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The effects of mixed proteins on the physical and rheological properties and the sensory qualities of a newly formulated plant-based soup for elderly consumers

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Abstract

Not only do healthy products for the elderly present the nutrition to meet their needs, such as protein, but they are also easy to consume. The objective of this study was to develop a plant-based soup for the elderly with the proper rheological properties by using a mixture of proteins. The protein mixtures, containing whey protein (WP), soy protein (SP), and egg white protein (EP), were incorporated into a plant-based soup, and were optimized. The mixtures of WP, SP, and EP had an impact on color, rheology, and on the gravity flow test with The International Dysphagia Diet Standardization Initiative (IDDSI). With the use of EP alone, the product viscosity and consistency of the plant-based soup formulation seemed to increase, while the WP decreased the viscosity. However, results from the acceptance test performed with elderly consumers (n=30) revealed that the different protein mixtures had not influenced the liking scores of all attributes, except for the texture of the soup samples ($p \leq 0.05$). The soup made from the optimized formulation (2.56% WP + 0.64% SP + 0.64% EP) had a viscosity of 1238 cP, showed the highest liking score (7.27), and had a high protein content (5.07%). Therefore, in response to their requirements, the formulated plant-based soup could provide both protein and energy for the elderly and offer them the proper viscosity.

Keywords: Optimization, Rheology, Soup formulations, Mixed Proteins, Sensory analysis, The elderly

1. Introduction

At present, it is well known that ‘aging populations’ are a global phenomenon. All over the world, elderly populations are growing rapidly, especially in developed countries [1]. It has been estimated that by 2050, the global population of elderly will be over 2 billion worldwide [2]. The data from National Statistical Office [3] showed that since 2017, more than 11.3 million elderly people have been identified in Thailand and still, the numbers continuously increase year after year. The prediction demonstrates that twice this number will occur by 2040 [4]. Therefore, we must be prepared to cope when both Thailand and the world completely become aging societies.

With aging, people have to deal with various changes given that every part of the body is relatively declining [5]. It has been reported that due to their health problems, the elderly would consume less food given their problems with oral ingestion and with regard to taste and smell, their losses of sensory acuity [6]. To avoid malnutrition in the elderly, food with the appropriate characteristics and good nutrition needs to be developed for the elderly especially plant-based protein. As changes take place in their bodies, a number of elderly individuals have weak muscle mass and strength that is related to swallowing food [7]. Previous studies have revealed that foods for the elderly, who have dysphagia, should be soft, smooth, moist, elastic, and easy to swallow [8]. For viscous foods like soup, viscosity, which can be evaluated by rheological measurements, represents a crucial property that can be used when developing products for the elderly [8].

The important nutrients to be included in food for elderly are protein, Vitamin C, Vitamin D, folate, iron, zinc, and fiber [9]. Protein and plant protein play a crucial role in maintaining muscle strength and function in the elderly. Protein plays a crucial role in maintaining muscle strength and function in the elderly. To maximally stimulate the postprandial muscle protein synthesis rate, the amount of protein per meal needed for older adults (about 0.4 g/kg body mass) is higher than that of their younger counterparts (about 0.24 g/kg body mass) [10]. Moreover, Stevenson et al [11] stated that having an adequate protein intake contributes to slowing the rate of muscle decline. However, the addition of protein has an impact on the physio-chemical properties, the sensory characteristics, and degree of acceptance for any developed products. When different types of protein are used for fortification, they yield different results with regard to taste, flavor, and the texture of foods [12]. Štreimikytė et al [13] found that the addition of different proteins (milk protein (MP), pea protein (PP), mixtures of MP and PP, as well as a mixture of MP added to konjac) at the same concentration yielded beverages of different viscosities depending upon the chemical properties of the protein. Moreover, Yang et al [14] found that the used of soy protein isolate and potato starch at ratio of 8:6 in plant-based omelet matched the texture of egg omelet well. In order to develop the appropriate protein content and the proper rheological properties for older consumers, the functional properties of the proteins used, and their interactions should be considered.

Consequently, this research aimed at developing high protein plant-based soup for elderly consumers. The effects of the types and ratios of the fortified protein products were evaluated. In addition, the physical characteristics of the soup and its sensory characteristics were investigated.

