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Research article

Effect of extracted celery dietary fiber on low-calorie salad dressing with probiotics

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Abstract

Importance of the work: Several celery residues generated after processing have mainly been utilized as a source of dietary fiber and could also be used as salad dressing supplements.

Objectives: To investigate dietary fiber extraction from celery using water, alkaline (NaOH), enzymes and ultrasonication and to study the extracted dietary fibers for their quality as a component in salad dressing.

Materials & Methods: Different methods were used to extract the dietary fiber and analyze its properties. The effects were investigated of extracted dietary fiber on the physicochemical, microbiological and sensory evaluation of low-fat salad dressing fortified with probiotic.

Results: Ultrasonic extraction produced the lowest yield (3.00%) and the highest soluble fiber content (34.90%) and L* value were obtained ($p \leq 0.05$). The dietary fibers extracted using the different methods were added to low-fat salad dressings and compared to dressing without added dietary fiber. The low-fat salad dressings with added extracted dietary fiber had increased viscosity ($p \leq 0.05$). The fat content and total energy were lower than the control, while the low-fat salad dressing fortified with ultrasonic dietary fibers (LF-U) had the highest sensory scores ($p \leq 0.05$) in terms of texture, appearance and overall liking. The probiotic LF-U contained viable probiotic cells at more than 7 log CFU/g and pathogen detection followed the industry standard during storage for 28 d.

Main finding: The ultrasonic dietary fibers had the highest soluble dietary fiber content that affected the salad dressing qualities and supported viable probiotic cells at more than 7 log CFU/g.

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Introduction

Agro-food industries have increased the bulky volume of byproducts, whose revaluation is essential for the circular economy (Vaz et al., 2022). For example, about 20% of celery residues are generated after processing, from which dietary fiber (DF) can be recovered (Minarovičová et al., 2018). Furthermore, the waste residues amounting to one-third of the entire food manufactured are giving rise to environmental concerns regarding their disposal. However, these seemingly "worthless: parts of the plant, are abundant in dietary fiber, as well as other compounds such as minerals, vitamins, phenolic compounds and bioactive compounds that could be developed (Vaz et al., 2022) to increase the value of fruits and vegetables left over from the food industry.

Celery, (family *Apiaceae*) has long been acknowledged for its special aroma and flavor, as well as its non-digestible carbohydrates, such as dietary fiber and oligosaccharides, which are presently considered prebiotics because they reach the colon undigested, where they are fermented mainly by bifidobacteria and lactic acid bacteria, thus producing a conclusive health effect that is gently and incompletely absorbed from the small intestine, while it can also be considered a potential prebiotic ingredient of functional foods, such as mannitol (Rupérez and Toledano, 2003). Comparably, celery is widely conceded as a functional food that encourages the prevention, management and regulation of chronic diseases by many consumers (Arsenov et al., 2021; Lau et al., 2021). Investigation has revealed that celery water extract can destroy viruses and inhibit their replication (Gaballah et al., 2020), showing therapeutic actions that are strongly linked to plant antioxidant status (Kharchenko et al., 2020).

DF comprises a combination of compounds containing carbohydrate polymers and non-carbohydrate part that are enhanced in whole grains, legumes, fruits and vegetables (Sun et al., 2018). In relation to water solubility, total dietary fiber (TDF) can be categorized into two groups, namely soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) (Vasanthan et al., 2002). It has been proposed that consumption of substantial amounts of dietary fiber significantly decreases the chance of developing coronary heart diseases, strokes, hypertension, diabetes, obesity and gastrointestinal diseases (Elleuch et al, 2011; Ding et al., 2014). Consequently, multiple biological (enzymatic), chemical (acidic and alkaline treatments) and physical (microwave, ultrasonic treatments) approaches have been applied to modify food-derived DFs in terms of their microstructure and composition, to improve their physiological and functional properties and apply them in the food industry (Jia et al., 2020).

Salad dressing is a semi-solid emulsion, typically consisting of oil and vinegar with herbs or other flavorings (Rathnayake et al., 2019). With the development of science and technology, consumers are becoming more aware of health and the potential to suffer from several chronic diseases. Mostly, cream-based salad dressing improves the taste of salads with better nutrition that is preferred by consumers because of the diverse flavors and tastes available from different dressing recipes; thus, this is one of the major reasons driving this market (Mirzanajafi et al., 2019).

