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The Qualities of Reconstructed Liquid Egg White Utilizing Plant-based Proteins

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Abstract

This study aimed to evaluate the properties of reconstructed liquid egg white formulated with plant proteins isolated from various sources (soy, pea, rice, and mung bean) and supplemented with carrageenan at concentrations ranging from 0% to 5%. The reconstructed products were prepared by mixing all ingredients, molding, and steaming to achieve the desired structure. Key quality attributes, including appearance, pH, color, water activity (a_w), texture, suitability for dysphagia diets, and sensory characteristics, were analyzed. The reconstructed liquid egg white with plant proteins exhibited an acceptable appearance and texture, resembling meat analogues. The addition of carrageenan significantly influenced the textural properties, with 3% carrageenan yielding the highest values for hardness, springiness, gumminess, and chewiness—characteristics desirable for the final product. The fork pressure test confirmed that the products met the criteria for dysphagia diets. However, sensory evaluation revealed relatively low acceptance scores across most attributes, with maximum scores below 7 ("like moderately"). Despite this, the products contained a high protein content, ranging from 19% to 22% on a wet basis. This study demonstrates a straightforward approach to formulating texturized foods using egg white and plant proteins, both high-quality protein sources, offering potential applications in specialized diets and protein-enriched food products.

Introduction

High-protein diets remain prevalent for weight reduction, type 2 diabetes management, and among athletes and physically active individuals (Antonio, 2019; Gang-Jee et al., 2020). The World Health Organization (WHO) indicated that the estimated average protein consumption requirement is 0.6 g/kg of ideal body weight daily, sufficient to prevent negative nitrogen balance and fulfill half of a population's needs. The advised daily protein intake is 0.83 g/kg, designed to satisfy the needs of 97%–98% of the population; two standard deviations above the estimated average requirement (WHO, 2007). A high-protein diet lacks a universally accepted definition, exhibiting a broad spectrum of protein consumption; however, most definitions establish a

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threshold between 1.2 and 2.0 g/kg per day (Gang-Jee et al., 2020). Prominent weight-loss regimens, including Ketogenic, Atkins, Paleo, and Mediterranean, advocate for increased protein intake while limiting carbohydrate consumption (Kusmy et al., 2024). As a result, numerous high-protein diets are available on the market in various forms, including beverages, powders, protein bars, and snacks. In Thailand, SBCS (2023) reported a significant expansion in the protein market in Thailand, with its value increasing from 2,898.3 million THB in 2019 to 3,323.8 million THB in 2021. As global demand for protein-rich diets continues to rise, there is growing interest in identifying alternative protein sources to meet this need. Traditionally, protein has been obtained primarily from fresh meats, fish, eggs, beans, and nuts. However, recent trends indicate a shift away from whole foods toward processed protein-based products (Lee et al., 2024).

Dairy and animal protein sources constitute the primary components of high-protein foods. Consumers are increasingly adopting plant-based diets due to environmental and health considerations (Boukid, 2021; Singh et al., 2021). Globally, the growth of plant-based protein market is projected to increase from $4.6 billion in 2018 to $85 billion in 2030 and, as a milestone by year 2026, reach $30.9 billion. This new market appears to be well positioned for further expansion and innovation (Sha & Xiong, 2020).

A variety of plant proteins are commercially accessible for selection. Plant proteins can be extracted from grains, legumes, oilseeds, nuts, tubers, and other sources (Nikbakht Nasrabadi et al., 2021). From a technological standpoint, plant proteins exhibit worse functional qualities compared to animal proteins, including low solubility, inadequate emulsifying and foaming capacities, and suboptimal gelling and extrusion characteristics (Gomes & Sobral, 2021; Tomczyńska-Mleko et al., 2023). Natural disparities between muscle and plant materials render it challenging to replicate the intricate and nuanced characteristics of animal meat products using plant proteins. Creating a highly ordered fine texture and water-binding ability in plant-based alternatives to replicate the mouthfeel of meat presents a significant challenge. Traditional and new structuring processes, such as thermomechanical extrusion and shear, have achieved a degree of success. However, the aggregates formed by highly denatured plant proteins do not microscopically resemble the three-dimensional anisotropic structure of a muscle fiber or a fiber bundle. The texture of muscle fibers and their capillarity for water immobilization are the most desirable structural attributes of meat. To compensate for these differences, various thickening, water-binding, and texture-enhancing agents are added in plant-based alternative products. Nevertheless, dryness (low juiciness) of cooked products remains a commonly observed drawback (Sha & Xiong, 2020).