2. Materials and methods

2.1 Materials

The materials used in this study and the companies that they were purchased from were as follows: 1) frozen corn from Siam Makro Public Company Limited (Bangkok, Thailand), 2) sugar from Mitr Phol Co., Ltd. (Bangkok, Thailand), 3) salt from the Thai Refined Salt Co., Ltd. (Bangkok, Thailand), 4) tapioca starch from McGarrett Co., Ltd. (Bangkok, Thailand), 5) yeast extract from Bega Cheese Limited (Australia), 6) soy protein and whey protein from the Krungthepchemi Co., Ltd. (Bangkok, Thailand), and 6) egg white protein from the Thai Food and Chemical Co., Ltd. (Bangkok, Thailand).

2.2 Preparation of the soup samples

To prepare the soup, 8.37% red bean, 2.79% job's tears, 2.70% creamer, 2.22% tapioca starch, 1.77% sugar, 0.36% salt, 0.80% grounded corn, 0.13% corn flavor, 0.08% yeast extract and 0.02% cheese were mixed together. All ingredients were added to 76.92% of boiling water. The protein mixtures (3.84%) (Table 1) were then added to soup, and after that, the soup samples were heated to 100°C for 10 minutes.

2.3 The experimental design

An augmented simplex-centroid design was used to optimize the three protein blends (Whey protein; WP, Soy protein; SP and egg white protein; EP). The design consisted of 10 points of treatment and the replication of 3 points as displayed in Table 1. The maximum level for each variable was 3.84%. Each sample was taken and subjected to an examination of its physical and chemical properties and further subjected to sensory analysis.

Table 1 The experimental design of the whey protein, soy protein, and egg white protein mixtures with regard to the qualities of plant-based soup for the elderly.

Treatments	The Proportions of the Components (%)		
	Whey protein (WP)	Soy protein (SP)	Egg white protein (EP)
Tr1	3.84	0	0
Tr2	0	3.84	0
Tr3	0	0	3.84
Tr4	1.92	1.92	0
Tr5	1.92	0	1.92
Tr6	0	1.92	1.92
Tr7	1.28	1.28	1.28
Tr8	2.56	0.64	0.64
Tr9	0.64	2.56	0.64
Tr10	0.64	0.64	2.56
*Tr11	3.84	0	0
*Tr12	0	3.84	0
*Tr13	0	0	3.84

*Tr11, Tr12, and Tr13 represented the replicated design points of Tr1, Tr2 and Tr3, respectively.

2.4 The analyses of the plant-based soup

2.4.1 Color

The color of the soups was performed with the CIE color system using a Hunter Lab spectrophotometer (Ultra Scan XE, Hunter Lab, USA). The colorimeter was standardized with black glass and white tile (L^* = 99.29, a^*= -0.25, and b^* = 0.00). Instrumental color data was presented in accordance with the CIE system in terms of L^*, a^*, and b^* (lightness, redness-greenness, and yellowness-blueness), respectively.

2.4.2 Viscosity

The viscosity of soup samples was carried out at 60±2°C using a Brookfield Viscometer (Brookfield, DV II plus) with S02 spindle at 50 rpm for 2 min by following the method outlined by Sugumar and Guha [15], but with some modifications.

2.4.3 Consistency

The texture and consistency of soup were measured using a Texture Analyzer (TA.XT plus, Stable Microsystems, Surrey, England) by following the method of Bourne [16], but with some modifications. The temperature of soup samples was controlled at 60±2°C. The measurement was carried out using a 40 mm diameter extrusion disk. The load cell was calibrated at 25 kg, and the crosshead speed was set at 2.0 mm/s. The consistency of samples was determined as the area under the positive and negative curve regions.

2.4.4 Rheological properties

All soup samples were examined using a Rheometer (HAAKE RS75, Karlsruhe, Germany). The mode employed serrated plate-and-plate geometry (35 mm diameter, 1mm gap), a shear rate range of 0.100-300.0 S^{-1}, and a temperature of 60°C [Adapted from 17]. The consistency index and flow behaviors were obtained by the fitting shear rates ($\dot{\gamma}$) versus the shear stress (σ). The well-known power-law model was used to describe the shear-induced behavior of the soup:

$$\sigma = K\dot{\gamma}^{n} \tag{1}$$

in which K is the consistency index (Pa.s^n); n (dimensionless) also indicates the closeness to Newtonian behaviors (The flow behavior index).

