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Physicochemical, textural, and antioxidant properties of Pandan Leaf Extract (PLE)-fortified gummy jelly

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ABSTRACT

The presented study focuses on fortifying pandan leaf extract (PLE) into a gummy product. The PLE preparation using two carrier agents, Tween 80 (P3) and black sesame oil (P4), was applied before adding to gummy processing. Then, the PLE-fortified gummy optimization was conducted by varying the PLE concentration at 1.0% (F1), 1.5% (F2), and 2.0% (F3) by weight. Their physicochemical properties were measured by textural by Texture Profile Analysis (TPA), and *In-vitro* biochemical properties of PLE-fortified gummy were analyzed. Results of the first experiment showed that there are significant differences in pH value, total soluble solids, and color attributes, with the black sesame oil-based formulation exhibiting higher lightness (L* value) and yellowness (b* value) values ($p < 0.05$). The result of the TPA analysis showed that the PLE-fortified gummy with black sesame oil formulation had higher hardness and chewiness than the PLE-fortified gummy with Tween 80 formulation ($p < 0.05$). For the second experiment, the physicochemical results demonstrated that total soluble solids, acidity, and color values increased when PLE-extract concentration was added ($p<0.05$). Regarding increasing PLE-extract levels, the texture of gummy jelly showed a decrease in hardness and gumminess while springiness increased ($p < 0.05$). Antioxidant properties, including free radical scavenging activity by DPPH and ABTS assays, supported the potential health benefits of pandan leaf extract in gummy jelly. This study suggests that black sesame oil is a suitable carrier for preparing pandan leaf extract for gummy production. Therefore, the PLE-fortified gummy can be produced as a functional confectionery product, paving the way for future applications in health-oriented gummy formulations.

Keywords: Gummy, Pandan leaf extract, Physicochemical properties, Phenolic compound

INTRODUCTION

Gummy jelly, classified as a gelled confectionery, constitutes a significant portion of the candy market in Thailand, accounting for approximately half of the total market share. Their increasing popularity can be attributed to consumer preferences for chewable confections [1]. Gummy jelly is a form of dried jelly highly favored among children, adolescents, and working adults due to their appealing shapes, vibrant colors, and balanced sweet-and-sour taste. These products possess a chewy, elastic texture that enhances the overall sensory experience during consumption [2, 3].

Gummy jelly typically comprises gelling agents (hydrocolloid compounds) - such as gelatin, carrageenan, or agar - combined with sweeteners like granulated sugar, glucose, or alternative sugar substitutes in carefully controlled proportions [2], making them a high-energy food product. This mixture is prepared under acidic conditions facilitated by organic acids, such as citric or malic acid. Additional ingredients may include fruit and vegetable powders, milk proteins, cereals, or herbal extracts. The formulation allows for the addition of coloring and flavoring agents. The ingredients are thoroughly mixed and heated during processing until a suitable viscosity is achieved. Then, the melted mixture is formed into molds of different sizes and/or shapes. The drying step aims to reduce the moisture content of the product and increase its solid content. Generally, the drying period ranges from 24 h to more [4]. Some gummies undergo further processing, such as coating or drying with sugar or starch, to ensure a optimize chewy texture and prevent stickiness [4]. The gummy texture can be measured by texture profile analysis (TPA), in which the deformation of different descriptors is under force, distance, and time deformation. TPA is a suitable technique for following the deformation of viscoelastic materials.

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Moreover, the change in texture may be affected by the ingredient changes [4].

There has been an increasing trend toward developing confectionery products, especially gummies fortified with various functional ingredients. This innovation is motivated by the convenience of gummy consumption, ease of transport, and the ability to mask the bitter taste of vitamins or herbal extracts with the inherent sweetness and acidity of the product. Furthermore, the attractive presentation of gummies enhances consumer compliance compared to traditional pill or tablet formats. Pandan leaf extract (PLE) is derived from *Pandanus amaryllifolius* and is widely recognized for its unique aroma, antioxidant properties, and bioactive compounds, including phenolics and flavonoids. These bioactive components have been associated with various health benefits, such as anti-inflammatory and antioxidant effects, which may contribute to improved well-being. Pandan leaf extracts have been investigated for their antioxidant capacity and their potential inhibitory effects on xanthine oxidase (XO), an enzyme pivotal in purine metabolism that catalyzes the oxidation of hypoxanthine to xanthine and subsequently to uric acid [5, 6].