Probiotics are live microorganisms that can bring health benefits when added to products, where the product shelf life is based on the count of viable and active cells, as these determine product efficacy (Terpou et al., 2019). The minimum necessary concentration of probiotic bacteria to produce a beneficial result has been generally accepted as 1×10^6 CFU/g/mL of product at the time the product is consumed (Mohammadi et al., 2011). Consequently, probiotic salad dressing could be considered a potential probiotic food which is beneficial to consumers (Mantzouridou et al., 2013, Samappito et al., 2021).

Generally, celery residue after minimal processing is wasted and can be a source of environmental pollution if disposed of incorrectly. Hence, the current study investigated the dietary fiber obtained from celery byproducts using four extraction methods (water, alkaline (NaOH), enzymes and ultrasonication). Specifically, this study focused on the effect of dietary fiber on the quality of low-fat dressings, by supplementing probiotics into products to increase the choice of functional foods.

Materials and Methods

Materials

The celery residue (stalks and leaves) was collected as a byproduct from a local supplier (Talad Thai; Pathum Thani, Thailand). Celery residue samples were washed, cut into 1–2 cm pieces and dried overnight in an oven (50 °C) until the moisture content was lower than 12% (weight per weight). After that, the dried samples were passed through a grinder and sieved (60 mesh) to obtain celery powder, which was stored in a desiccator at room temperature. Alpha amylase and protease (food grade commercial enzyme) were purchased from Reach Biotechnology Co., Ltd. (Thailand). All chemicals and reagents (food grade and analytical grade) were purchased from CT Laboratory Co., Ltd. (Thailand).

Extraction process

The four different processes used to extract the dietary fiber from celery were: 1) water, 2) NaOH, 3) enzyme and 4) ultrasonic extraction were based on Moczkowska et al. (2019) with some modifications to extract dietary fiber (DF) powder.

Water extraction

Celery powder was added to water (ratio 1:10 (weight per volume; w/v)) for 2 h at 30 °C (room temperature) and mixed using a magnetic stirrer. Centrifugation (4,000×*g*) of the resultant solution was carried out for 15 min using a centrifuge. After centrifugation and supernatant collection, 95% ethanol (4-fold volume) was added and incubated for 12 h at 30 °C to collect the extracts. Then, the extracts were centrifuged at 4,000×*g* for 15 min, followed by oven drying at 50 °C for 1 h to obtain the water-extracted dietary fiber (W-DF). The extraction yield of the DF was calculated using Equation 1:

$$Y (\%) = C / W \times 100\% \tag{1}$$

where C is the W-DF weight and W is the celery powder weight, both measured in grams.

Alkali extraction

DF was extracted utilizing 5% (w/v) NaOH solution. The NaOH solution (100 mL) was added to celery powder (10.0 g) and the resultant solution was placed in a water bath at 50 °C for 2 h, followed by centrifugation (4,000×*g*) for 15 min using a centrifuge. Later, the supernatants were collected, 95% ethanol was added and the solution was incubated for 12 h. Absolute ethanol was used to wash the resulting residues, which were oven-dried at 50 °C for 1 h to produce the alkaline-extracted dietary fiber (AL-DF). The extraction yield of the AL-DF was calculated using Equation 1.

Commercial enzymatic extraction

Celery powder (10 g) was placed in a beaker with 100 mL of distilled water that had been adjusted to pH 5.5 using 0.1 mol HCl. Then, 1% g/g of thermostable α-amylase (> 40,000 international units per milliliter; IU/mL)) was added to degrade the starch and soluble oligosaccharide. Afterward, the solution was incubated at 95 °C for 30 min and allowed to cool before the pH was adjusted to 6.0 using 0.1 M NaOH, followed by incubation with protease (>80,000 IU/ml) at 60 °C for 30 min. Later, the samples were subjected to centrifugation (4,000×*g*) for 15 min and the supernatant was accumulated. Then, absolute ethanol was added and the solution was incubated for 12 h to wash the resulting extracts, which were dried at 50°C for 1 h to obtain the commercial enzyme-extracted dietary fiber (CEN-DF). The extraction yield of the CEN-DF was calculated using Equation 1.

