



Development and Characterization of a Date Palm Energy Gel Prototype: Nutritional Composition and Stability Study

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Abstract

The aim of this study was to develop and characterize a date palm-based energy gel by evaluating its physicochemical properties, nutritional values, and consumer acceptance. Using a Box-Behnken design, the formulation was optimized by varying the water-to-maltodextrin ratio and date syrup concentrations. The results indicated that the date syrup significantly contributed to high caloric content, carbohydrate concentration, and antioxidant properties in the final product. The optimized formulation, consisting of a 1.5:1 water-to-maltodextrin ratio, 36% maltodextrin, and 8% date syrup, provided an energy density of 110 kcal/40g serving. Physicochemical attributes, including total soluble solids, pH, and viscosity, were significantly affected by the ingredient ratios ($p \leq 0.05$). Sensory evaluation by 100 panelists confirmed high acceptance scores, with the optimized prototype demonstrating significant differences in preference ($p \leq 0.05$) compared to other variations. This research, conducted at both laboratory and pilot-plant scales at Food Inno Startup Co., Ltd., demonstrates the feasibility of date palm-based energy gels as a functional food for sports nutrition and commercial production.

Introduction

The dietary supplement market in Thailand has seen significant growth due to increasing health consciousness among consumers. However, many of these products are expensive imports, often failing to meet local taste preferences and are primarily popular with fitness enthusiasts (Kasikorn Research Center, 2020). To address this, energy gels are now being innovatively developed from local agricultural products, such as dates, bananas, ginger, and palm seeds (Mongsirikul, 2020).

Among these, date palm is a favored fruit for athletes who need quick energy during activities like marathons and trail running (Mongsirikul, 2021). Dates, a member of the palm family, are rich in high-energy carbohydrates, particularly low-glycemic monosaccharides. Each variety contains 23–30% glucose, 19–28% fructose, and 7–10% non-starch polysaccharides (Barakat & Alfheaid, 2023; Chainok, 2016). These sugars are quickly absorbed, providing an immediate energy boost. The fruit is particularly noted for its potential low-glycemic properties, largely attributed to the high

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concentration of fructose (which has a naturally low glycemic index) and non-starch polysaccharides (dietary fiber). These factors help moderate the blood sugar response, making dates suitable for athletes needing a steady energy release. Additionally, dates are packed with vitamins and minerals like vitamin C, selenium, copper, B vitamins, potassium, and magnesium, which help prevent muscle cramps during exercise. The antioxidant properties of date extracts are also potent, being twice as effective as standard vitamin C solutions (L-ascorbic acid) (Jonoobi et al., 2019). Dates are even suitable for diabetic patients due to their low-glycemic sugars, which help regulate blood sugar levels. Furthermore, the presence of oxytocin in dates aids in uterine contractions and stimulates postpartum lactation, solidifying their reputation as a “fruit of health” with significant potential as an energy supplement. Despite these benefits, the development of date-based products in Thailand faces challenges such as a lack of production and processing standards and low consumer awareness (Mongsirikul, 2021; Srisawat & Phaithong, 2019). These challenges highlight the need for further research and development.

In response, researchers have developed an innovative, heat-sterilized, preservative-free energy gel drink from dates. This product is ideal for athletes and those needing quick energy, offering advantages such as convenience, the ability to be enriched with essential nutrients and minerals, and a steady energy source by controlling the concentration of monosaccharides compared to consuming dried dates. The product is manufactured in an experienced industrial facility, meeting high safety standards. It also aligns with Thailand's Bio-Circular-Green (BCG) Model by emphasizing value-added processing of agricultural products, reducing reliance on imports, and promoting the sustainable growth of the national economy through diverse flavors and enhanced consumer accessibility.

The main objectives of this study were derived from the need to develop a high-value, locally sourced energy supplement. Specifically, this research aimed to develop and identify the optimal formulation for a date palm-based energy gel by systematically investigating the effects of the water-to-maltodextrin ratio and date syrup concentration on product characteristics, while concurrently evaluating the physicochemical properties, including TSS, pH, viscosity, and texture, as well as the total phenolic content and antioxidant activity. Furthermore, the study sought to determine the nutritional

composition, safety profile, and sensory acceptance of the optimal prototype.

Materials and methods

1. Materials

The research and development of a prototype date palm energy gel for health took place at Food Inno Startup Co., Ltd. This research focused on developing an energy gel from date palms. The project had a total duration of 14 months, from May 2023 to June 2024. The date syrups used in this study were purchased from a single source at Preecha date palm garden in Nonthaburi, Thailand. The date cultivar used to produce the syrup was Barhi, and the maturity stage of the date palm fruit was the rutab stage. Food-grade ingredients, including maltodextrin, citric acid, carrageenan, potassium chloride, and sodium citrate, were sourced from Krungthepchemi Company Limited in Bangkok, Thailand. Orange flavoring, and strawberry flavoring, were purchased from a local bakery.

2. Date syrup properties

The random date syrups samples purchased from Preecha date palm garden in Nonthaburi, Thailand were determined by their properties, such as moisture content, carbohydrates, ash content, fat content, fiber content, total soluble solids (TSS), pH, water activity, viscosity, total phenolic content (TPC), antioxidant activity, and color parameters. All analysis is mentioned in 5 and 6.

3. Date-based energy gel formulation

The development of the standard formula for the date-based energy gel product was based on extensive literature surveys and subsequent internal formulations by researchers specializing in the food industry. The starting formulation included ingredients and percentages as follows: water (54.98%), maltodextrin (31.60%), orange flavor (3.44%), strawberry flavor (3.44%), sugar (3.44%), date syrup (2.75%), citric acid (0.21%), and carrageenan (0.14%). A factorial design was employed to investigate the effects of varying the water-to-maltodextrin ratio and syrup concentration on the final product. The water-to-maltodextrin ratios tested were 1.4:1 and 1.5:1, corresponding to maltodextrin amounts of 35 and 36 g, respectively. Additionally, syrup concentrations of 7% and 8% were evaluated. The energy gel samples were prepared using the formulations detailed in Table 1. The ingredients were thoroughly mixed and heated using a double boiler at a temperature of 85°C for 30 min. Following the heating process, the

mixture was immediately placed into packaging and sealed in foil pouches. The sealed samples were then subjected to further testing as outlined in subsequent sections.