2.4.5 The gravity flow test with the international dysphagia diet standardization initiative (IDDSI) measurement requirements

The soup samples (10 mL) were loaded into 10 ml slip-tip syringes with a barrel length of 61.5 mm, and stoppers were placed on the nozzle to impede flow [18]. Using the IDDSI framework detailed descriptors, the amount of liquid sample that remained after the stopper had been released (allowing for 10 seconds of flow) was used to classify the thickness of the liquid. The 5 levels of classification for the soup samples were as follows: Level 0: no liquid remained in the syringe (a thin liquid), Level 1: 1-4 mL are released (a slightly thick liquid), Level 2: 4-8 mL are released (a mildly thick liquid), Level 3: >8 mL remains (liquidized), or Level 4: all 10 mL of the soup remains (a puree or extremely thick).

2.4.6 Acceptance test

To determine the acceptance of the soup samples, liking tests were conducted with 30 elderly untrained panelists (60 years of age and over), who commonly consume soup. The soups were served randomly in accordance with "balance order and carry-over effects design" [19] and were labelled with three-digit random numbers. The soup samples, which were served at 60±2°C, were evaluated using a 9-point Hedonic Scale for 6 attributes (appearance, color, odor, flavor, texture, and overall liking). After evaluating each soup, the panelists rinsed out their mouths with water to cleanse their palates.

2.4.7 Optimization of protein mixtures

The adopted model, which was based on color, viscosity, consistency, and on the rheological properties, as well as on the results of the acceptance test, was used to optimize the protein proportions by using the software

Design Expert version 12 Demo program (Trial version) (Stat-Ease, Inc., Minneapolis, MN, USA). The optimized formula was then produced and was subsequently subjected to analysis by employing the objective methods and the acceptance test as described above.

2.4.8 Protein contents

The amount of protein in the plant-based soup samples was determined in accordance with the method for cereal foods from the AOAC [20].

2.4.9 Statistical analysis

The experiments were carried out in triplicate using three different lots of samples. A completely randomized design (CRD) was performed for the statistical analysis of the physical analysis. The analysis of the acceptance test was conducted based upon a randomized complete block design (RCBD). An analysis of variance (ANOVA) was used for data analysis, while the means were compared by using Duncan's New Multiple Range test at α-level of 0.05 ($p \leq 0.05$). Analysis was achieved using the Statistical Package for Social Science (SPSS for Windows, SPSS Inc., Chicago, IL, USA).

3. Results and discussion

3.1 Color

The color of the plant-based soup was one of important parameters affecting consumer acceptance. The color attributes of the soup samples had been significantly affected by the protein mixtures ($p \leq 0.05$). Incorporation of WP (Tr1) into the plant-based soup resulted in higher L^* value (80.64), giving a lighter color to the plant-based soup. Ertaş et al [21] found that when the whey protein concentration was increased, the L^* value of Tarhana soup (a Turkish Fermented Cereal-based Food) increased, whereas the a^* and b^* values decreased. Moreover, the plant-based soups containing SP (Tr12) obtained the lowest level of lightness, but the highest for yellowness (b^*) ($p \leq 0.05$) because SP has lower L^* than WP (Data not shown). The b^* value, which presents a yellow color, was positive for all studied samples. All soup samples to which WP, SP, EP protein, and the protein mixtures had been added, exhibited yellowness ($+b^*$). This was most likely due to the corn in the formulation and the color of protein, which was pale yellow. These results agreed with findings from Singh et al [22], who reported that the b^* of soup mix increased with increased amounts of baby corn powder.