Ultrasonication extraction

Celery powder (10 g) was added to a beaker with 100 mL of distilled water. Then, the resulting mixture was placed in an ultrasonic water bath (Crest P1200H-45; 45 kHz; Marshall Scientific; USA) at 30 °C for 10 min, followed by centrifugation at 4,000×*g* for 15 min. Later, the supernatants were collected and 95% ethanol was added and the mixture was incubated for 12 h. Absolute ethanol was used to wash the extracts, which were dried at 50 °C for 1 h to obtain the ultrasonication-extracted dietary fiber (U-DF). The extraction yield of the U-DF was calculated using Equation 1.

All extracted samples were packed in aluminum foil bags and kept in a desiccator until being analyzed for insoluble dietary fiber content (IDF), soluble dietary fiber content (SDF) and total dietary fiber content (TDF). In addition, color reported as L* a* and b*values was measured using a color meter (Hunter Lab; Mini Scan XP Plus; USA). Water activity (a_w) was determined using an AquaLab 3TE water activity meter (Decagon Devices Inc.; USA).

Determination of dietary fiber content

The dietary fiber (TDF, SDF and IDF) contents were examined based on the Association of Official Agricultural Chemists 991.43 enzymatic-gravimetric method (Association of Official Agricultural Chemists, 2005). Briefly, powder samples were first gelatinized with heat-stable a-amylase (95 °C for 35 min). Then, the samples were digested with protease and amyloglucosidase to remove protein and starch. Thereafter, the IDF was filtered and washed with 60 °C distilled water integrated with 4-fold volumes of 95% ethanol to precipitate the SDF. The oven-dried residues at 105 °C were weighed. The TDF was calculated as the sum of the IDF and SDF.

Physicochemical properties of dietary fiber

The water holding capacity (WHC) and oil holding capacity (OHC) were assessed based on Sun et al. (2018). Distilled water (15 mL) was added to 0.25 g of the sample in a 50 mL centrifuge tube. The sample was stirred and left at room temperature for 1 h. After centrifugation at 3,000×*g* for 20 min, the supernatant was discarded, the residue was weighed and the WRC was calculated as grams of water per gram of dry sample. The duplicate protocol as above was followed using commercial soybean oil instead of water. The OHC was expressed as grams soybean oil retained per gram of dry sample.

Effect of powdered fiber from celery on quality of low-energy dressing

Preparation of salad dressing. Low energy dressings were prepared by taking 0.33% of DF extracted (LF-W, -AL, -CEN, -U) instead of using modified starch (without DF; LF-C), 0.42% of guar gum, 0.51% of Konjac flour, 0.53% of salt, 0.53% of mustard, 0.87% of lecithin, 3.20% of lime juice, 6.39% of whey powder, 8.50% of vinegar, 9.11% of sugar, 16.70% of soybean oil and 52.91% of water. The ingredients were combined and blended into a completely homogeneous mix before pasteurizing at 70 °C for 30 min and then adding 5% (v/w) probiotic cell suspension.

Probiotic cell preparation. A cell pellet of *Pediococcus pentosaceus* ARG-MG12 (Tanganurat et al., 2015) was cultured on De Man, Rogosa and Sharpe (MRS) agar (Merck; Germany), incubated at 37 °C for 48 h. Subsequently, a single colony was inoculated in 5 mL of MRS broth (Merck; Germany), incubated at 37 °C for 48 h; then, the cell suspension was centrifuged at 5,000×*g* for 5 min and the cells were washed twice with sterilized saline solution (0.9% NaCl). A cell suspension (9 log CFU/ml) was used and added with 5 % (v/w) of the dressing which was analyzed for viscosity (Brookfield Viscometer; USA), proximate analysis, pH value (pH meter) and color measurement (color meter; Chroma; CR200; Japan).

Proximate analysis. The moisture, protein, fat, ash and fiber contents of each byproduct were determined using the methods in Association of Official Agricultural Chemists (2005). The moisture content was determined by heating 0.2 g of each sample in an oven (Sibata; SPF-600; Japan) at 105 °C until a constant weight was achieved. The total protein content was estimated using a Kjeldahl distillery (Buchi; K-350; UK). Fat was obtained in a Soxhlet extractor (Buchi; E-500; UK) using hexane as the solvent extractor solution. Ash was determined gravimetrically using a muffle furnace device (Carbolite CWF 1100; Carbolite Gero Ltd.; UK) at 550 °C for 24 h. Digestible carbohydrates were calculated as the difference between 100 and the total values of moisture, protein, fat and ash.