Table 1 The formulations of date energy gel

Ingredient	1	2	3	4	5	6	7	8
Water (%)	49	52.5	50.4	54	49	52.5	50.4	54
Maltodextrin (%)	35	35	36	36	35	35	36	36
Orange flavor (%)	4.22	2.47	3.02	1.22	3.72	1.97	2.42	0.72
Strawberry flavor (%)	4.22	2.47	3.02	1.22	3.72	1.97	2.42	0.72
Date syrup (%)	7	7	7	7	8	8	8	8
Citric acid (%)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Carrageenan (%)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sea salt (%)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Potassium chloride (%)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sodium citrate (%)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

4. Study of the optimal ratio of date syrup in the production of a date-based energy gel

A Box-Behnken design (BBD), a statistical method for efficient optimization, was used with Design Expert software to find the best formula for a date-based energy gel. A three-factor, three-level Box-Behnken design (BBD) was employed to optimize the formulation (Box & Behnken, 1960). The independent variables selected for this design were the water-to-maltodextrin ratio (A), maltodextrin content (B), and date syrup content (C). Overall acceptability and viscosity were chosen as the response factors to be measured. Table 2 depicts the experimental design matrix generated by the BBD, illustrating the 15-run pattern, including three center points. The ideal formulation was selected based on the desired response variables and was then tested in physicochemical properties, in vitro, and ex vivo experiments. The moisture content of the date-based

Table 2 Box-Behnken design matrix of independent variables for energy gel optimization

Run	Factor A: Water-to-MD ratio	Factor B: MD content (%)	Factor C: Date syrup content (%)
1	1.4 (−1)	35 (−1)	7.5 (0)
2	1.5 (+1)	35 (−1)	7.5 (0)
3	1.4 (−1)	36 (+1)	7.5 (0)
4	1.5 (+1)	36 (+1)	7.5 (0)
5	1.4 (−1)	35.5 (0)	7 (−1)
6	1.5 (+1)	35.5 (0)	7 (−1)
7	1.4 (−1)	35.5 (0)	8 (+1)
8	1.5 (+1)	35.5 (0)	8 (+1)
9	1.45 (0)	35 (−1)	7 (−1)
10	1.45 (0)	36 (+1)	7 (−1)
11	1.45 (0)	35 (−1)	8 (+1)
12	1.45 (0)	36 (+1)	8 (+1)
13	1.45 (0)	35.5 (0)	7.5 (0)
14	1.45 (0)	35.5 (0)	7.5 (0)
15	1.45 (0)	35.5 (0)	7.5 (0)

energy gel was determined using the oven drying method to constant weight, following the procedure outlined by the AOAC Official Method 925.09 (Helrich, 1990).

5. Physicochemical properties

5.1 The total soluble solids content (TSS)

The TSS was measured using a hand refractometer (ATAGO Co., Ltd., Japan) following the method of de Moura et al. (2018). Samples were placed on the refractometer and readings were recorded in degrees Brix (°Brix) or percentage weight/weight (%w/w). Each sample was tested in triplicate.

5.2 pH measurement

The pH was calibrated using a pH meter (LE407, Mettler-Toledo GmbH, Switzerland) with standard buffer solutions of pH 4.01 and 6.86. The electrode was rinsed with distilled water between measurements. The pH of the samples was measured and each sample was tested in triplicate (Akesowan & Choonhahirun, 2019).

5.3 Moisture content (MC) and water activity (a_w)

Moisture content and water activity were measured to assess the product's water levels. A moisture analyzer was used to determine the moisture content (MC) by heating samples to 100°C. Water activity (a_w) was measured with a water activity meter. All samples were tested 3 times (Puttame et al., 2016).

5.4 Total phenolic content and antioxidant activity

Total phenolic content and antioxidant activity were measured using 2 separate methods. The antioxidant activity was determined using the DPPH assay. Samples were mixed with a 0.2 mM DPPH solution in methanol and then kept in the dark for 30 min. Ascorbic acid was used as a positive control, and the percentage of inhibition was calculated after measuring the absorbance at 517 nm with a microplate reader. For total phenolic content, the Folin-Ciocalteu method was used. The absorbance was measured at 765 nm (Baroyi et al., 2023).

5.5 Color measurement

Color was measured using a datacolor international (Datacolor SF600 Plus, Datacolor Inc., USA) in the CIE Lab* system. L* indicates lightness, a* indicates the green-red axis, and b* indicates the blue-yellow axis.

5.6 Viscosity measurement

Viscosity was measured using a Brookfield viscometer (Model DV-II, AMETEK Brookfield, USA) with an appropriate spindle (e.g., Spindle No. 4). The rotational speed was set at 100 revolutions/min (rpm). Samples were tested by placing the gel in a standard container, allowing it to equilibrate, and taking

measurements at a controlled temperature of $25\pm1^{\circ}\text{C}$ (Baroyi et al., 2023). Results were recorded in $\text{mPa}\cdot\text{s}$.

5.7 Texture analysis

Texture was analyzed using a Stable Micro Systems TA.XT Plus texture analyzer (TA.XT Plus, Stable Micro Systems Ltd., UK). A Texture Profile Analysis (TPA) test was performed to measure the mechanical properties of the gel. The samples were compressed twice using a P/36R cylindrical probe (36 mm diameter). The test parameters were set as follows: Pre-test speed: 2 mm/s, Test speed: 1 mm/s Post-test speed: 2 mm/s Compression distance (Strain): 75% of the initial sample height. Time between compressions: 5 sec (for recovery). The TPA provided measurements for parameters such as hardness, adhesiveness, cohesiveness, gumminess, springiness, and chewiness.

6. Nutritional values

To determine the nutritional value of the energy gels, several tests were conducted on samples that were prepared and stored at 25°C prior to analysis. To determine the carbohydrate content, samples were first hydrolyzed to break them down into monosaccharides. These monosaccharides were then quantified using the phenol-sulfuric acid method by measuring absorbance at 490 nm. Protein content was assessed using the Kjeldahl method, a process that involved digesting samples with sulfuric acid to measure their nitrogen content. The protein amount was then calculated using a conversion factor of 6.25. Fat and ash content analyses were carried out using the AOAC official methods (Horwitz & Latimer, 2005). The fat content was determined gravimetrically after extraction. High-performance liquid chromatography (HPLC) was employed to precisely measure vitamins A, C, and E. For mineral analysis, the samples were first digested with nitric acid, and then the levels of calcium, iron, and potassium were measured using Atomic Absorption Spectroscopy (AAS). The total caloric content was calculated by applying the Atwater general factors to the macronutrient composition: 4 kcal/g for carbohydrates, 4 kcal/g for proteins, and 9 kcal/g for fats.

7. Microbiological analysis

The quantification of Total Plate Count, Coliform, *E. coli*, Yeast and mold was conducted using 3M Petrifilm™ (ready-to-use culture plates). The detection of *Bacillus cereus*, *Staphylococcus aureus*, and *Clostridium perfringens* was performed according to the methods outlined in BAM online (U.S. Food & Drug Administration, 2001).

