.907 ± 1.22^a	-4.368 ± 1.85^{abc}	21.346 ± 0.89^a	34.675 ± 6.38^a

Note: Values are means ± SD. Different lower-case letters in the same column indicate significant differences ($p < 0.05$).

The data analysis presented in Table 6 indicates that the hardness value of the gummy candy decreased following the incorporation of encapsulated sungkai leaf extract. This phenomenon can be attributed to the fact that the addition of encapsulated sungkai leaf extract enhances the moisture level of the sample, consequently leading to a reduction in the hardness of the low-calorie gummy candy. The substantial moisture content within the gummy candy will diffuse into the gel matrix, softening the gel structure and reducing its hardness.

Negative adhesiveness values reflect lower stickiness. [19]. Ideally, gummy candy should have a low adhesiveness value, suggesting minimal stickiness. A high adhesiveness value in gummy candies is unfavorable, as it implies that they stick more easily to the teeth, palate, and tongue. [20]. The data analyzed in Table 6 revealed that the adhesiveness values for all low-calorie gummy candy treatments were low (negative). These results align with the established criteria for gummy candy products.

The gumminess value depends on the gel strength achieved and is generally directly proportional to the hardness. The higher the hardness value, the higher the gumminess of the product will be [21]. The gumminess exhibits a decrease following the addition of encapsulated sungkai leaf extract. Similar results were obtained in the research of Kia et al. (2020), who reported that the incorporation of red beet extract resulted in a reduction of the gumminess value in gummy candy. This decline is attributed to the structural heterogeneity of the gummy candy, thus reducing the number of cross-linkages responsible for the hardness and chewiness of the gummy product.

Moreover, the chewiness value also experienced a reduction after the inclusion of encapsulated sungkai leaf extract. This occurs due to the increased moisture content within the gummy candy, thus reducing the chewiness value. According to Charoen et al. (2015), incorporating guava leaf extract into gummy candy may also cause acid hydrolysis of gelatin, which can compromise gel strength and reduce the chewiness value.

3.6. Color Properties of Gummy Candy

The color properties of low-calorie gummy candy formulated with encapsulated sungkai leaf extract demonstrated that various treatments provide significant differences ($p < 0.05$) towards all color properties of the samples. This suggests that the color properties of the gummy candy are influenced by the replacement of low-calorie sweeteners and the addition of encapsulated sungkai leaf extract.

Table 7. Color properties of gummy candy

Sample	L*	a*	b*	°Hue	Chroma	ΔE
C_0	51.83 ± 0.67^{c}	5.68 ± 0.09^{d}	25.86 ± 0.26^{e}	77.61 ± 0.32^{b}	26.48 ± 0.24^{e}	-
C_1	51.58 ± 0.10^{c}	4.69 ± 0.05^{b}	22.89 ± 0.03^{c}	78.42 ± 0.11^{c}	23.36 ± 0.03^{c}	3.18 ± 0.13^{a}
C_2	50.02 ± 0.13^{b}	3.84 ± 0.01^{a}	22.25 ± 0.16^{b}	80.22 ± 0.03^{e}	22.57 ± 0.16^{b}	4.47 ± 0.09^{b}
C_3	49.10 ± 0.07^{a}	3.95 ± 0.01^{a}	21.32 ± 0.00^{a}	79.52 ± 0.02^{d}	21.68 ± 0.00^{a}	5.60 ± 0.11^{c}
C_4	49.64 ± 0.01^{ab}	5.54 ± 0.23^{d}	23.75 ± 0.28^{d}	76.87 ± 0.38^{a}	24.39 ± 0.32^{d}	3.11 ± 0.09^{a}
C_5	49.12 ± 0.11^{a}	5.18 ± 0.01^{c}	22.30 ± 0.05^{b}	76.92 ± 0.06^{a}	22.90 ± 0.04^{b}	4.54 ± 0.24^{b}
C_6	49.10 ± 0.59^{a}	4.59 ± 0.06^{b}	22.26 ± 0.21^{b}	78.34 ± 0.25^{c}	22.73 ± 0.19^{b}	4.66 ± 0.28^{b}

Note: Values are means ± SD. Different lower-case letters in the same column indicate significant differences ($p < 0.05$).