In addition, plant proteins possess comparatively low levels of essential amino acids in relation to animal-based proteins (Gorissen et al., 2018). Blends of plant and animal proteins have been examined to tackle food transition issues and to investigate synergistic effects regarding consumer acceptance, nutrition, digestibility, and techno-functional attributes of food systems (Guyomarc'h et al., 2021; Kuang et al., 2023). Egg white is a sought-after component in several animal-derived protein products, including baked goods, meringues, and meat products, due to its superior foaming and gelling capabilities (Lv et al., 2022; Tatiyatrirong, 2024). Egg white is regarded as a high-quality protein source, with around 11% protein (Abeyrathne et al., 2013; Matsuoka & Sugano, 2022). Egg white comprises numerous functional proteins, whose characteristics are extensively understood. Nevertheless, the industrial application of egg white proteins is somewhat constrained (Abeyrathne et al., 2013).

This study explores the potential of pasteurized liquid egg white as a protein-rich ingredient by reformulating it into a structured product analogous to meat analogues, incorporating plant proteins and other functional ingredients. The primary objective was to evaluate the physicochemical properties of reconstructed liquid egg white fortified with plant proteins derived from various sources, including soy, pea, bean, and rice. The target formulation aimed to achieve a high protein content comparable to commercial meat analogues (11–19%). Additionally, the study assessed the suitability of these reconstructed products for inclusion in dysphagia diets. The findings may contribute to the development of high-protein dietary options while promoting the utilization of high-quality protein sources from both egg whites and plant-based proteins.

Materials and methods

1. Materials

Plant protein powders were obtained from Krungthep Chemi Co., Ltd. (Bangkok, Thailand). These included soy protein isolate (SPI), pea protein isolate (PPI), rice protein isolate (RPI), and mung bean protein isolate (MPI). The protein contents of SPI, PPI, RPI and MPI were declared by the supplier to be 90%, 80%, 85% and 85% dry weight basis, respectively. Their particle size was screened using a 100 mesh-screen for uniformity. The powder forms of plant proteins are more suitable for mixing with other ingredients in this study. Commercial pasteurized liquid egg white (CP brand) was obtained from CPF Public Company Ltd., (Thailand). A food grade kappa carrageenan (CAR) was obtained from Chemipan Co., Ltd. (Bangkok, Thailand).

2. Preparation of the reconstructed products

The formulation (by weight) for reconstructed liquid egg white and plant proteins was derived from the recipe established by the Home Economics Program at Pibulsongkram Rajabhat University. It consisted of 50% pasteurized egg white, 20% protein powder, 15% minced cooked oyster mushroom, and 15% almond powder. Carrageenan was added into the formulation at a concentration of 0-5% by weight, as per the supplier's recommendations. This study utilized molding and steaming technique to recreate the shape of the products. The ingredients were mixed thoroughly using a food stand mixer (4.3L Model, HAFELE, Thailand) at medium speed for 15 min, until the unform paste was observed. The paste was then filled into silicone molds to form the round shape (3 cm diameter and 3 cm height). The molds filled with the mixtures were steamed for 15 min in a steamer (VC204 Model, Tefal, Thailand). The cooked reconstructed products were cooled to room temperature prior to analysis.

3. Physical properties

The appearances of the reconstructed liquid egg white and plant proteins (cross sectioned) were captured using a digital camera. Physical properties including color (L*a*b* color space), pH and water activity (a_w) were measured in triplicate for each sample using specific instruments. Color measurement was conducted using a color meter (Konica Minolta, Model CR-10 Plus, Japan) by positioning the probe directly on the surface of the samples. For pH analysis, 100 g of the sample was mixed with 20 g of distilled water and homogenized using a blender. The pH was then determined using a pH meter (Mettler Toledo, Model SevenMulti, Germany). Water activity (a_w) was measured by first grinding the samples using a mortar, followed by transferring the ground material into a measuring cup. The aw was then assessed using an a_w, meter (AQUALAB, Model 4TE, USA).