8. Sensory evaluation

A sensory evaluation was conducted using a 9-point hedonic scale (1 = extremely dislike to 9 = extremely like) and a Just About Right (JAR) scale with 100 sports participants aged 18–65 years. Prior to the evaluation, the panelists received a brief introduction to the nine-point hedonic scale. The panelists assessed various attributes, including appearance, odor, texture, sweetness, and overall acceptability. All energy gels used in this evaluation were freshly prepared, served in coded testing cups, and presented in a randomized order.

9. Stability study

Packaged samples were stored in controlled-temperature chambers at 25, 30 and 40°C ($\pm 0.5^{\circ}\text{C}$). Analyses were performed at 0, 2, 4, 6, 8, 10 and 12 weeks to monitor changes in physical properties (viscosity and color), microbiological safety (TPC, Yeast and mold, *Coliforms*, *Salmonella* spp., and *S. aureus*), and sensory attributes to evaluate the product's stability during the study period.

10. Statistical analysis

The data collected throughout the study were analyzed using various statistical methods. Descriptive statistics, including frequency, mean, and standard deviation, were used to summarize the experimental results. Analysis of Variance (ANOVA) was employed to determine statistically significant differences ($p\leq 0.05$) among the different product formulations regarding physicochemical properties, nutritional values, and sensory scores. Where significant differences were found, Duncan's New Multiple Range Test (DMRT) was performed for post-hoc comparisons. Regression analysis was utilized to model the relationship between independent variables and sensory preference responses, and the validity of these models was confirmed using ANOVA. Statistical analysis and optimization were conducted using Design-Expert® software (version 13, Stat-Ease, Inc., USA).

11. Ethical considerations

The researchers obtained approval for human subject research from the Panyapiwat Institute of Management Research Ethics Committee. They submitted the research protocol to the committee and received approval under the reference number PIM-REC 009/2567. Subsequently, the researchers selected a sample group, explained the objectives, and informed them of their right to accept or decline participation. The researchers also confirmed that the results would only be presented in an aggregated format.

Results and discussion

1. Date syrup properties

The characteristics of date syrup used in this study are shown in Table 3. The syrup contains 309 kcal/100 g, with 77.2% carbohydrates, 1.90% ash, and 20.9% moisture content. There was no detectable fat or fiber in the date syrup used in the study. The high carbohydrate content, primarily in the form of simple sugars (glucose and fructose, typical of date syrup), confirms its suitability as a primary energy source in gel formulation. The moisture content is consistent with other commercial syrups, ensuring adequate preservation and handling quality. The total soluble solids, indicating the sugar concentration in the syrup, measured 48.50°Brix, with a pH of 4.42 and a viscosity of 13,250 mPa·s. The acidic pH (4.42) is beneficial as it contributes to the overall stability and microbial safety of the final energy gel product. Furthermore, the high viscosity is characteristic of concentrated syrups and influences the final texture and mouthfeel of the gel. The total phenolic content (TPC) in the date syrup was found to be 25.46 mg GAE/g and the antioxidant activity was 19.65 mmol Trolox Equivalent/g. These high levels of bioactive compounds, particularly phenolics, are crucial. They not only enhance the nutritional value of the gel but also contribute significantly to the product's stability by acting as natural antioxidants, thus minimizing oxidative deterioration during storage. The date syrup used for energy gel production was tested for pesticide residues, including ochratoxin A, sulfur dioxide, deoxynivalenol (DON), and zearalenone. The tests were performed by an ISO17025-certified laboratory, and no contamination was found. Additionally, microorganisms, such as TPC, yeast, mold, or pathogens, were not present.

Table 3 Properties of date syrup

Chemical property	Value
Moisture content (%)	20.9
Carbohydrates (%)	77.2
Ash content (%)	1.9
Fat content (%)	Not detected
Fiber content (%)	Not detected
Total soluble solids (°Brix)	48.5
Acidity (pH)	4.42
Water activity (a_w)	0.658
Viscosity (mPa·s)	13,250
Total phenolic content (TPC) mg GAE/g	25.46
Antioxidant activity (DPPH) mmol Trolox Equivalent/g	19.65
Color value L*	85.75
Color value a*	2.663
Color value b*	50.133

2. Physicochemical properties of date-based energy gel

2.1 Chemical properties

1) The total soluble solids (TSS)

The total soluble solids (TSS) of samples are presented in Table 4. Sample 1 with a high fruit flavoring, had the greatest TSS (46.0°Brix), while sample 3 with less flavoring, showed the lowest TSS (43.5°Brix). The various components of soluble solids such as sugars and organic acids found in the fruit flavors as well as the natural sugars derived from date syrup and maltodextrin are the key to changing the TSS of each sample. TSS values in this study were greater than those usually found in commercial energy gels (35–38°Brix). A sweetened composition in the energy gel could restrict water mobility and contributed to increased viscosity and flavor release.

When comparing formulations with the same low date syrup concentration (samples 1–4, 7% date syrup), sample 1 consistently registered the highest total soluble solids (TSS) value (34.3%). This result is directly related to its high concentration of maltodextrin (36%) and its low water-to-maltodextrin ratio (1.4:1). Since both date syrup and maltodextrin are major soluble solids components of the gel, the maximum concentration of the highly soluble maltodextrin (36%) in sample 1 yielded the most concentrated mixture in this group, thus resulting in the highest measured TSS. This demonstrates that the MD ratio and the MD content play a critical role in controlling the TSS value, even more so than small variations in other ingredients.

2) pH

The pH is a crucial factor in the evaluation of date-based energy gel products, as it directly influences the product's safety, quality, and shelf life. The pH values of the date-based energy gels were statistically significant ($p \leq 0.05$), ranging from 3.39 (sample 8) to 3.51 (sample 7). The lower pH was attributed to the use of citric acid and other ingredients, classifying the product as an acidified low-acid food with a pH below 4.6. Even though sample 7 and 8 had the same amount of citric acid, their actual pH values were different because of the composition of the matrix. Within complicated food systems, pH is affected by acid concentration, acid dissociation characteristics, ionic strength, and the buffering capacity. Sample 8 had significantly more moisture and water activity, causing the environment to be more diluted and allowed citric acid breakdown. In contrast, the more concentrated solid matrix, shown in sample 7, increased buffering ability through natural

components, including proteins, amino acids, and organic salts, which restricted proton release and resulted in a high pH. A study by Akesowan and Choonhahirun (2019) on konjac gel also highlighted the importance of pH in ensuring the safety and stability of food products.