Sensory evaluation. The salad dressing was investigated for the effect of probiotic supplementation based on sensory quality assessment in terms of color, smell, taste, texture, appearance and overall acceptance by 30 untrained panelists using a 9-point hedonic scale (from 1 = most disliked through to 9 = most liked), according to Permana et al. (2020). A randomized complete block design was used to assess statistical differences based on significance at $p \leq 0.05$.

Microbiological analysis. Salad dressing samples were stored at 8–10°C and examined on days 0, 7, 14, 21 and 28 for viable counts of lactic acid bacteria, total bacterial count, coliforms, and yeasts and molds. Each sample (25 g) was weighed and combined with 225 mL of 0.1% buffered peptone water (Difco; USA). Samples were homogenized in a stomacher, 10-fold serial dilutions were made and 0.1 mL of each dilution was poured onto MRS agar (Merck, Germany) for lactic acid bacteria count analyses and on plate count agar (Hi-media, India) for total bacterial count analyses. Most plates were incubated at 35 °C for 24–48 h. Counts were expressed in log colony forming units per gram (CFU/g). The most probable number (MPN) method was used for coliforms (Sutton, 2010).

Statistical data analysis

All experimental results were undertaken in triplicates ($n = 3$). One-way analysis of variance was used to determine significance of treatment effects in the SPSS statistical package (SPSS Inc.; USA). The differences between the means were evaluated using Duncan's multiple-range tests with 95 % confidence limits ($p < 0.05$).

Results and Discussion

Physicochemical properties of celery fiber extraction process

The celery yield and color values resulting from the different extraction processes are shown in Table 1.

Table 1 shows that CEN produced the significantly highest percentage of dietary fiber yield (6.25%), followed by not significantly different yields for W (5.55%) and AL (4.13%) and U (3.00%). The a_w values± SD for the celery extraction methods were in the range 0.28–0.36 (Table 1) and the moisture contents were significantly different and in the range 2.25–3.29% (W, 2.25 ± 0.31; AL, 3.29 ± 0.65; CEN, 2.63 ± 0.64; U, 2.80 ± 0.33). The results of the water activity and color analysis based on brightness (L*), redness (a*), and yellowness (b*) values of the celery fibers were significantly different, as shown in Table 1. Dietary fibers extracted from celery

Table 1 Yield and physicochemical characteristics of celery fiber extracted using various processes

Extraction method	a_w	Yield (%)	Color value		
			L*	a*	b*
W	0.35±0.00^{a}	5.55±0.01^{b}	80.27±0.02^{c}	0.80±0.01^{b}	14.39±0.01^{b}
AL	0.36±0.03^{a}	4.13±0.15^{bc}	58.23±0.29^{d}	1.62±0.09^{a}	27.15±0.37^{a}
CEN	0.28±0.00^{b}	6.25±0.24^{a}	81.55±0.19^{b}	0.16±0.02^{d}	13.65±0.02^{c}
U	0.25±0.01^{b}	3.00±0.07^{c}	88.06±0.17^{a}	0.73±0.04^{c}	11.25±0.12^{d}

a_w = water activity; L* = lightness; a* = redness; b* = yellowness; W = water; AL = alkali; CEN = commercial enzyme; U = ultrasonication
Mean ± SD (n = 3) in the same column superscripted by different lowercase letters are significantly ($p < 0.05$) different.

based on ultrasonics (L* = 88.06) had the highest lightness value, whereas b* was highest in the NaOH-extracted samples (27.15) and lowest in the ultrasonication-extracted samples (11.25), as shown in Fig. 1. Other researchers reported similar observations and found that DF extracted after ultrasonic treatment had a decreased b* value, indicating the higher L* value could have been caused by a lower content of impurities present in samples (Kurek et al., 2018).