4. Textural properties

The texture of reconstructed liquid egg white and plant proteins was evaluated using a texture analyzer (Stable Micro Systems, Model TA-XT plus, UK). Texture profile analysis (TPA) was used to determine hardness, springiness, cohesiveness, gumminess, and chewiness. A 75 mm flat-end probe with a 50 kg load cell was used for the compression. Samples were steamed-cooked for 15 min and cooled to room temperature prior to analysis. For each sample, measurements were performed in triplicate as a double compression test with 50% deformation, with 5 s between the two compression steps and a compression speed of 2 mm/s. Textural attributes were extracted from the stress–strain curve using the Exponent software (Stable Micro Systems, UK). Hardness was defined as the peak tensile stress in the first compression cycle (50% compression), springiness was defined as the rate at which the deformed material returned to its original state, cohesiveness was determined from the area of the first compression and the second compression peak, and chewiness was taken from the peak stress and the areas and time of the first and second compression.

5. The IDDSI testing

To ensure that the reconstructed liquid egg white and plant proteins are suitable for people with dysphagia, level 6 soft & bite-sized category, this study follows the framework of International Dysphagia Diet Standardization Initiative (IDDSI Framework) (Cichero et al., 2017). The products were sectioned into 15 x 15 mm pieces and thereafter evaluated utilizing the fork pressure test in accordance with IDDSI Testing Methods. Three 15 mm cubes of cooked reconstituted products were obtained from each protein type. Each cube was compressed using the prescribed technique, specifically by positioning the thumb on the fork's bowl and applying sufficient pressure to induce blanching of the thumbnail. This blanching transpires when the pressure surpasses average arterial blood pressure, estimated at around 17 kPa, which nearly aligns with the average tongue pressure exerted during swallowing. To satisfy the criteria for a level 6 dysphagia diet (soft & bite-sized), the food sample must yield to pressure from a fork and should not revert to its original form upon the removal of pressure.

6. Sensory properties

The selected samples (3% CAR) were cooked by steaming as described above and then tested for preference test using the 9-point hedonic scale method, in terms of appearance, color, odor, taste and overall acceptance. The scale comprises a series of nine verbal categories ranging from "dislike extremely" to "like extremely". The total of 30 undergraduate students in Food Science and Technology program were employed as untrained panelists. The protocol was approved by Pibulsongkram Rajabhat University Human Ethics Committee (PSRU-EC: 2024/006).

7. Protein content

The selected samples (3% CAR) were cooked by steaming as described above and then analyzed for protein content. The Kjeldahl method using Tecator™ Digestor 8, Tecator™ Scrubber and Kjeltec™ 8200 Auto Distilling Unit (FOSS Analytical, Hoganas, Sweden) was used to determine the protein content of all samples. The protein content was calculated with a nitrogen conversion factor of 6.25 (Chiang et al., 2021).

8. Statistical analysis

Completely Random Design (CRD) experimental design was employed. The experimental results were expressed as mean ± SD of triplicate observations. Data were analyzed statistically by ANOVA and Duncan's new multiple range tests and a p-value of less than 0.05 was considered significance (SPSS Version 22, New York, USA).

Results and discussion

1. Physical properties

The appearances of the reconstructed liquid egg white and plant proteins with added CAR at 0-5% are illustrated in Fig. 1 In addition, the color (L*a*b*), pH and a_w of the samples are shown in Table 1.