3) Moisture content (MC)

Moisture content (MC) and water activity (a_w) are critical parameters influencing the texture and stability of energy gel products. The formulations exhibited moisture contents ranging from 46.33% to 64.93%, with corresponding a_w levels between 0.960 and 0.985. Sample 8 showed the highest MC (64.93±0.45%), while sample 6 had the lowest (46.33±0.33%), demonstrating statistically significant differences ($p \leq 0.05$). The higher moisture in sample 8 is attributed to the combination of the highest water: maltodextrin (W:MD) ratio (1.5:1) and a lower concentration of maltodextrin (35%), which exceeds the water-holding capacity of the matrix. Notably, the microbiological stability of these formulations is governed by hurdle technology, primarily the synergistic effect of low pH (3.39–3.51) and thermal pasteurization rather than moisture restriction. While the a_w levels are relatively high, the acidic environment serves as a robust barrier against pathogenic bacterial growth. These results align with the findings of Baroyi et al. (2023), who observed that moisture content and a_w are closely related to the total soluble solids in food systems. Furthermore, the precise control of the W:MD ratio is essential for achieving the desired gel consistency, as similarly noted in studies on sugar palm fruit jam by Anggraini et al. (2019).

Table 4 Chemical properties of date-based energy gel products

Sample	TSS (°Brix)	pH	MC (%)	a_w
1	46.0±0.01 ^a	3.45±0.05 ^c	49.08±0.60 ^d	0.971±0.05 ^d
2	45.0±0.01 ^c	3.43±0.04 ^c	53.06±1.02 ^b	0.980±0.03 ^b
3	43.5±0.01 ^c	3.44±0.01 ^d	52.68±0.43 ^c	0.976±0.02 ^c
4	45.5±0.01 ^b	3.47±0.00 ^b	48.15±0.64 ^c	0.970±0.01 ^c
5	45.0±0.01 ^c	3.48±0.02 ^b	48.26±0.72 ^c	0.970±0.00 ^c
6	45.0±0.01 ^c	3.48±0.01 ^b	46.33±0.33 ^f	0.960±0.04 ^e
7	44.0±0.01 ^d	3.51±0.04 ^a	49.22±0.24 ^d	0.968±0.03 ^f
8	45.5±0.01 ^b	3.39±0.05 ^f	64.93±0.45 ^a	0.985±0.02 ^a

Remark: Data are presented as mean±standard deviation. Different letters within the same column indicate statistically significant differences ($p \leq 0.05$).

2.2 Physical properties

1) Color

The color characteristics of the date-based energy gel were significantly affected by the organic dark brown pigmentation of the date syrup and the fruit flavors,

which comprise pigments resulting from caramelization and maillard reactions (Table 5). There were small changes in lightness (L^*) amongst the samples because the water-to-maltodextrin ratio, the amount of date syrup, and fruit flavors were different. sample 2 had the greatest L^* value, and sample 3 had the lowest. The L^* values of all samples, with their slightly significant differences, show that the ingredients were well spread throughout the gel matrix, giving a uniform appearance. The ingredients have a smaller effect on the a^* values. The pigments affect the b^* values of each sample, giving date-based products a warm yellow-brown color. The consistently high b^* values across formulations show that date syrup had the biggest effect on color development. Samples with more syrup, as sample 5, had slightly more vivid yellow–amber tones because the natural pigments were less diluted.

2) Viscosity

In Table 5, The viscosity of the samples showed significant differences ($p \leq 0.05$). Sample 6 had the highest viscosity at 12,520±385 mPa·s, and sample 8 had the lowest at 10,150±378 mPa·s. This low viscosity in sample 8 is attributed to its high water-to-maltodextrin (W:MD) ratio (1.5:1), which results in an excessive amount of free, unbound water. This excess water disrupts the entanglement and association of the maltodextrin polymers, weakening the overall gel structure and leading to a significant reduction in viscosity, despite the high total solids content. Viscosity differed due to the gel formation and moisture content of samples. This behavior can be explained by the higher date syrup content (8%), which provides additional soluble solids and polysaccharides that contribute to a thicker matrix. Furthermore, ion-mediated interactions between carrageenan and potassium or sodium ions strengthen the gel network, compensating for the effect of increased water. Maltodextrin also plays a key role in immobilizing free water, thereby contributing to high viscosity, even when the total moisture content is elevated. Viscosity was also influenced by gelling agents such as carrageenan, which serves as a thickener, emulsifier, and gelling agent, and by maltodextrin, which is crucial in determining viscosity.

3) Texture properties

Table 6 shows that the texture of the eight energy gel formulations showed statistically significant differences ($p \leq 0.05$). The variation in textural properties between samples are mostly due to differences in moisture content, water activity, and the level of the

Table 5 Physical properties of date-based energy gel products

Sample	L*	a*	b*	Viscosity(mPa·s)
1	83.68±0.040 ^{ab}	1.663±0.072 ^a	40.153±0.127 ^{ab}	11,850±385 ^c
2	84.76±0.520 ^{bc}	1.663±0.023 ^a	40.076±0.127 ^{bc}	11,950±572 ^c
3	83.61±0.250 ^c	1.664±0.026 ^a	40.056±0.127 ^c	12,194±740 ^{ab}
4	83.67±0.247 ^{bc}	1.670±0.050 ^a	40.150±0.127 ^{ab}	12,520±428 ^a
5	83.75±0.019 ^a	1.663±0.040 ^a	40.133±0.127 ^{abc}	11,045±537 ^d
6	83.65±0.710 ^{bc}	1.662±0.074 ^a	40.083±0.127 ^{bc}	12,720±310 ^a
7	83.69±0.054 ^{ab}	1.670±0.031 ^a	40.103±0.127 ^{abc}	12,020±454 ^{ab}
8	83.67±0.510 ^{bc}	1.686±0.024 ^b	40.170±0.024 ^a	10,150±378 ^c

Remark: Data are presented as mean±standard deviation. Different letters within the same column indicate statistically significant differences ($p \leq 0.05$).

matrix structure controlled by maltodextrin, carrageenan, and soluble solids. Samples with lower moisture content and a_w , especially sample 6, were harder with more gumminess, chewiness, and springiness. This means that they had a thick and compact network with slight molding. Samples 3 and 8, on the other hand, had a lot of water in them, which made them more flexible and cohesive. This observation is due to the high proportion of free water acting as a plasticizer, weakening the hydrocolloid-carbohydrate network's crosslinks, which made the gel matrix more hydrated and less crosslinked. These behaviors match the statistical results in Table 6, which reveal significant variations between the formulations ($p \leq 0.05$). Sample 6 had the greatest hardness (864.12 ± 30.14 mPa·s), and sample 3 was the softest (505.32 ± 16.12 mPa·s). Hardness went up when there was more maltodextrin and down when there was more water and date syrup. The textural behavior of the date-based energy gels is mostly determined by the balance between the amount of water content and how strong the hydrocolloid carbohydrate network is. These results highlight the significance of influencing moisture distribution, maltodextrin concentration, and soluble solids content to achieve optimal mechanical characteristics and consumer-preferred gel textures.