The celery dietary fiber contained over 30% TDF. The water and ultrasonic extraction methods had the highest contents in the range 39.14–41.28 g/100 g dry weight (DW) of TDF. There was no significant difference in the TDF values between alkaline extraction (35.08 g/100 g DW) and enzymatic extraction (35.49 g/100 g DW) (Fig. 2). However, the SDF content in celery extracted using was significantly the highest (34.90%). furthermore, water extraction of the celery was characterized by 11.63% IDF. Enzymatic and ultrasonic extraction produced the lowest amounts of IDF (4.24–5.20%). Ashoush et al. (2017) determined that the crude fiber content in raw celery leaves was 19.85%. In celery roots, Minarovičová et al. (2018) reported 62.19 g/100 g DW of TDF, 48.08 g/100 g DW of IDF and 14.11 g/100 g DW of SDF. Differences in the classification of DF in the parts of the plant could explain these variations (Vaz et al., 2022). The current results indicated that the soluble amount of DF from celery was in the range 29.65–34.90%, which was more than insoluble fibers in the range 4.24–11.63%. The DF combined well with water, so it was likely to be leached along with water for easy extraction. Insoluble dietary fibers are usually complex carbohydrates such as cellulose, hemicellulose, and lignin (Moczkowska, et al., 2019). Therefore, there was a loss during extraction with water. This could have been exacerbated due to the conditions used to extract celery fibers in the current study, where a low temperature (30 °C) was used to extract celery fiber with water for 2 h and with ultrasonic extraction for 10 min. As shown in Fig. 2, the significantly highest SDF was using ultrasonic extraction. The efficiency of the ultrasound extraction procedures was greater than for the water, alkaline and acid extraction procedures. To achieve similar or higher yields of dietary fibers fractions, the extraction temperature

Fig. 1 Appearance of dietary fiber powder obtained from celery using various extraction methods: (A) water; (B) sodium hydroxide; (C) commercial enzymes; (D) ultrasonication

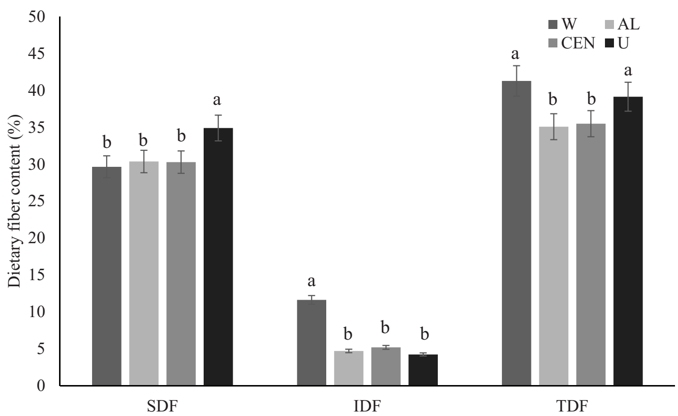

Fig. 2 Soluble dietary fiber (SDF), insoluble dietary fiber (IDF) and total dietary fiber (TDF) contents from celery, based on four extraction processes, where bars represent mean ± SD (n = 3), different lowercase letters above histohrams denote significant ($p < 0.05$) difference within each type of content obtained from different extraction methods: W = water, AL =alkali, CEN = commercial enzyme and U = ultrasonication.

could be reduced to 30 °C, the extraction time could be shortened to 10 min of ultrasound extraction, and ultrasound could be used increase the extraction rate of the SDF (Sun et al., 2018), where such increases could be due to strong forces, such as the shear force generated by the mechanical shock during the ultrasonic treatment, disrupting the dietary fiber structure (Wei et al., 2021). These changes indicated that the hydrophilic groups of SDF increased the exposed lipophilic groups, which eventually led to enhancement of the WHC and OHC (Niu et al., 2020).

WHC and OHC are important indices to evaluate the quality and physiological function of DF. The effects ofthe different extraction methods in the current study on the hydration properties of celery DF are presented in Fig. 3. DF extracted using ultrasonication had the highest WHC (2.74 g/g) that was probably influenced by the hydrophilic sites available in SDF. In contrast, OHC is dependent on the overall electrical charge density, surface properties and hydrophobicity (Wang et al., 2021).