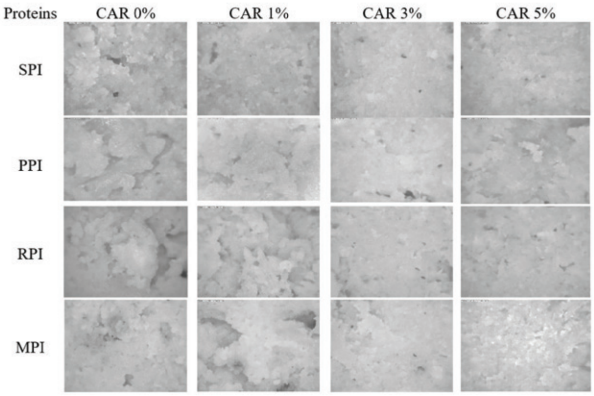

Fig. 1 Appearances of the reconstructed liquid egg white and plant proteins

Table 1 The color, pH and a_w of the reconstructed liquid egg white and plant proteins

Proteins	CAR (%)	L*	a*	b*	pH	a_w^{ns}
SPI	0	61.41±0.01^{g}	3.60±0.02^{c}	16.40±0.01^{e}	6.91±0.03^{c}	0.98±0.00
	1	61.30±0.04^{f}	3.25±0.00^{de}	16.34±0.03^{e}	7.14±0.03^{b}	0.98±0.00
	3	58.88±0.10^{i}	3.05±0.01^{f}	16.29±0.03^{e}	7.21±0.02^{a}	0.98±0.00
	5	55.40±0.09^{l}	3.21±0.00^{e}	15.27±0.0^{g}	7.20±0.02^{a}	0.98±0.00
PPI	0	63.58±0.20^{d}	2.29±0.06^{i}	16.18±0.04^{e}	6.77±0.02^{d}	0.99±0.00
	1	62.90±0.02^{e}	2.25±1.09^{h}	15.47±0.11^{g}	6.81±0.03^{d}	0.99±0.00
	3	58.06±0.03^{j}	3.04±0.06^{f}	15.49±0.02^{g}	6.66±0.00^{f}	0.99±0.00
	5	56.47±0.09^{k}	3.50±0.05^{c}	15.85±0.05^{f}	6.73±0.06^{e}	0.99±0.00
RPI	0	69.46±0.37^{a}	5.03±0.03^{a}	13.97±0.08^{i}	6.20±0.00^{j}	0.99±0.00
	1	68.52±0.22^{b}	2.98±0.05^{f}	14.40±0.32^{h}	6.23±0.01^{ij}	0.99±0.00
	3	67.77±0.16^{c}	3.07±0.03^{f}	18.84±0.02^{b}	6.26±0.01^{hi}	0.99±0.00
	5	67.55±0.01^{c}	4.77±0.20^{b}	18.89±0.08^{b}	6.30±0.02^{h}	0.99±0.00
MPI	0	69.65±0.16^{a}	2.26±0.78^{i}	19.57±0.36^{a}	6.50±0.09^{g}	0.98±0.00
	1	68.51±0.13^{b}	2.40±0.35^{i}	19.67±0.26^{a}	6.60±0.00^{f}	0.98±0.00
	3	61.14±0.10^{gh}	2.66±0.05^{g}	16.92±0.24^{d}	6.69±0.01^{ef}	0.98±0.00
	5	60.79±0.32^{h}	2.44±0.01^{h}	17.50±0.03^{c}	6.72±0.02^{e}	0.98±0.00

Remark: Values are mean ± standard deviation (SD), n=3. Means that do not share a letter in a column are significantly different ($p \leq 0.05$). ns: not significant.

The reconstructed liquid egg white and plant proteins can be produced from all the studied proteins with acceptable appearances, as evidenced in Fig. 1 The products exhibited porous structure with uniformity in shape and size. The addition of CAR at 3-5% exhibited smaller air cells and greater uniformity when compared to the addition of CAR at 1% and control samples. The capacity to construct and shape protein powders and other ingredients into desired shapes amplifies their application as food ingredients. In terms of physical properties, the natural color of each protein powder plays a major role in controlling the color of the finished products. The whiteness of the products from soy protein was found to be slightly lower than that of the other proteins. All the reconstructed products showed positive a* and b* values, indicating appearances of redness and yellowness. Their pH values were neutral, and the aw values were high (0.98-0.99) as they are fresh foods. Pasteurized liquid egg white and cooked oyster mushrooms as well as the steaming process, used for preparation of the products, caused the high aw in the finished products. High aw values indicate perishable products, and proper handling is required for food safety purposes.