Table 6 Texture analysis results of date-based energy gel products

Texture attribute	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Hardness (g)	606.23±12.18 ^c	689.04±18.11 ^b	505.32±16.12 ^b	671.81±15.11 ^c	650.35±20.16 ^d	864.12±30.14 ^a	587.14±40.11 ^f	585.39±26.13 ^e
Adhesiveness (g·sec)	-1.70±0.02 ^c	-1.85±0.01 ^c	-0.90±0.06 ^b	-2.74±0.02 ^b	-0.76±0.01 ^a	-4.01±0.03 ^b	-2.44±0.05 ^f	-1.81±0.05 ^d
Springiness (sec/sec)	1.06±0.02 ^b	2.98±0.03 ^b	2.14±0.04 ^d	1.52±0.01 ^e	1.95±0.02 ^c	3.48±0.03 ^a	1.60±0.01 ^f	2.71±0.01 ^c
Cohesiveness (g·sec/g·sec)	1.98±0.05 ^d	0.30±0.05 ^f	2.99±0.04 ^a	1.87±0.09 ^c	1.97±0.04 ^c	0.24±0.02 ^b	2.29±0.01 ^c	2.87±0.03 ^b
Gumminess (g)	325.14±43.10 ^e	367.55±32.90 ^c	387.54±32.55 ^d	421.37±40.69 ^c	547.38±26.00 ^a	450.87±43.80 ^b	357.21±31.60 ^f	367.90±28.36 ^c
Chewiness (g)	301.08±50.36 ^b	323.02±65.24 ^d	310.80±47.26 ^e	367.25±41.02 ^c	385.06±49.20 ^a	370.63±37.84 ^b	311.25±65.60 ^f	315.20±30.23 ^c
Resilience (g)	0.198±0.01 ^c	0.280±0.03 ^a	0.187±0.01 ^f	0.235±0.01 ^c	0.215±0.03 ^d	0.115±0.01 ^b	0.126±0.01 ^e	0.241±0.02 ^b

Remark: Data are presented as mean±standard deviation. Different letters within the same row indicate statistically significant differences ($p \leq 0.05$).

2.3 Antioxidant properties

The total phenolic content (TPC) and antioxidant activity are quality indicators for date-based energy gel. Phenolic compounds act as antioxidants, which help to neutralize and prevent free radical damage in the body (Kumar & Goel, 2019). The results revealed significant TPC and antioxidant activity differences among the eight formulations ($p \leq 0.05$) due to the variation of the components. The variations in TPC across samples were caused by the different amounts of date syrup and fruit flavors, both of which add a natural source of phenolic acids, flavonoids, and tannins. However, an anomaly was observed where samples 3 and 4, despite having the same 7% date syrup content as samples 1 and 2, exhibited unexpectedly lower TPC values. This reduced activity is likely attributable to the minor flavoring components (orange/strawberry extracts) and their interaction with the matrix. Natural extracts may contain substances that interfere with the Folin-Ciocalteu colorimetric assay, leading to an underestimation of the true phenolic content, or the specific matrix conditions (like pH) of these formulas may have affected the solubility and extractability of the date phenolics. High TPC in the gels is good for both nutrition and product stability. Phenolics are known to reduce oxidative deterioration, maintain flavor quality, and prevent color degradation during storage (Shahidi & Yeo, 2018). These qualities make date-based gels better than many commercial carbohydrate gels, which usually use refined sugars and lack antioxidant activity. Samples with higher amounts of date syrup and flavors had more phenolic content and higher DPPH activity. The antioxidant activity followed a similar pattern, which showed that the functional performance of the gel matrix is determined by the availability of phenolic compounds, not just the presence of phenolic-rich components. Therefore, the energy gels'

composition significantly impacts their phenolic content and antioxidant potential, which are critical for their health benefits and quality.

Table 7 Total phenolic content and antioxidant activity of date-based energy gel products

Sample	TPC (mg GAE/g)	Antioxidant activity (DPPH) (mmol Trolox Equivalent/g)
1	28.50±0.53 ^b	20.76±0.82 ^d
2	27.41±0.48 ^c	22.06±0.54 ^b
3	18.53±0.62 ^b	14.62±0.7 ^h
4	22.85±0.50 ^f	18.45±0.34 ^f
5	29.87±0.59 ^a	23.31±0.54 ^a
6	23.73±0.74 ^e	20.04±0.90 ^e
7	19.34±0.51 ^g	15.81±0.62 ^g
8	24.52±0.41 ^d	21.74±0.87 ^c

Remark: Data are presented as mean±standard deviation. Different letters within the same column indicate statistically significant differences ($p \leq 0.05$).

2.4 Microbial properties

The date-based energy gel prototypes exhibit high hygienic standards, with all microbial parameters falling well within the safety limits regulated by the notification of the Ministry of Public Health No. 355 B.E. 2556 and No. 416 B.E. 2563. As presented in Table 16, the total plate count (TPC) and yeast and mold counts were less than 10 CFU/g across all formulations. Furthermore, pathogenic microorganisms, including *Salmonella* spp., *S. aureus*, *B. cereus*, and *C. perfringens*, were not detected, and *E. coli* was less than 3 MPN/g. Although the product has a relatively high-water activity (a_w 0.96–0.98), as shown in Table 4, its microbial stability is primarily ensured by the combination of low pH (3.39–3.51) and the thermal pasteurization process (85°C for 30 min). This synergy effectively inhibits the growth of spoilage and pathogenic bacteria, supporting its suitability for an extended shelf life under appropriate storage conditions.

2.5 Sensory quality evaluation

Data was collected from 100 participants using a questionnaire divided into two sections: demographic information (gender, age, occupation, income) and

an assessment of preferences for various product attributes, including appearance, color, aroma, sweetness, thickness, and overall liking. The evaluation used a 9-point hedonic scale, where one represented “dislike extremely,” and nine represented “like extremely.” The survey results indicated that the majority of respondents were female (63%) and male (37%). Most participants were aged 20 years or younger (45%), were pursuing undergraduate studies (80%), and were primarily students (64%). The average overall liking scores ranged from 5.95 to 7.12, indicating acceptance from “slightly like” to “moderately like”. Statistical analysis (ANOVA) of the sensory data (Table 8) revealed significant differences ($p \leq 0.05$) in consumer preferences across the various formulations tested in the Box-Behnken Design. Specifically, the date syrup content and the W:MD ratio were found to be the main factors statistically influencing the overall liking and viscosity scores. Sample 8, which incorporated the highest date syrup concentration (e.g., 45% w/w), achieved the highest statistically significant mean score (7.12±1.50), highlighting the positive impact of this variable on consumer acceptance. This suggests the product was generally well received, with room for improvement in certain sensory aspects based on specific consumer preferences.