The data presented in Table 7 shows that an increase in the concentration of encapsulated sungkai leaf extract corresponds to a reduction in the L* (brightness) value, indicating a decrease in the brightness of the gummy candy. This phenomenon is attributed to the antioxidant properties of sungkai leaf extract, which can influence the pigmentation of the gummy candy. Pambayun et al. (2018) explained that the darkening of the colour is a consequence of the oxidation of the antioxidant during the thermal processing, consistent with the findings that a higher concentration of betel leaf extract results in a more intense jelly candy colour.

The a* (redness) value remains positive across all treatment conditions, indicating reddish colour dominance. However, the a* value tends to decrease with an increase in the concentration of encapsulated sungkai leaf extract, suggesting a transition in the colouration of the gummy candy towards a greener spectrum. This occurs due to the green pigment from its high chlorophyll content. Research conducted by Paternina et al. (2022) Similarly indicated that incorporating spirulina into gummy candy produced a lower a* value compared to the control sample.

The b* (yellowness) value remains positive for all treatments, indicating the dominance of yellowish colour within the sample. The b* value also decreases as the concentration of encapsulated sungkai leaf extract increases. This reflected a reduction in the intensity of the yellow colour in low-calorie gummy candy. This trend aligns with declines in both the a* and L* values. Encapsulated sungkai leaf extract can reduce the intensity of the yellow colour at higher concentrations.

The °hue value of the samples resides within the angular range of 54° to 90°, which represents a reddish-yellow colour. [25]. However, the intensity of this colour is less intense, as shown in the low chroma value. The increased concentration of encapsulated sungkai leaf extract suggests a tendency for a decrease in the chroma value. It is suspected that the homogenization of encapsulated sungkai leaf extract was not optimal during the making of low-calorie gummy candy, thereby the colour was not evenly distributed.

Based on the data in Table 7, the addition of 7% encapsulated sungkai leaf extract results in the highest ΔE value, whereas the addition of 3% encapsulated sungkai leaf extract results in the lowest ΔE value. This indicates that an increase in the concentration of encapsulated sungkai leaf extract correlates with a more pronounced colour differentiation when compared to untreated gummy candy.

3.7. Sensory Evaluation of Gummy Candy

The sensory evaluation results of low-calorie gummy candy formulated with encapsulated sungkai leaf extract are shown in Table 8. There were significant differences ($p < 0.05$) in all sensory evaluation parameters of the samples, except odor parameters. This indicates that the sensory evaluation of gummy candy is influenced by the substitution of low-calorie sweeteners and the addition of encapsulated sungkai leaf extract.

As the concentration of encapsulated sungkai leaf extract increased, the attributes of colour, texture, taste, aftertaste, and overall acceptance tended to decrease. However, the evaluation scores remained within the neutral to favorable category. The gummy candy incorporation with 7% encapsulated sungkai leaf extract received a comparatively low evaluation score. This phenomenon can be attributed to the green colour of the sungkai leaf extract, which results in a darker and less vibrant colour in the gummy candy with increased extract addition. According to Bouphun et al. (2023)A reddish-yellow colour in food products enhances consumer appeal. The incorporation of encapsulated sungkai leaf extract did not affect the aroma of the low-calorie gummy candy, which is likely due to the relatively low concentration of addition. Furthermore, the encapsulation process may also prevent the influence of phenolic compounds on the product's aroma.

Table 8. Sensory evaluation of gummy candy

Sample	Odor	Colour	Texture	Taste	Aftertaste	Overall Acceptance
C_0	3.31 ± 0.93^{a}	4.86 ± 0.55^{d}	4.20 ± 0.80^{c}	4.29 ± 0.79^{d}	4.06 ± 0.84^{d}	4.31 ± 0.63^{d}
C_1	3.17 ± 0.82^{a}	3.43 ± 0.78^{bc}	4.11 ± 0.58^{bc}	3.83 ± 0.98^{c}	3.57 ± 1.04^{bc}	3.71 ± 0.67^{c}
C_2	3.11 ± 0.87^{a}	3.43 ± 0.61^{bc}	3.86 ± 0.69^{ab}	3.57 ± 0.74^{bc}	3.37 ± 1.11^{abc}	3.46 ± 0.78^{abc}
C_3	3.20 ± 0.68^{a}	3.14 ± 0.77^{b}	3.71 ± 0.83^{a}	3.37 ± 1.03^{ab}	3.20 ± 1.02^{ab}	3.37 ± 0.84^{ab}
C_4	3.23 ± 0.77^{a}	3.63 ± 0.77^{c}	3.60 ± 0.88^{a}	3.80 ± 0.90^{c}	3.71 ± 1.02^{cd}	3.69 ± 0.68^{bc}
C_5	3.34 ± 0.64^{a}	3.11 ± 0.87^{b}	3.57 ± 0.70^{a}	3.26 ± 0.78^{ab}	3.40 ± 0.91^{abc}	3.40 ± 0.69^{abc}
C_6	3.26 ± 0.85^{a}	2.74 ± 0.89^{a}	3.69 ± 0.76^{a}	3.17 ± 1.10^{a}	3.14 ± 1.09^{a}	3.23 ± 0.84^{a}