In this study, the addition of CAR did not dramatically alter the color, pH and aw of the products. However, color L* and a* values slightly decreased, while the b* values increased as the concentration of CAR increased. This was due to the high concentration of CAR causing smaller air cells and greater uniformity of the product surface (Fig. 1), resulting in the dense surface. Consequently, this affected the color shade as evidenced by decreased L* and a* values and increased b* values. For pH, the addition of CAR slightly increased pH of the products. The elevated pH might be due to the alkaline nature of CAR (Liu et al., 2022).

This study illustrated a straightforward way for reconstructing liquid egg white using plant protein powders to create goods resembling meat substitutes. The finished products displayed satisfactory fibrous characteristics with texture profiles akin to meat substitutes. The primary components are liquid egg white and plant proteins, making the reconstructed products suitable for a high-protein diet. They may also serve as a high-protein component in several recipes. Protein content of the products are discussed in the following section. Notably that the reconstructed products in this study are intended to be used as freshly prepared. They are generally neutral in pH value and high-water activity which are considered perishable products (refer to Table 1).

2. Textural properties

The textures of the reconstructed liquid egg white and plant proteins as examined by hardness, springiness, cohesiveness, gumminess and chewiness are presented in Table 2.

Table 2 The textural properties of the reconstructed liquid egg white and plant proteins

Proteins	CAR (%)	Hardness (g)	Springiness	Cohesiveness	Gumminess (g)	Chewiness (g)
SPI	0	$3,639\pm44^{de}$	0.79 ± 0.02^{abc}	0.59 ± 0.03^{bc}	$2,022\pm36^{d}$	$1,602\pm34^{cd}$
	1	$2,597\pm20^{fgh}$	0.71 ± 0.06^{cd}	0.49 ± 0.01^{defg}	$1,163\pm12^{g}$	926 ± 17^{efg}
	3	$3,098\pm96^{defg}$	0.66 ± 0.02^{e}	0.42 ± 0.02^{hij}	$1,155\pm17^{g}$	858 ± 99^{fg}
	5	$1,837\pm53^{h}$	0.49 ± 0.25^{f}	0.40 ± 0.01^{ij}	685 ± 15^{h}	336 ± 10^{h}
PPI	0	$2,677\pm37^{fgh}$	0.72 ± 0.05^{bdc}	0.39 ± 0.01^{j}	$1,105\pm27^{g}$	641 ± 14^{gh}
	1	$3,202\pm90^{fed}$	0.69 ± 1.09^{e}	0.48 ± 0.01^{defg}	$1,554\pm46^{f}$	$1,110\pm46^{ef}$
	3	$5,018\pm62^{b}$	0.74 ± 0.03^{bcd}	0.47 ± 0.02^{fgh}	$2,221\pm65^{cb}$	$1,634\pm48^{cd}$
	5	$4,077\pm42^{cd}$	0.71 ± 0.06^{cd}	0.43 ± 0.01^{ghij}	$1,884\pm24^{ed}$	$1,299\pm16^{ed}$
RPI	0	$2,785\pm13^{efg}$	0.83 ± 0.01^{a}	0.52 ± 0.02^{cdfg}	$1,382\pm38^{gf}$	$1,122\pm27^{ef}$
	1	$2,214\pm11^{gh}$	0.71 ± 0.04^{cd}	0.48 ± 0.00^{defg}	$1,069\pm32^{g}$	771 ± 72^{fg}
	3	$9,465\pm89^{a}$	0.79 ± 0.00^{abc}	0.46 ± 0.00^{fghi}	$4,700\pm24^{a}$	$3,484\pm30^{a}$
	5	$5,238\pm23^{b}$	0.78 ± 0.00^{abc}	0.48 ± 0.01^{defg}	$2,534\pm99^{bc}$	$1,945\pm12^{ab}$
MPI	0	$3,444\pm12^{ed}$	0.79 ± 0.10^{abc}	0.63 ± 0.12^{b}	$2,096\pm34^{d}$	$1,686\pm43^{c}$
	1	$3,811\pm16^{d}$	0.86 ± 0.00^{a}	0.70 ± 0.00^{a}	$2,676\pm10^{b}$	$2,312\pm99^{b}$
	3	$5,130\pm13^{b}$	0.81 ± 0.05^{ab}	0.54 ± 0.01^{cde}	$2,697\pm67^{c}$	$2,272\pm89^{b}$
	5	$4,686\pm28^{bc}$	0.55 ± 0.01^{f}	0.55 ± 0.01^{f}	$2,660\pm10^{b}$	$2,141\pm16^{b}$

Remark: Values are mean ± standard deviation (SD), n=3. Means that do not share a letter in a column are significantly different ($p \leq 0.05$). ns: not significant.