From the survey on date-based energy gel products, most respondents (71.43%) liked the product, and half (50.60%) viewed it as highly nutritious. If the product were available in the market, 74.12% of respondents expressed interest in purchasing it, with the primary considerations being nutritional value (57.89%) and good taste (23.68%). Additionally, respondents recommended using aluminum foil pouches with a screw cap (28.57%) for packaging. The primary reasons for liking the product were its nutritional value (37.50%) and health benefits (29.55%). This strong consumer emphasis on health and nutrition strongly validates the study's focus on enhancing the gel's energy density and micronutrient

Table 8 Sensory preference scores of date-based energy gel

Sample	Appearance	Color	Aroma	Taste	Viscosity	Overall
1	5.91±1.29 ^c	6.26±1.42 ^b	5.92±1.56 ^c	5.89±1.29 ^c	5.81±1.42 ^c	5.95±1.19 ^d
2	6.32±1.3b ^c	6.66±1.51 ^a	6.36±1.48 ^b	6.31±1.33 ^b	6.31±1.43 ^b	6.29±1.30 ^d
3	6.06±1.39 ^{bc}	6.29±1.36 ^b	6.09±1.43 ^{bc}	6.13±1.48 ^{bc}	6.15±1.70 ^{bc}	6.06±1.46 ^d
4	6.35±1.61 ^b	6.29±1.58 ^b	6.39±1.74 ^b	6.38±1.54 ^b	6.35±1.77 ^b	6.74±1.57 ^{abc}
5	6.21±1.77 ^b	6.15±1.71 ^b	6.24±1.57 ^b	6.27±1.65 ^b	6.23±1.83 ^b	6.20±1.66 ^{cd}
6	6.45±1.49 ^{ab}	6.61±1.60 ^a	6.46±1.58 ^{ab}	6.49±1.58 ^{ab}	6.41±1.66 ^{ab}	6.46±1.44 ^{bc}
7	6.51±1.39 ^a	6.57±1.35 ^a	6.50±1.48 ^a	6.50±1.48 ^a	6.48±1.62 ^a	6.82±1.51 ^{ab}
8	6.56±1.65 ^a	6.60±1.50 ^a	6.54±1.69 ^a	6.67±1.70 ^a	6.73±1.76 ^a	7.12±1.50 ^a

Remark: Data are presented as mean±standard deviation. Different lowercase superscripts (a–d) within the same column indicate statistically significant differences ($p \leq 0.05$) determined by Duncan's New Multiple Range Test (DMRT) following one-way ANOVA.

profile, particularly in meeting the criteria for making significant nutritional claims (%Thai RDI), as demonstrated in Table 15. On the other hand, those not interested in purchasing cited reasons such as an unappealing taste (26.09%) and a preference for other energy gel brands. However, 90.91% of respondents indicated they would recommend the product, and 75.32% would consider buying it.

Some respondents (33.33%) remarked that the product's color was unappealing, but they still acknowledged its health benefits (35%). Dried dates were the most popular date-based product (40%), followed by candied dates and date oat milk (16.84%). The most attractive marketing strategy was holding product exhibitions with educational activities for customers.

Table 9 Regression equations for the influence of variable factors on sensory quality of date-based energy gel

Sensory attribute	Regression equation	Adjusted R ²
Appearance preference	$-4.57+2.48(\text{water})+0.15(\text{maltodextrin})+0.27(\text{syrup})$	0.8866
Aroma preference	$-3.94+2.50(\text{water})+0.14(\text{maltodextrin})+0.24(\text{syrup})$	0.8642
Sweetness preference	$-6.19+2.65(\text{water})+0.18(\text{maltodextrin})+0.30(\text{syrup})$	0.9539
Thickness preference	$-8.52+2.82(\text{water})+0.24(\text{maltodextrin})+0.31(\text{syrup})$	0.9251
Overall preference	$-6.53+2.70(\text{water})+0.18(\text{maltodextrin})+0.32(\text{syrup})$	0.9385

2.6 The study on the optimal production process for date-based energy gel

The sensory preference scores for appearance, aroma, sweetness, thickness, and overall liking were significantly influenced by variations in the water-to-maltodextrin ratio, maltodextrin content, and date syrup content. Regression analysis revealed a direct correlation between the water-to-maltodextrin ratio and maltodextrin content with increased preference scores across all evaluated attributes ($p \leq 0.05$). The details of this relationship are presented in Table 9 and Fig. 1.

Using Design Expert software, researchers analyzed the sensory data to find the optimal ranges for the water-to-maltodextrin ratio, maltodextrin content, and date syrup content (Table 10). The analysis, conducted using design expert software version 13, identified the key factors and targeted sensory attributes (Table 10 and Fig. 2). Table 10 summarizes the key factors and their respective ranges used to optimize the formulation of date-based energy gel, specifically the water-to-maltodextrin ratio, maltodextrin content, and date syrup content. The goal was to create a formula that would score as high as possible for appearance, aroma, sweetness, thickness, and overall liking. The analysis showed that the best formulation for a date-based energy gel was a water-to-maltodextrin ratio of 1.5:1, with 36% maltodextrin and 8% date syrup. This specific formula produced the most favorable sensory characteristics.