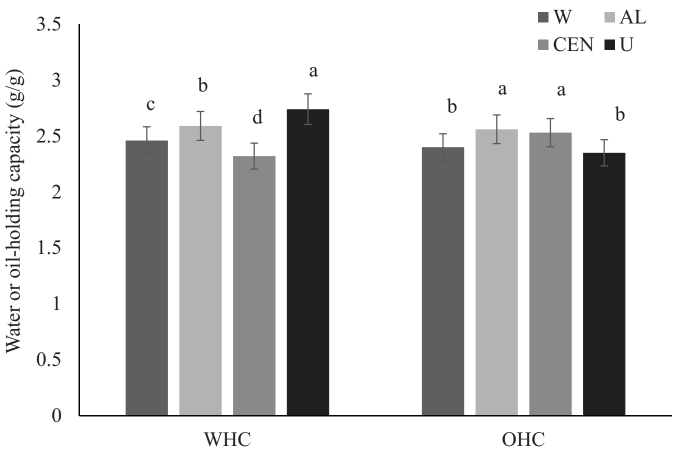

Fig. 3 Water holding capacity (WHC) and oil-holding capacity (OHC) from celery extracted by four extraction processes, where bars represent mean ± SD (n = 3); different lowercase letters above bars denote significant (p < 0.05) difference within each parameter; extraction methods are W = water, AL =alkali, CEN = commercial enzyme and U = ultrasonication.

As mentioned above, the extraction of fiber from waste materials with ultrasound can increase the SDF output and reduce the duration and energy of extraction. In addition fiber quality can be improved in terms of water-holding and oil-holding properties (Martinez-Solano et al., 2020). These advantages support the capability of ultrasound extraction processes applied for the isolation of byproduct dietary fiber from celery.

Quality analysis of low-fat salad dressing mixed with dietary fiber powder from celery supplemented with probiotics

Table 2 shows the physicochemical properties of salad dressing samples supplemented with DF and probiotic. Their pH values were in the range 3.90–4.18 and the values were significantly different for each type of DF addition, with LF-U having the lowest pH value and highest acidity (0.10 % acetic acid). The (TSS) values were in the range 19–21 °Brix. Salad dressings are characterized by low pH, reduced water activity and storage under refrigeration, which contribute to the microbial safety of these products (Ifesan et al., 2009). The pH values of probiotic LF-C, LF-CEN and LF-U salad dressings were determined according to the standard specifications of Thai Industrial Standard no 1402−2540: mayonnaise and salad cream (Thai Industrial Standard, 1997) with pH < 4.1 being one of the qualifications needed (except for LF-W and LF-AL).

The salad dressing viscosity values with DF addition based on the different DF extraction methods were significantly different, with the greatest effect for the. The DF supplemented in salad dressing from ultrasonication had the greatest viscosity (1,402 ± 3.99 cP), as shown in Table 2. This showed that DF affected the salad dressing gel-producing capability. The addition of celery DF could effectively increase the viscosity to the same extent as modified starch in LF-C. Furthermore, the materials were able to absorb water and swell to many times their original size, which resulted in increased viscosity (Ibarhim and Khalifa,

Table 2 Characteristics of probiotic salad dressing supplemented with celery dietary fiber from various extraction methods

Salad dressing	TSS (°Brix)	pH	Acidity (%)	Viscosity (cP)
LF-C	20.00±0.03^{ab}	4.06±0.00^{b}	0.07±0.00^{b}	1,290±3.02^{b}
LF-W	19.00±0.12^{b}	4.13±0.01^{a}	0.08±0.01^{b}	1,110±4.02^{c}
LF-AL	20.00±1.27^{ab}	4.18±0.01^{a}	0.06±0.01^{b}	1,180±2.53^{c}
LF-CEN	19.00±0.36^{b}	4.09±0.00^{b}	0.07±0.00^{b}	1,130±1.58^{c}
LF-U	21.00±0.09^{a}	3.90±0.01^{c}	0.10±0.01^{a}	1,402±3.99^{a}

LF-C = low-fat salad dressing with no dietary fiber; W = water; AL = alkali; CEN = commercial enzyme; U = ultrasonication.
Mean ± SD (n = 3) in each column superscripted by different lowercase letters are significantly (p < 0.05) different.

2015). The different DFs from the various extraction methods resulted in characteristics of the salad dressing related to WHC. The highest WHC was produced using the ultrasonic method, perhaps because the celery DF functional properties could bind water optimally, thus increasing the salad dressing viscosity and also improving the texture. Viscosity is related to dietary fiber, particularly soluble dietary fibers (Dikeman and Fahey, 2006).

The significantly highest L* color value of the probiotic salad dressing made with different extraction methods for DF from celery was in LF-U (85.98). The differences in color values could be related to the DF powder color that was used to produce the salad dressing (data not shown).