Nowadays, the adult and elderly group of consumers is increasingly seeking food products that promote health and well-being, such as those with antioxidant, anti-inflammatory, or uric acid-lowering properties. The previously research related studies demonstrate leaf extracts impact on gel-liked texture [7- 9]. The incorporation of pandan leaf extract (PLE) rich in phenolics and flavonoids-may be particularly beneficial for this group, as it offers potential health benefits including oxidative stress reduction and xanthine oxidase inhibition, which may contribute to better management of conditions such as hyperuricemia or gout. Currently, there is no research publication specifically on the incorporation of PLE into gummy products. A study of PLE on preserving salted duck eggs showed that an increasing amount of PLE, its texture become chewier in gel-based product [10]. This study also aims to evaluate the effects of PLE incorporation in gummy formulations, focusing on the impact of different carrier agents and varying extract concentrations on their physicochemical, texture, and antioxidant properties. The findings of this study will provide insights into the potential application of PLE in functional products for adults and elderly people.

MATERIALS AND METHODS

Pandan leaf extract preparation

The fresh Pandan (*Pandanus amaryllifolius*) leaves were purchased from an organic local farm in Thailand. They were washed with tap water, cut into small pieces, and dried using a hot air dryer at 50-55°C for 18-20 hr. After that, they were finely ground into a powder (4-6% of moisture content). The PLE was performed using the maceration technique according to the process of Sithisam-ang et al. 2023 [11]. Briefly, ground Pandan leaf powder (18 kg) was dissolved into a 95% ethanol solution (food grade). The mixture was continuously stirred for 1 hr. and followed by a filter press machine. The residue was then re-extracted to two additional extraction cycles under the same conditions. The combined ethanolic extract from all three rounds was subsequently concentrated by solvent evaporation under vacuum conditions. The viscous PLE-extract (1.63 kg, Figure 1) is a semi-liquid phase with a dark green color containing 2.79 to 7.49 mg/kg of 2-Acetyl-1-Pyrroline (2AP). The extract was kept at -20°C until further use.

Figure 1 Pandan leaf extract.

Gummy production

The preparation of gummy fortified with pandan leaf extract was conducted as following: PLE was premixed with different carrier agents to facilitate its incorporation into the gummy jelly formulation. The 1 portion (by weight) of PLE was stirred with the 1 portion (by weight) of either Tween 80 (P1) or Black sesame oil (P2) for 20-30 min to ensure uniform dispersion. The selected carrier agent was added at a concentration of 0.50% of the total gummy formulation weight.

In the secondly experiment, it was focused on evaluating the effect of varying levels of PLE incorporation using black sesame oil as the carrier agent. The pre-mixed PLE-black sesame oil combination (1:1 w/w) was added to the gummy formulation at three different concentrations by weight: 1.0% (F1), 1.5% (F2), and 2.0% (F3), respectively, in comparison with a control (0.5% PLE-carrier mixture).

The PLE-carrier mixtures were then mixed with a standard gummy jelly base comprising 30% granulated sugar, 20% glucose syrup, 0.5% citric acid, 0.5% pectin, 8% gelatin 250 bloom, including 500 ppm of sodium benzoate and 200 ppm of potassium sorbate at 70-80°C. After that, the mixture was formed in molds into a rectangular shape and placed at 25-30°C for 2-4 hr.

Physico-chemical properties analysis

The sample was chopped and blended to analyze the moisture content using a moisture analyzer (IR-35, Denver instrument, USA). The water activity (a_w) was

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also measured using a water activity analyzer (4 TE, Agua lab, UK).

The gummy sample (5 g) was vortexed with 20 mL of distilled water and homogenized at 5000 rpm for 30 sec. A clear sample solution was taken for measurement. The total soluble solid (TSS) content and pH value were conducted using a digital hand-held pocket refractometer (PAL-1 and PAL-3, Atago, Japan) and a pH meter (Seven easy, Mettler Toledo, Switzerland), respectively.

The titrimetric method No.986.13 [12] was used to analyze total titratable acidity (TTA) using an auto-titrator (DL53, Mettler-Toledo, Switzerland). Each data was calculated and reported as the percentage of citric acid content.