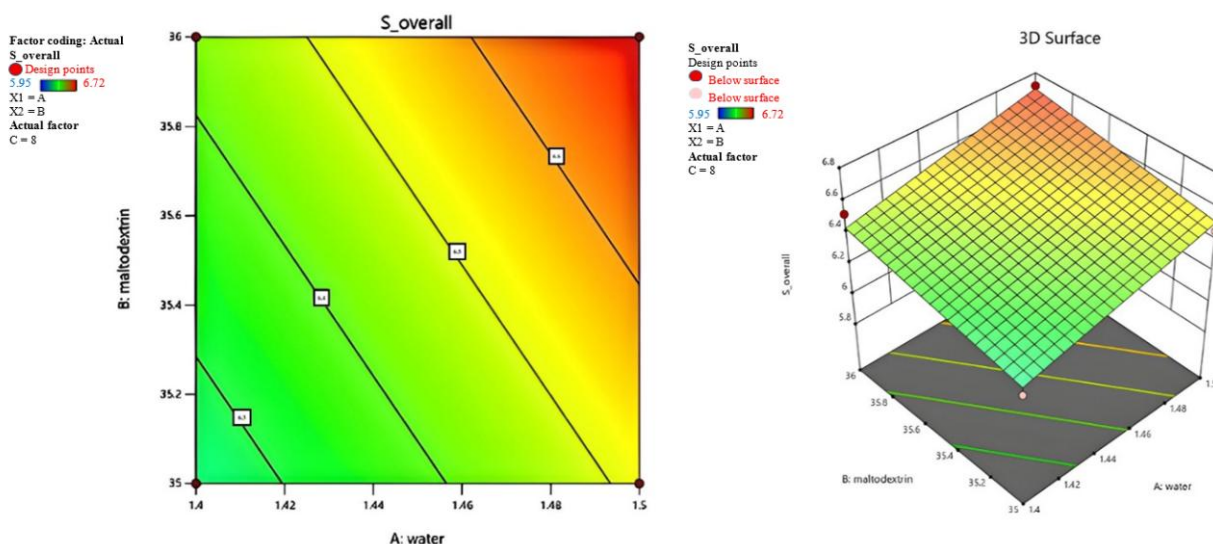


Fig. 1 Overall preference optimal proportions for the production process of date-based energy gel

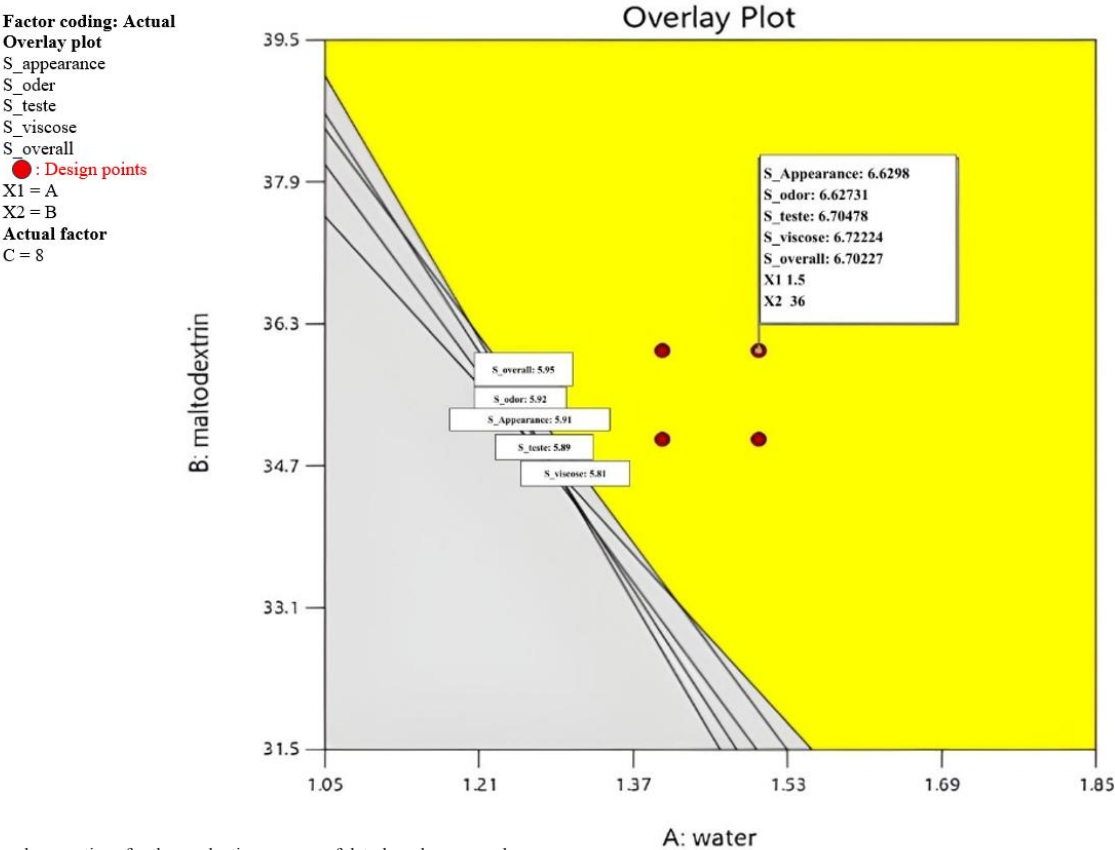


Fig. 2 Optimal proportions for the production process of date-based energy gel

Table 10 Range of factors and desired attributes to produce date-based energy gel

Factor	Defined range	Minimum value	Maximum value	Unit
Water-to-maltodextrin ratio	Within the studied range	1.4:1	1.5:1	Percent
Maltodextrin content	Within the studied range	35	36	Percent
Date syrup content	Within the studied	7	8	Percent
Quality attribute				
Appearance	Close to maximum	5.91	6.56	Score
Aroma	Close to maximum	5.92	6.57	Score
Sweetness	Close to maximum	5.89	6.67	Score
Thickness	Close to maximum	5.81	6.73	Score
Sensory: Overall	Close to maximum	5.95	7.12	Score

Samples with the highest overall preference scores in sensory quality testing, based on variations in the water-to-maltodextrin ratio, maltodextrin content, and date syrup content, were selected for further evaluation using the Just About Right (JAR) test. This assessment involved 100 athletes, as participants, with an appropriate criterion set at 70%. In optimal formulation, the aroma scored below the 70% threshold,

whereas appearance, sweetness, and thickness all exceeded this benchmark. The net effect analysis revealed a value greater than 20%, suggesting that the intensity of the date Flavor should be reduced. However, as the net effect for appearance, sweetness, and thickness remained below 20%, no modifications to these attributes were deemed necessary.

Based on the prototype's sensory evaluation, the researchers found that the date-based energy gel's aroma needed improvement. To address this, they modified

Table 11 Mean scores of consumer testing on just about right

Attributes	Mean percentage of consumer testing					Net effect
	Much too weak (1)	Little too weak (2)	JAR (Just about right) (3)	Little too strong (4)	Much too strong (5)	
Appearance	2.3	4.8	79.5	4.1	9.3	6.3
Date syrup odor	1.8	0.8	48.8	12.5	36.1	46.0
Sweetness	2.4	8.9	76.3	4.2	8.2	1.1
Thickness	1.7	11.5	70.1	8.5	8.2	3.5

the formula by adjusting the amounts of orange and strawberry flavoring, date syrup, water, and maltodextrin. The initial 4.0% flavoring powder was reduced to 1.0%. The date syrup content was adjusted to a range of 7.95–25%, water content was changed to a range of 49.25–51.75%, and maltodextrin was reduced to a range of 23.16–34.75%, as seen in Table 12.