Different protein sources provided different texture profiles. The amount of carrageenan used in the formulas also influenced the textures of the reconstructed liquid egg white and plant proteins. The hardness of the products tended to increase as the carrageenan level increased by up to 3%. But it decreased when adding carrageenan for up to 5%. The reconstructed products provided springiness and cohesiveness values, ranging from 0.49 to 0.86 and 0.39 to 0.70, respectively. The addition of carrageenan tended to decrease the springiness and cohesiveness values. The gumminess and chewiness can be calculated from the other values. These values can be used to compare among samples. Although the reconstructed products exhibited similar visual appearances (Fig. 1), their textural properties, as assessed by instrumental analysis, differed significantly (Table 2). Texture profile analysis revealed that, for each protein type, the addition of 3% carrageenan resulted in higher values of hardness, springiness, gumminess, and chewiness. Consequently, the formulation containing 3% carrageenan was selected for further analysis of sensory attributes and protein content.

Considering the reconstructed liquid egg white and plant proteins as meat analogues, consumer acceptance is critically dependent on the capability to structure plant proteins into matrices that in their textural properties and appearance resemble meat (Sun et al., 2022). Despite recent progress, meat analogues still differ from genuine meat in terms of mouthfeel, texture, taste and flavor (Samard & Ryu, 2019). To gain the fibrous structure of plant-based meat analogues, extrusion process is the most commonly used commercial process in the industry (Yuliarti et al., 2021). Textured vegetable protein (TVP) is commonly known as “texturates” made from plant-based protein sources and water by going through a transformation from a powder-type material to a structured material using the extrusion process. However, the extrusion process is not commonly found in small-scale food manufacturers due to its high installation cost. This study proposed the simple mixing and molding method which requires no sophisticated equipment to produce reconstructed products similar to meat analogues. The proposed process should be suitable for small-scale food manufacturers or home industry.

Unlike myosin and actomyosin found in muscle tissue, the molecular connection and structural alignment of plant proteins, particularly legume globular proteins, in their native forms do not impart the fibrous texture and water-binding ability seen in muscle cells (Dekkers et al., 2018). As a result, intensive processes like thermal extrusion and enzymatic cross-linking are required to achieve meat-like fibrous structure, conformation, and chewiness (Yuliarti et al., 2021). For industrial processing of TVP, thermal extrusion and fiber spinning, which transform native globules into filamentous aggregates or interactive fibers become a necessity (Sha & Xiong, 2020).

As this study did not involve an intensive processing method for producing reconstructed liquid egg white with plant proteins, we propose potential mechanisms contributing to the textural formation of the final products. Liquid egg white was combined with plant protein powders and natural fibrous ingredients specifically minced oyster mushroom in this study along with added carrageenan to facilitate the formation of a structured, texturized product. The final products demonstrated satisfactory appearance, color, and texture. Although the texture profiles of the reconstructed products were not directly compared with real meats or meat analogues, the results of texture profile analysis indicated acceptable textural properties. The values of hardness, springiness, cohesiveness, gumminess, and chewiness of the reconstructed products fell within the ranges reported in the literature (Godschalk-Broers et al., 2022; Mishal et al., 2022; Samard & Ryu, 2019).