The measurement of color value was followed using a Minolta chromameter (CR-400, Konica Minolta, Japan). The chromameter was calibrated by a white color standard plate (Y=92.50, x=0.3165, y=0.3329) using the light source of Illuminant D_{65} 2° observer. The colorimetric data was operated as a CIE Lab scale in triplicated measurement and displayed the average data in forms of L* value (Lightness, 0-100), a* value ((-) green to (+) red), and b* value ((-) blue to (+) yellow) value.

Texture qualities analysis

Texture parameters were conducted by measuring the texture profile analysis (TPA) with a Texture Analyzer (TA500, Lloyd instrument, UK). The gummy sample was compressed twice with a cylinder prob (SMS P/25, 25 mm. diameter) and a 5-kg load cell. A probe penetrated to a depth of 50% distance at a 30.0 mm./min test speed and a 0.05 N trigger point. Ten pieces of gummy sample were evaluated for each treatment. The hardness was expressed as the maximum force (N) achieved at the first bite. Springiness related to the height that the gummy recovers during the time that elapses between the end of the first bite and the start of the second bite, unit was mm. Cohesiveness was calculated as ratio of area of second compression cycle to that of area of first compression cycle. Gumminess is defined as the multiplication of product hardness and cohesiveness and chewiness is defined as the product of hardness x cohesiveness x springiness.

Antioxidant properties analysis

The total polyphenol content (TPC) of the samples was determined using the Folin-Ciocalteu method, modified from Miliauskas et al. 2004 [13]. A standard gallic acid solution with working solutions at 10-100 mg/mL was prepared through serial dilution. The 50 µL of the sample extract was diluted with 0.95 mL of distilled water, mixed using a vortex mixer, and combined with 1 mL of the sample solution, 5 mL of 10% Folin-Ciocalteu reagent, and 4 mL of 7.5% sodium carbonate solution. After incubation at 30°C for 30 min, absorbance was measured using the U2900 UV/Vis spectrophotometer (Hitachi, Japan) at 760 nm. A calibration curve was generated using gallic acid standards, and TPC was expressed as mg gallic acid equivalent (GAE) per g of sample.

The ferric-reducing antioxidant power (FRAP) assay, adapted from Kang et al. (2010) [14], was used to assess the reducing capacity of the sample. The 0.5 mL of sample extract, standard Fe (II) solution (0-0.5 mM), or ethanol (as a blank) was added into the 2.5 mL of FRAP reagent. It was mixed and placed in the darkness at 37°C for 10 min. The spectrophotometer absorbance at 593 nm was measured. The ferric reducing capacity of each extracted sample was determined by comparing its absorbance with the standard curve and expressed as µM Fe (II)/g of sample.

The antioxidant activity of the sample extracts was assessed using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay adapted from Wong and Chye (2009) [15]. A 0.2 mL aliquot of the sample extract or distilled water (blank) was mixed in a test tube, followed by 2.0 mL of 0.1 mM DPPH-methanolic solution. The mixture was shaken thoroughly and placed in the darkness at room temperature for 30 minutes. The absorbance at 517 nm was measured using a spectrophotometer. The percentage of DPPH radical inhibition was computed in comparison with a blank.

The antioxidant activity of the sample extracts was evaluated using the ABTS radical scavenging assay, following the method of Wojdylo et al. (2007) [16]. The diluted $ABTS^{+}$ solution (2.0 mL) was mixed with the sample extract (0.2 mL) and incubated for 6 mins before absorbance measurement at 734 nm. The percentage inhibition of its antioxidant capacity was calculated.

Statistical analysis

Data were analyzed using both the independent sample T-test and analysis of variance (ANOVA). The T-test was applied to compare means between two independent groups with the addition of different carrier agents. For multiple group comparisons, a completely randomized design (CRD) was employed with ANOVA to evaluate the effects of various levels of pandan leaf extract used in gummy jelly. The results were presented as mean and standard deviation. Mean separation was performed using Duncan's New Multiple Range Test (DMRT) at the 95% confidence level. All statistical analyses were performed using SPSS version 18.