Note: Values are means ± SD. Different lower-case letters in the same column indicate significant differences ($p < 0.05$).

3.8. Total Calories of Gummy Candy

The calculation of total calorie content was conducted based on the best treatment gummy candy, as determined by the DeGarmo effectiveness index assessment. The formulation recognized as the best treatment was the gummy candy utilizing xylitol as a substitute sweetener, combined with an addition of 3% encapsulated sungkai leaf extract.

The calorie value was calculated by totaling the nutritional content of each ingredient, which consists of protein, carbohydrate, and fat. The estimated nutritional content of the ingredients is based on the Indonesian Food Ingredients Composition List (DKBM) table established by Indonesia's Ministry of Health. [27]. The calorie value assessments were performed on both the best gummy candy formulation and the control gummy candy for comparative analysis. The results of the calorie value calculations are presented in Table 9.

Table 9. Total calories of gummy candy

Sample	Total Calorie (kcal/g)
C_0	3.23
C_1	2.76

Based on the empirical nutrient analysis using the DKBM table, the calorie values of samples C_0 and C_1 were determined to be 3.23 kcal/g and 2.76 kcal/g, respectively. These results indicate that the use of xylitol for 75% of the total sucrose in the gummy candy formulation resulted in a reduction of calorie value by 0.46 kcal/g. The selection of xylitol as a sucrose substitute facilitates the maintenance of the same sugar quantity while achieving a reduced calorie value. The same amount of sugar contributes to the production of gummy candy characteristics that are similar to those of gummy candy produced from full sucrose. The research of Naknaen & Itthisoponkul (2015) Indicated that the use of xylitol as a substitute sweetener in the making of melon jam resulted in a total sugar reduction of 19.26 g/100 g at a substitution concentration of 75%. A decrease in sugar content in food products correlates with a lowering of calorie value.

4. Conclusion

Gummy candies incorporating 3%, 5%, and 7% encapsulated sungkai leaf extract increased in total phenolic, IC50, moisture content, ash content, pH level, and ΔE. In contrast, attributes such as hardness, adhesiveness, gumminess, chewiness, L*, a*, b*, and chroma experienced a decrease. The resultant gummy candy displays a °hue that is categorized as reddish yellow. The gummy candy formulated with xylitol and 3% encapsulated sungkai leaf extract was identified as the best formulation through the effectiveness index assessment. The use of xylitol as a replacement for sucrose was evidenced to reduce the calorie value of the gummy candy. In summary, the low-calorie gummy candy formulated with encapsulated sungkai leaf extract received favorable evaluations from panelists, with results falling within a neutral to favorable category. From the perspective of food science and technology, the results of this study indicate that microencapsulation techniques can be an effective solution to integrate bioactive compounds of herbal plants into functional food products without compromising the stability of the active compounds or the sensory quality of the product. These findings contribute to the development of functional food innovations that not only have additional nutritional value but also support a healthy lifestyle by reducing sugar consumption and increasing intake of natural antioxidants.

In the food and health industry, these gummy candies have potential as a mild supplement to support the prevention of oxidative stress-related degenerative diseases. This product can be targeted to health-conscious consumers, such as diabetics, low-sugar diet consumers, and the general public who want to increase antioxidant intake. However, this study has several limitations, including not conducting long-term stability tests, bioavailability of active compounds after consumption, and industrial-scale testing. Further research is needed to explore other applications of sungkai leaf extract, the effect of storage on the stability of active compounds, and broader consumer preferences through market testing. Studies on the interaction of bioactive components with other carrier materials also need to be conducted to expand the utilization of sungkai leaves in various functional food matrices.

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Conflict of Interests
The author declares that there is no conflict of interest regarding the publication of this paper.

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