The minced, cooked oyster mushroom contributed to the coarse structure by encapsulating the liquid egg white and protein powders within its fibrous network. Upon steaming, the liquid egg white formed a gel matrix that acted as a cross-linker, effectively binding all components together. Carrageenan, a hydrocolloid used in this formulation, functioned as a thickening agent, enhancing the binding capacity and contributing to the firm yet moist texture of the reconstructed products. Hydrocolloids, widely utilized as thickeners and gelling agents in the food industry, are water-soluble or water-dispersible polysaccharides that enhance textural properties by serving as cross-linkers and stabilizing protein filaments (Dinani et al., 2023). In meat analogues, hydrocolloids have been extensively applied to retain water, immobilize fat, improve rheological and textural properties, reduce syneresis, and emulsify oils. The effects of hydrocolloids on texture depend significantly on their type and concentration, with different hydrocolloid formulations improving only specific aspects of meat analogue characteristics (Dinani et al., 2023).

In this study, the addition of carrageenan at 3% resulted in the highest values for key textural parameters, including hardness, springiness, cohesiveness, gumminess, and chewiness (Table 2). However, increasing the carrageenan concentration to 5% led to a decline in these values, likely due to excessive hydrocolloid content, which retained excessive water, increased dryness, and caused the fibrous structure to collapse.

3. The IDDSI testing results

Fig. 2 presents the results of the IDDSI fork pressure tests conducted on the reconstructed liquid egg white with plant proteins. The findings indicate that the products are sufficiently soft and meet the criteria for IDDSI Level 6 (soft and bite-sized for adults). During the fork pressure test, the thumbnail blanched to white upon pressing, and the reconstructed products were completely compressed without regaining their original shape, as illustrated in Fig. 2 These results suggest that the reconstructed liquid egg white with plant proteins developed in this study may be suitable for individuals with dysphagia.

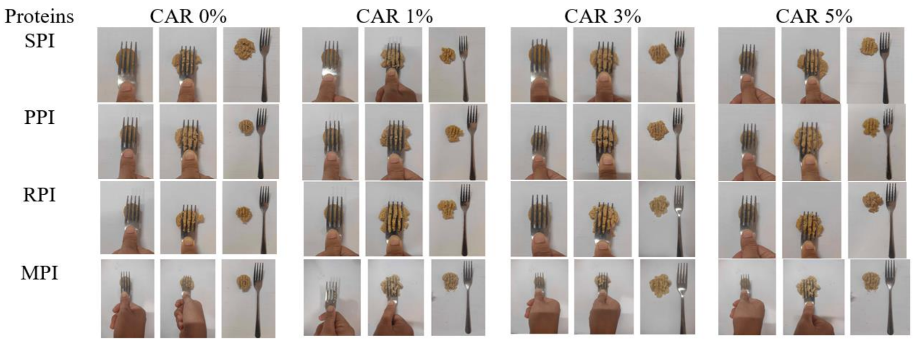

Fig. 2 The IDDSI fork pressure tests of the reconstructed liquid egg white and plant proteins. Pictures show before, during and after pressing by fork

Dysphagia is a condition characterized by difficulty or an inability to swallow liquids, semi-solid, or solid foods (Loret, 2015). It affects approximately 580 million individuals worldwide, particularly infants and the elderly, whose reduced muscle mass and strength impair swallowing function (Raheem et al., 2021). Dysphagia can lead to nutritional deficiencies, further exacerbating health risks (Sungsinchai et al., 2019). Beyond aging-related cases, dysphagia may also affect individuals of all ages with medical conditions such as trauma, cancer, post-surgical complications, cerebral palsy, stroke, and other neurological disorders (Raheem et al., 2021). The reconstructed liquid egg white with plant proteins developed in this study may serve as a nutritionally viable option for individuals requiring specialized diets due to dysphagia or related conditions.

4. Sensory properties

The sensory properties of the reconstructed liquid egg white and plant proteins are shown in Fig. 3 In general, the products provided low acceptance scores in most of the attributes evaluated. The maximum score was less than 7 (like moderately). The reconstructed liquid egg white with SPI showed higher scores in terms of odor, taste and overall acceptance when compared to the other proteins. SPI is the most widely used plant protein in meat analogues in recent years. SPI provides great taste, and consumers are more familiar with the taste of soy proteins. Edible mushrooms and SPI were used to produce meat analogues, and exhibited close textural and sensorial profiles to real meat (Yuan et al., 2021). Appearance and color for all treatments showed similar sensory scores, confirming their visual appearance as illustrated in Fig. 1 The reconstructed egg white with PPI, RPI and MPI exhibited similar sensory properties for all attributes.