RESULTS AND DISCUSSION

Pandan leaf extract (Figure 1) is characterized as a semi-solid, viscous resin and poor water solubility. The ethanolic pandan leaf extract contains lipophilic bioactive compounds that exhibit low solubility in water, posing challenges for their uniform incorporation

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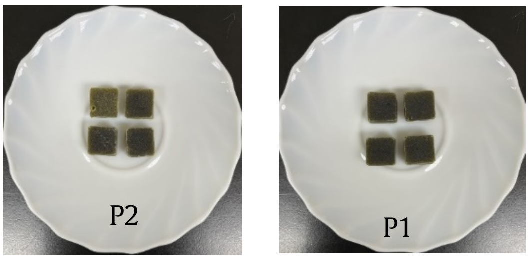
into hydrophilic gummy jelly matrices. In a preliminary study aimed at identifying an appropriate pandan leaf extract preparation, different carrier agents, Tween 80 and black sesame oil, improved the miscibility of the otherwise viscous and semi-solid ethanolic extract. Moreover, the combination of PLE with other ingredients such as glycerin, maltitol syrup, and gelatin affected the solubility of the extracts and its functional integration into the gummy jelly product.

In this experiment, carrier agent refers to a substance used to facilitate the incorporation, dispersion, stabilization, or controlled release of PLE active compounds. Therefore, the first experiment investigated the use of different carrier agents, specifically Tween 80 and black sesame oil, to facilitate the incorporation of pandan leaf extract into gummy formulations at a minimum concentration of a minimum concentration 0.5% by weight, as illustrated in Figure 2.



Tween 80 Black sesame oil

Figure 2 Gummy fortified with pandan leaf extract mixed with different carrier agents.

Table 1 Physicochemical properties of the PLE-fortified gummy using different carrier agents.

Physicochemical properties	P1	P2
Water activity (a_w)^{ns}	0.73 ±0.01	0.74 ±0.01
pH value^{ns}	4.18 ±0.02	4.18 ±0.02
Total soluble solids (°Brix)	76.54 ±1.60^{a}	75.43 ±1.53^{b}
Total acidity as citric acid (%)	1.57 ±0.04^{a}	1.26 ±0.02^{b}
Color:		
L* value	15.94 ±0.91^{b}	26.8 3±0.88^{a}
a* value	1.97 ±0.18^{a}	1.15 ±0.22^{b}
b* value	2.98 ±0.64^{b}	8.46 ±1.68^{a}

Note: $^{a-b}$Different superscript letters in the same row are significantly different according to independent sample T-test at p<0.05.
^{ns}no significant difference values ($p \geq 0.05$).

Table 2 Texture properties of the PLE-fortified gummy using different carrier agents.

Texture properties (TPA)	P1	P2
Hardness (N)	90.75 ±25.45^{b}	97.77 ±13.03^{a}
Adhesiveness (N.mm)	0.26 ±0.14^{b}	0.32 ±0.20^{a}
Springiness^{ns}	0.94 ±0.04	0.97 ±0.04
Gumminess (N)^{ns}	48.62 ±13.80	47.25 ±9.26
Chewiness (N)	41.82 ±10.70^{b}	45.82 ±9.03^{a}
Stringiness (mm)	0.66 ±0.08^{a}	0.25 ±0.11^{b}

Note: $^{a-b}$Different superscript letters in the same row are significantly different according to the independent sample T-test at p<0.05.
^{ns}no significant difference values ($p \geq 0.05$).

The chemical and physical characteristics of both formulations are presented in Table 1. The results indicated that the two formulations of gummy exhibited similar pH values, ranging from 4.18 to 4.19, with water activity levels between 0.733 and 0.742, and total soluble solids measuring between 75.43°Brix and 76.54°Brix. The physicochemical properties of gummy formulations fortified with pandan leaf extract (PLE) were significantly influenced by the type of carrier agent used. Similarly, the report that the commercial gummies contained a high moisture and varied in widely water activity between 0.51-0.79 [17, 18].

In terms of color value, the incorporation of black sesame oil as a carrier agent resulted in significantly higher lightness (L*) and yellowness (b*) values compared to using Tween 80 (p<0.05). The differences in pH value and total soluble solids between two formulations were relatively minor; however, total acidity was significantly lower in the black sesame oil-based formulation (p<0.05). It might be Tween 80 was more effective in improving solubility and

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integrating the PLE within the gummy jelly matrix, possibly due to its amphiphilic composition, which aids in emulsification and dispersion.

In terms of texture parameters, as assessed by Texture Profile Analysis (TPA) (as shown in Table 2), gummy formulas utilizing Tween 80 and black sesame oil as carrier agents revealed significant differences in textural attributes such as hardness, chewiness, adhesiveness, and stringiness ($p<0.05$). The hardness of the gummy formulation incorporating black sesame oil was exceptionally high compared to that of the formulation using Tween 80. It could be due to the slight polarity of Tween 80. However, due to the low fortification level of PLE at 0.5%, no significant effects in adhesiveness and springiness were observed.