The nutritional value analysis of the probiotic dressings with DF from the various procedures showed that LF-C and LF-W contained significantly higher fat levels, while LF-CEN had the highest total carbohydrate. Carbohydrates in foods include monosaccharides, disaccharides, higher oligosaccharides and polysaccharides (Vaz et al., 2022). The resulting LF-CEN was rich in carbohydrates, based on the analysis of the celery residues by amylase activity. The moisture, protein and ash contents were not significantly different among the other treatments (Table 3).

Table 4 Total energy and energy from fat of probiotic salad dressing supplemented by celery dietary fiber

Salad dressing	Total energy (Kcal/100g)	Energy from fat (Kcal/100g)
LF-C	220.89±0.22[a]	154.17±0.08[a]
LF-W	221.11±0.14[a]	153.63±0.11[a]
LF-AL	217.37±0.06[b]	149.13±0.24[b]
LF-CEN	209.71±0.13[c]	137.43±0.35[c]
LF-U	217.93±0.27[b]	149.13±0.15[b]

C = cream salad dressing; LF-C = low-fat salad dressing with no dietary fiber, W = water; AL = alkali; CEN = commercial enzyme; U = ultrasonication

Mean ± SD (n = 3) in each column superscripted by different lowercase letters are significantly ($p < 0.05$) different.

The total energy and energy from fat in the probiotic LF-CEN exhibited the lowest ($p \leq 0.05$) compare with others (Table 4) according as the lowest fat content.

Sensory acceptance analysis using the 9-point hedonic scale method was used to assess the preferences in terms of color, odor, flavor, texture, appearance and overall liking of each dressing product, as shown in Fig. 4. The mean (± SD) texture, appearance and overall liking scores of the probiotic LF-U salad dressing were significantly the highest (7.23±0.09, 7.20±0.07 and 7.18±0.10, respectively) compared to the other LFs, due to the LF-U having the highest viscosity. Consequently, the LF-U was well accepted by the panelists, indicating that the sensory attributes of probiotic salad dressings containing dietary fiber from celery were considered suitable.

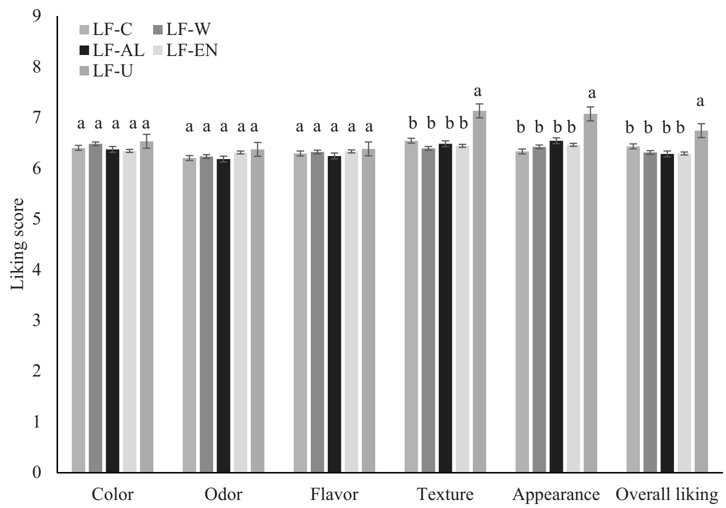

Fig. 4 Sensory analysis results of fiber supplement dressing products from celery, where bars represent mean ± SD (n = 30); different lowercase letters above bars denote significant ($p < 0.05$) difference within each sensory category; LF-C = low-fat salad dressing with no dietary fiber, W = water, AL = alkali, CEN = commercial enzyme and U = ultrasonication

Table 3 Proximate analysis of probiotic salad dressing supplemented with celery dietary fiber

Salad dressing	Moisture (%)[ns]	Protein (%)[ns]	Fat (%)	Ash (%)[ns]	Total carbohydrate (%)
LF-C	65.07±0.02	2.35±0.13	17.13±0.25[a]	1.12±0.04	14.33±0.11[b]
LF-W	64.89±0.04	2.19±0.14	17.07±0.13[a]	1.17±0.15	14.68±0.02[b]
LF-AL	65.22±0.23	2.17±0.07	16.57±0.20[b]	1.15±0.12	14.89±0.03[b]
LF-CEN	65.53±0.16	2.06±0.13	15.27±0.16[c]	1.13±0.07	16.01±0.02[a]
LF-U	65.11±0.18	2.09±0.22	16.57±0.04[b]	1.12±0.05	15.11±0.12[b]

LF-C = low-fat salad dressing with no dietary fiber; W = water; AL = alkali; CEN = commercial enzyme; U = ultrasonication

Mean ± SD (n = 3) in each column superscripted by different lowercase letters are significantly ($p < 0.05$) different.