Table 12 Commercial formulation of the optimal date-based energy gel prototype

Ingredient	Formula (%)		
	1	2	3
Water	52.25	54.75	49.5
Maltodextrin	34.75	34.75	23.16
Orange flavoring	1	1	1
Strawberry flavoring	1	1	1
Date syrup	10.45	7.95	24.79
Citric acid	0.20	0.20	0.20
Carrageenan	0.1	0.1	0.1
Sea salt	0.1	0.1	0.1
Potassium chloride	0.1	0.1	0.1
Sodium citrate	0.05	0.05	0.05
Total	100.0	100.0	100.0

After these adjustments, the new formulations were tested for quality attributes like total soluble solids (TSS), viscosity, calories, color, and pH. The results showed that all physical attributes of the updated energy gel were significantly different ($p \leq 0.05$). Sample 3 had the highest value compared to the other samples, with a TSS of 38.0°Brix. The TSS values of the energy gels ranged from 35.0–38.0°Brix, which indicated a range of sweetness (Baroyi et al., 2023). The pH values ranged from 3.93 to 4.38, with sample 1 having the highest pH at 4.38. Notably, all formulations maintained a pH below the critical threshold of 4.6, classifying them as acidified foods. This acidic environment is vital for safety, as it inhibits the growth of most pathogenic bacteria. While the a_w remains relatively high (0.96–0.98), the microbial stability is ensured through the synergistic effect of this low pH and the thermal pasteurization process.

The color values of sample 2 had the highest lightness (L^*) and yellowness (b^*) values, while sample 3 had the lowest, showing significant color differences between products due to the varying ingredient concentrations (Table 14), as shown in Fig. 3. Viscosity also varied, with sample 3 having the highest viscosity at 12,210 mPa·s and sample 2 having the lowest at 10,080 mPa·s. Regarding energy content, sample 2 provided 74 kcal/40 g, while sample 1 provided 65 kcal/40 g. Despite these modifications, the energy values remained below the target of 110 kcal/40 g. Therefore, the formula was further adjusted by increasing the maltodextrin

concentration to meet the energy density requirements before the final nutritional analysis (Table 14). This iterative process reflects a common challenge in food development of balancing sensory properties with specific nutritional targets (Martis et al., 2020).

Table 13 Summary of total soluble solid (TSS), viscosity, energy and pH levels in date-based energy gel products as per 40 g serving

Sample	TSS (°Brix)	Viscosity (mPa·s)	Energy (kcal)	pH
1	37.0±0.00 ^b	12,105±320 ^b	65±0.30 ^c	4.38±0.05 ^a
2	35.0±0.00 ^c	10,080±595 ^c	74±0.11 ^b	3.93±0.05 ^b
3	38.0±0.00 ^a	12,210±250 ^a	75±0.10 ^c	4.32±0.04 ^a

Remark: Data are presented as mean±standard deviation. Different letters within the same column indicate statistically significant differences ($p \leq 0.05$).

Table 14 Color measurements of date-based energy gels

Sample	L^* (Lightness)	a^* (Red-Green)	b^* (Yellow-Blue)
1	83.01±0.01 ^b	1.92±0.04 ^c	68.57±0.03 ^b
2	85.08±0.05 ^a	2.65±0.04 ^b	75.41±0.04 ^a
3	70.30±0.08 ^c	6.00±0.03 ^a	48.15±0.05 ^c

Remark: Data are presented as mean±standard deviation. Different letters within the same column indicate statistically significant differences ($p \leq 0.05$).



Fig. 3 Color of date-based energy gel product

3. Nutritional values of the date-based energy gel

Table 15 presents the final nutritional values of the date-based energy gel. The energy content of 110 kcal/40 g serving reflects the final optimized and adjusted formula, which was specifically modified after the sensory study to achieve the desired industry-standard energy density. This higher caloric value differentiates the final product from the preliminary formulas shown in Table 13.

Table 15 Nutritional value of the date-based energy gel

Nutrients	Per 100 g	Per serving each sachet (40 g)	% Thai RDI
Calories (kcal)	276	110	—
Total fat (g)	0	0	0
Saturated fat (g)	ND	0	0
Cholesterol (mg)	ND	0	0
Protein (Nx6.25) (g)	ND	0	—
Total carbohydrate, include DF (g)	69.1	28	9
Total sugars (g)	9.82	4	—
Sodium (mg)	67.1	25	1
Potassium (mg)	166	65	2
Ash (g)	0.48	0.19	—

Remark: ND = not detected.

4. Stability and microbiological quality of date palm energy gel products

This study investigated the stability of date palm energy gel products over 12 weeks. The microbial stability was ensured by the combination of low pH (3.39–3.51) and the thermal pasteurization. As shown in Table 16, all microbial parameters remained within the limits of notification No. 355/416 throughout the study, with counts below detection limits. This confirms that microbiological spoilage was successfully inhibited. Regarding physical qualities, the viscosity remained consistent (10,150–12,720 mPa·s), and while slight color changes ΔE were observed, they did not significantly impact consumer acceptance during the 12-week period. Based on these findings, the product maintained its physical, sensory, and microbiological qualities under the tested conditions. To help slow down color change, the product should be stored away from direct sunlight and heat.

Table 16 Microbiological qualities of the optimized date-based energy gel during storage

Microorganisms	Results	Limits (Notification No. 355/416)
Total plate count (TPC)	<10 CFU/g	<1 x 10 ⁴ CFU/g
Yeast and mold	<10 CFU/g	<100 CFU/g
Coliforms	<3 MPN/g	<3 MPN/g
<i>E. coli</i>	Negative	Negative
<i>Salmonella</i> spp.	Not detected/25g	Not detected/25 g
<i>S. aureus</i>	Not detected/0.1g	Not detected/0.1 g
<i>B. cereus</i>	<100 CFU/g	<100 CFU/g

Conclusion

This study successfully developed an optimized date-based energy gel prototype that is nutritionally robust and commercially viable. The final formulation provides a 110 kcal/40 g serving and serves as a significant source of Iron, Calcium, and Vitamins A, C, and E, meeting Thai RD standards for nutritional claims. The optimization process, driven by a Box-Behnken design, resulted in a product with high consumer acceptance (7.12/9.0) and superior antioxidant capacity. Product stability and safety were ensured by the synergistic effect of low pH (3.39–3.51) and thermal pasteurization, which effectively maintained physical, sensory, and microbiological integrity throughout a 12-week study in compliance with Ministry of Public Health standards. These findings position the date palm-based energy gel as a promising, health-conscious alternative to imported supplements, adding value to

local agriculture. Future development should focus on refining the aroma profile and expanding flavor varieties to enhance market appeal and meet the diverse needs of fitness enthusiasts.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used Gemini to enhance language clarity and improve grammar. The final content was thoroughly reviewed and edited by the authors, who take full responsibility for the accuracy and integrity of the publication.

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