Studies have demonstrated that incorporating oils and emulsifiers into gummy formulations can improve the integration and stability of hydrophobic compounds. For instance, research on oil-in-water emulsions prepared with sesame oil and protein isolates showed that stable emulsions with suitable rheological properties could be formulated, highlighting the emulsifying capabilities of sesame oil. Additionally, using emulsifiers in confectionery has been shown to aid in emulsifying fats in products like caramel, fudge, and toffee, suggesting a similar potential in gummy formulations. While direct studies on black sesame oil in gummy products are limited, the findings indicate that lipid-based composition could similarly aid emulsification and dispersion within gummy matrices [19].

Table 3 shows the antioxidant properties of PLE-fortified gummies regarding total phenolic content (TPC), ferric reducing antioxidant power (FRAP), and DPPH and ABTS free radical scavenging assays. The results were found that the PLE-fortified gummy formulation with Tween 80 had a higher TPC than that of the formulation using black sesame oil, but the latter exhibited greater FRAP values ($p<0.05$). This discrepancy suggests that while Tween 80 may enhance efficient phenolic solubility (as the report of Skrypnik & Novikov (2020) [20], who demonstrated significantly increased phenolic recovery from apple pomace at 0.5-1.0% Tween 80), black sesame oil exhibits a more favorable medium for antioxidant activity (as a previously report of Bopitiya & Madhujith (2013) [21], that showed vigorous antioxidant activity with high total phenolic content and significant DPPH and ABTS radical scavenging activities. Regarding the biochemical compound of pandan leaf extracts and black sesame oil, which possess notable antioxidant properties, gummy fortified with PLE was also found to have significant antioxidant activity.

Table 3 Biochemical properties of the PLE-fortified gummy using different carrier agents.

Biochemical properties	P1	P2
Total phenolic content (μg GAE/g sample)	177.42 ±20.07^{a}	109.22 ±4.53^{b}
FRAP (μM Fe^{2+}/g sample)	766.02 ±26.37^{b}	1180.19 ±191.83^{a}
DPPH* (%Inhibition)^{ns}	37.72 ±0.55^{a}	26.75 ±0.60^{b}
ABTS* (%Inhibition)	18.34 ±0.05^{a}	9.54 ±0.20^{b}

Note: $^{a-b}$Different superscript letters in the same row are significantly different according to the independent sample T-test at $P<0.05$.
^{ns}no significant difference values ($p \geq 0.05$).

Tween 80 (polysorbate 80), a nonionic surfactant, is commonly used in food systems to emulsify hydrophobic substances due to its ability to reduce interfacial tension and enhance the dispersion of lipophilic compounds in hydrophilic matrices [22]. It effectively disperses ethanolic extracts in aqueous environments by lowering interfacial tension, thus promoting the homogeneous distribution of the extract throughout the gummy matrix. In contrast, black sesame oil serves as a natural lipid-based carrier and is also suitable for solubilizing hydrophobic plant compounds. Its rich content of unsaturated fatty acids and antioxidant compounds makes it an excellent natural carrier that may contribute to both the nutritional value and positively influence the sensory flavor and texture of the finally gummy jelly [23]. However, using Tween 80 as a carrier agent may impart a slightly bitter and astringent taste to products, as indicated by its characteristic properties -the interaction of Tween 80 with salivary proteins and mucous membranes, leading to a puckering mouthfeel. Due to the use of Tween 80, its surfactant properties may disrupt the lipid-protein balance in saliva, causing a similar tactile sensation. Additionally, residual surfactant on the tongue may interfere with taste perception or enhance bitter notes, especially at higher concentrations [24]. Moreover, other agents such as sugars, fat, and oil frequently used to mask astringency, which is linked with plants extract. They may inhibit the interactions between salivary proteins and tannin compound or other astringents [24].

These findings suggest that the use of black sesame oil enhanced color parameters. At the same time, Tween 80 was more effective in improving solubility and integrating the PLE within the gummy jelly matrix, possibly due to its amphiphilic composition,

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which aids in emulsification and dispersion. Consequently, the P2 formulation, which uses black sesame oil as the PLE-carrier agent for gummy processing, was selected for the second experiment, in which the concentration of pandan leaf extract incorporated into the product was varied between 1.00% and 2.00%.