Sensory properties are major concerns when developing special foods. The reconstructed products in this study exhibited low acceptance in most sensorial attributes (refer Fig. 3) The reluctance of the elderly or dysphagia patients to accept the appearance, texture, and flavor of pureed foods poses a challenge to their ingestion. There is a need to make tasty, nutrient-dense foods while keeping portion sizes appropriate (Ilhamto et al., 2014). Formulating dishes with reconstructed products flavored with colored vegetables or grains may assist in addressing the issues. It is vital to find a balance between safety and enjoyable (Chadwick, 2014). Greater emphasis has been placed on textural and nutritional properties; more emphasis is needed on attributes that lead to liking, and future research can provide guidance to food manufacturers.

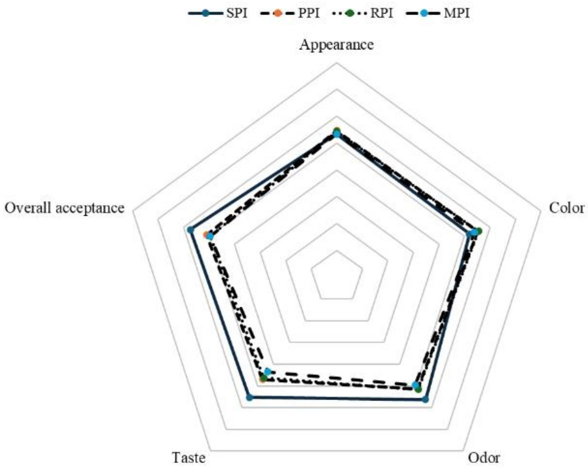

Fig. 3 Sensory properties of the reconstructed liquid egg white and plant proteins

5. Protein content

Fig. 4 shows the protein content (% wet basis) of the reconstructed liquid egg white and plant proteins. The samples exhibited high protein content ranging from 18.97% (MPI) to 22.09% (PPI). Although, the protein content of all samples were found not significantly different ($p<0.05$). It is worth to note that the protein content of the developed products in this study are higher than those found in the commercially available meat analogues in the Thailand market. For example, MEAT ZERO products provide proteins in the range of 11-18%.

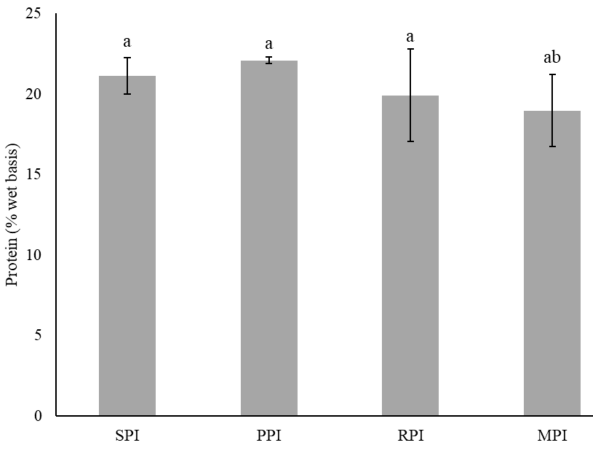

Fig. 4 Protein contents of the reconstructed liquid egg white and plant proteins

Conclusion

This study developed the reconstructed products using a simple method that could be employed by small scale food manufacturers. Liquid egg white was mixed with protein powders, other fibrous ingredients, and carrageenan. The mixtures were then molded and steamed to form the shapes. The reconstructed liquid egg white with plant proteins exhibited acceptable appearances and textures similar to meat analogues. All the types of protein powders in this study could be used as the main ingredient with liquid egg white. The developed reconstructed products could be consumed as high protein diets. Their protein contents ranged from 18.97% (MPI) to 22.09% (PPI) which are considered high. They were found to be suitable for individuals with dysphagia as they passed IDDSI fork pressure test. However, the product needs improvement in terms of sensory acceptance. Among all the plant proteins used in this study, SPI exhibited higher sensory scores when compared to the other proteins.

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