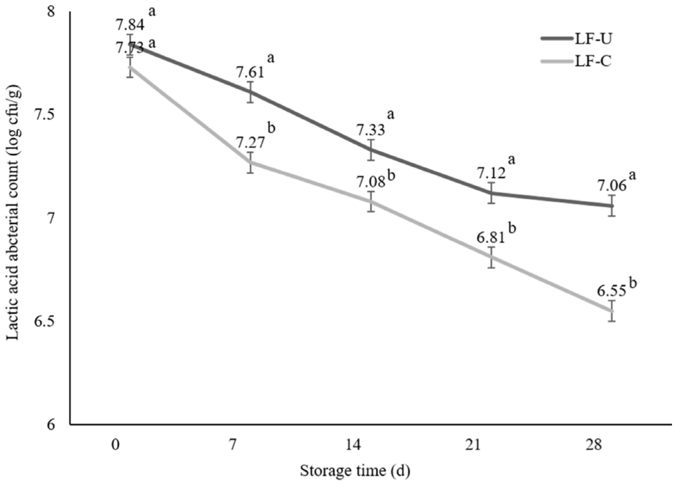

Fig. 5 Viability of lactic acid bacteria in low-fat salad dressing with ultrasonication DF during 28 d storage; values represent mean at each time point and error bars represent SD (n = 3); different lowercase letters represent significant ($p < 0.05$) difference between means at the same time point; LF-C = low-fat salad dressing with no dietary fiber and U = ultrasonication

The results of the microbiological analysis based on the *P. pentosaceus* count in LF dressing product supplemented with DF-U and stored at refrigerator temperature (4–8 °C) for 28 d had probiotic survival of more than 7 log CFU/g, as shown in Fig. 5. The results of the pathogens were consistent with the acceptable levels according to the Thai Industrial Standard no 1402−2540: mayonnaise and salad cream (Thai Industrial Standard, 1997) for up to 28 d of storage: coliform (< 3 MPN/g), total bacteria count (< 1,000 CFU/g), and yeast and mold (< 10 CFU/g).

The survival rates of lactic acid bacteria in low-fat salad dressing supplemented with celery dietary fiber extract using ultrasonication and the control are shown in Fig. 5, with the number of probiotic counts decreasing during storage (28 d). LF-U levels were approximately less than 1 log loss in the total number of probiotic cells, although LF-C contained a lower amount of cell loss (> 1 log CFU/g) over 28 d. These results indicated that extracting DF from celery helped to support the growth of bacteria during storage and the DF could be considered as a potential probiotic product. Samappito et al. (2021) reported that viable lactic acid bacteria cells in purple waxy corn yogurt and probiotic salad dressing were maintained at 8.45−8.65 log CFU/g, which supported the growth of bacteria during the fermentation process. In general, the total therapeutic minimum level of lactic acid bacteria in probiotic food is 6 log CFU/g of viable cells (Terpou et al., 2019).

In summary, ultrasonic fiber extraction from celery resulted in 34.90% SDF, which was significantly higher than for the other extraction methods. Furthermore, ultrasonic extraction produced the best lightness (L*) values for both the DF and probiotic salad dressing. A higher SDF values resulted in increased viscosity in the low-fat dressing. Furthermore, the nutritional value based on the lowest fat content, highest carbohydrate content and lowest energy value was significantly the best for LF-CEN, followed by LF-U. In addition, probiotic LF-U received the best sensory preference ratings in terms of texture, appearance and overall liking. Attempts are being made to extend the viable cell counts in probiotic salad dressing, while retaining the product's therapeutic benefits throughout its shelf life. Supplementing salad dressing with DF and probiotic bacteria had little effect on the compositional characteristics. Consequently, probiotic salad dressing with celery DF could be considered as a potential functional food. Further research should be carried out regarding increasing the yield of celery extracts for more food applications, investigating the prebiotic properties of DF and studying the effect of DF on the survival of probiotics during storage.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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