The study investigated the incorporation of pandan leaf extract into gummy formulations by mixing 1 portion of pandan leaf extract with 1 portion of black sesame oil by weight and adding this mixture to the product at concentrations of 1.0% (F1), 1.5% (F2), and 2.0% (F3) by weight, respectively in comparison with a control gummy formulation. Representative product images are presented in Figure 3, and the chemical-physical characteristics are detailed in Table 4. The experimental results indicated that the three gummy formulations exhibited water activity (a_w) values between 0.74 and 0.75, total soluble solids ranging from 76.54°Brix to 79.22°Brix, and pH values between 4.20 and 4.25. Total acidity levels were within the range of 0.52% to 0.68%, showing minimal variation among the formulations. While statistical analysis indicated slight differences in lightness (L* value) and yellowness (b* value) among the formulations, particularly with lower values observed in F1 compared to F2 and F3 with a decreasing trend of PLE, (p <0.05), these variations were not visually distinguishable. This suggests that higher amounts of pandan leaf extract contribute to a slightly darker product color.

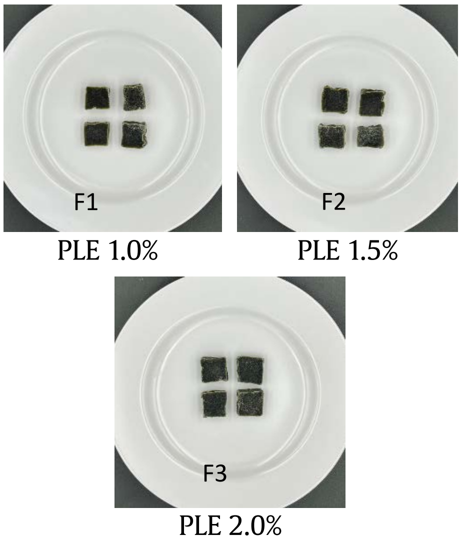

Figure 3 Gummy fortified with different amounts of pandan leaf extract.

Table 4 Physicochemical properties of gummy fortified with pandan leaf extract at different amounts.

Physicochemical properties	**F1**	**F2**	**F3**
Water activity (a_w) ^{ns}	0.74 ± 0.01	0.74 ± 0.01	0.75 ± 0.02
pH value^{ns}	4.20 ±0.01	4.25 ±0.01	4.20 ±0.01
Total soluble solids (°Brix)	79.01 ±0.05^{a}	79.22 ±0.00^{a}	76.83 ±2.05^{b}
Total acidity as citric acid (%)	0.68 ±0.01^{a}	0.52 ±0.00^{c}	0.63 ±0.01^{b}
Color:			
L* value	40.23 ± 0.41^{b}	41.13 ± 0.56^{a}	41.53 ± 0.30^{a}
a* value	3.51 ± 0.05^{a}	3.41 ± 0.05^{b}	3.34 ± 0.06^{c}
b* value	-1.99 ±0.18^{a}	-1.93 ± 0.07^{a}	-1.63 ± 0.17^{b}

Note: $^{a-c}$Different superscript letters in the same row are significantly different according to Duncan's new multiple range test at p <0.05.
^{ns}no significant difference values ($p \geq 0.05$).

Table 5 Texture properties of gummy fortified with pandan leaf extract at different amounts.

Texture properties (TPA)	**F1**	**F2**	**F3**
Hardness (N)	121.15 ±25.66^{a}	60.85 ±8.61^{b}	70.25 ±5.76^{b}
Adhesiveness (N.mm)^{ns}	0.22 ±0.13	0.28 ±0.09	0.16 ±0.11
Springiness	0.89 ±0.08^{b}	0.93 ±0.04^{ab}	0.98 ±0.03^{a}
Gumminess (N)	52.18 ±19.05^{a}	29.03 ±4.48^{b}	30.34 ±7.71^{b}
Chewiness (N)	46.68 ±13.66^{a}	27.54 ±3.57^{b}	29.52 ±6.96^{b}
Stringiness (mm)	1.00 ±0.39^{a}	0.75 ±0.23^{b}	0.44 ±0.13^{b}

Note: $^{a-b}$Different superscript letters in the same row are significantly different according to Duncan's new multiple range test at p <0.05.
^{ns}no significant difference values ($p \geq 0.05$).

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The analysis of textural attributes in gummy formulations, conducted through Texture Profile Analysis (TPA), revealed that increasing the concentration of pandan leaf extract from 1.0% to 2.0% resulted in statistically significant differences (p <0.05) in parameters such as hardness, springiness, gumminess, chewiness, and stringiness. Specifically, there was a trend of decreasing hardness and gumminess, while springiness increased, leading to a reduction in chewiness. Notably, the variations in pandan leaf extract concentration did not significantly affect the adhesiveness of the gummies, as detailed in Table 5. These findings align with previous research indicating that the incorporation of plant extracts can influence the textural properties of gummy candies, affecting parameters such as hardness and springiness. Similarly, the report by Charoen et al. (2015) [9] supports this result. The addition of herbal extracts to gelatin-based gummy formulations altered the gel network structure, resulting in changes to mechanical properties including reduced hardness and increased elasticity. This effect is likely due to interactions between phytochemical compounds in the extracts and the gelatin matrix, which may interfere with protein crosslinking and water distribution, thus modifying the gummy's texture.

Regarding the biochemical compound of pandan leaf extracts, which possess notable antioxidant properties, gummy fortified with *Pandanus amaryllifolius* extract was found to have significant antioxidant activity, as shown in Table 6. While the PLE concentration increased, antioxidant activity in DPPH and ABTS assays also improved (p <0.05). Notably, the highest concentration (2.0%) exhibited significantly enhanced DPPH and ABTS radical scavenging abilities (p <0.05), confirming the presence of potent bioactive compounds in the extract, especially flavonoids and phenolic compounds. The PLE had a total phenolic content (TPC) 126.76 ±1.45 mg GAE/g sample and exhibited 57.01 ±4.23% of ABTS free radical scavenging inhibitory activity (Do not shown in this report). This result showed the potential of pandan leaf extracts as functional ingredients in food products, owing to their rich phytochemical profile and associated health benefits. While direct studies on PLE-infused gummy confections are scarce, successfully incorporating other herbal extracts into gummies suggests a promising avenue for future research and product development.

The incorporation of PLE into gummy formulations presents a promising avenue for functional food development. The findings indicate that black sesame oil is a preferable carrier agent due to its superior impact on color, texture, and antioxidant retention. Additionally, increasing PLE concentration enhances bioactivity, though it may alter textural attributes.

Table 6 Biochemical properties of gummy fortified with pandan leaf extract at different amounts.

Biochemical properties	F1	F2	F3
Total phenolic content (μg GAE/g sample)	283.00±67.21^{b}	268.54±68.67^{b}	356.97±89.74^{a}
FRAP (μM Fe^{2+}/g sample)	357.80±0.50^{c}	431.00±0.25^{b}	508.53±0.85^{a}
DPPH* (%Inhibition)	34.39±0.80^{c}	39.02±0.34^{b}	51.97±0.74^{a}
ABTS* (%Inhibition)	6.98±0.55^{c}	19.04±0.63^{b}	22.72±0.76^{a}

Note: $^{a-c}$Different superscript letters in the same row are significantly different according to Duncan's new multiple range test at p <0.05.

CONCLUSIONS

This study explored the development and characterization of PLE-fortified gummy formulations, focusing on their physicochemical, textural, and antioxidant properties. The incorporation of PLE using black sesame oil as a carrier agent led to a more desirable texture and color, and compared to Tween 80, resulted in a more favorable texture, color, and antioxidant power in terms of FRAP. The increasing PLE concentration between 1.0%-2.0% influenced the gummy's structural integrity, reducing hardness and gumminess while increasing springiness. Furthermore, antioxidant assays confirmed the potential bioactive benefits of PLE-black sesame oil, particularly at higher concentrations, suggesting its suitability as a functional ingredient in confectionery products. However, the study's claim of success is limited by the absence of sensory evaluation, a critical step for assessing consumer acceptability and ensuring the success of the product in the market.

Additionally, the results of this study not only demonstrate a predictable cause–effect relationship between PLE concentration and antioxidant capacity but also highlighting the potential applications of these finding. A greater emphasis on the potential degradation or transformation of PLE components during processing, along with comparison with a control (without PLE), would have provided more insightful conclusions. The findings of this research provide a foundation for future innovations in health-oriented gummies, emphasizing the potential application of PLE as a natural antioxidant source in functional food development.

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