3.2 Viscosity, Consistency, and Rheological properties

The effects of various proteins on the viscosity, consistency, and the rheological properties of the plant-based soups are displayed in Tables 2 & 3. The viscosity of the plant-based soup samples was altered due to the concentration and types of proteins used in the formulations. The viscosity was in agreement with the consistency and rheological properties of soup samples. The soup samples (Tr3 and Tr13), to which EP had been added, showed the highest viscosities (2829.33 and 2974.67 cP, respectively) and consistency coefficients (K) (18.180 and 17.270 $Pa.s^n$, respectively). Meanwhile, the sample with 50% WP and SP (Tr4) showed the lowest K (6.524 $Pa.s^n$) ($p \leq 0.05$). There are many factors that can have an effect on the viscosity of proteins, such as pH, temperature, protein concentration, and the rate of heating [23]. Onwulata et al [24] found that the viscosity of egg albumin had had a higher value than other protein samples (whey protein isolate, soy protein isolate, and fish protein isolate) and showed the highest values at 60°C (pH 2.5). Concurrently, the viscosity of whey protein was slightly affected by temperature and pH, which indicated a weak solution. Moreover, the value was slightly decreased when increasing the temperature to 60°C (pH 2.5). At all pH conditions and all temperatures, the sample containing whey protein had shown a low viscosity value, which indicated that it was a very weak solution. In a previous study, Onwulata et al [24] found that when whey protein had been mixed with egg albumin, there had been a higher viscosity than when whey protein and soy protein had been mixed. This result was coincidental with our study. The soups, to which 2.56% EP had been added, exhibited a higher viscosity and consistency than those with 1.28% EP ($p \leq 0.05$). The viscosity of the protein mix may depend upon the structure and the mechanical properties of the gel and may also depend upon the nature of the gel system formed [24]. Surprisingly, the viscosity and consistency of two mixed proteins at 1.92% SP+EP had the highest, which was followed by 1.92% WP+EP and 1.92% WP+SP, respectively ($p \leq 0.05$). Onwulata et al [24] reported that blending isolated whey protein (WP) with other proteins in a mixed system had led to decreased viscosity. In contrast, mixing egg albumin in mixed proteins systems had resulted in increased viscosity due to gel formation from the egg albumin.

Moreover, the results are in agreement with consistency coefficient (K). The consistency coefficient index (K) is an informative parameter that is used to determine the viscous properties of a sample; the higher K-values indicate that the character of the sample is more viscous [25]. The soup sample with 3.84% EP had the highest K-values. Interestingly, the soup sample with EP mixed with other proteins had a higher viscosity than the mixtures with SP and WP ($p \leq 0.05$). Yilmaz et al [26] showed that the K value of soup at 80°C had decreased when the whey protein concentration was increased from 6.25 to 25%. The determination coefficients (R^2) of all plant-based soup samples were higher than 0.900. An excellent fitness of equation had a high in R^2 and low in RMSE value [27,28]. Furthermore, the flow behavior index (n) for all the plant-based soup samples had been lower than 1 (ranging from 0.420 to 0.511), which indicated a pseudo-plastic behavior (shear thinning). Pseudo-plastic behavior ($n < 1$) has been widely observed in various soups [29]. These results agreed with reports from Fasogbon and Taiwo [29] found that the flow behavior of dika kerel soup ranged from 0.284 to 0.402. The sample with low n values indicated that the flexible structure [28]. Moreover, Erbas et al [30], who found that the flow behavior index of Tarhana soup had been 0.39, which was presented as shear thinning or as a pseudo-plastic liquid. The viscosity results were in agreement with Mohamed et al [31], who reported that a soup for the elderly, to which 22.5% chickpeas and 2% whey protein had been added, had exhibited an apparent viscosity of 679 cPs and was more acceptable than soup to which 1% whey protein had been added.

3.3 The gravity flow test

The IDDSI framework, which was employed to measure the thickness and to verify the consistency of the plant-based soup samples, is used in dysphagia management [18]. Dysphagia patients require texturally-modified foods that can be effortlessly swallowed without being chewed or compressed between tongue and palate. Therefore, foods for dysphagia patients should have less hardness and adhesiveness but should be able to be easily chewed and have the appropriate cohesiveness [32]. The levels of liquid thickness of the soup samples, which was based upon the IDDSI framework, is shown in Table 2. The soup samples, to which EP alone was added (Tr3 and Tr13), were classified as Level 4 in the IDDSI framework and were categorized as an 'extremely thick puree.' Moreover, the plant-based soup, which contained only WP, was categorized as a 'mildly thick liquid' (Level 2). However, the plant-based soups with a combination of WP, SP, and EP were gauged as a 'moderately thick or liquidized' food [18]. IDDSI classifies level 3 that samples can be sucked through straw with no bolus formation [33]. The results are coincidental with Ribes et al [34] who reported that texture-modified honey-like consistency soup added with chia seed mucilage had appearance viscosity of 1297 mPa.s and being judged safer to swallow by dysphagia patients. Moreover, the results of the gravity flow test were in agreement with those of viscosity, consistency, and the rheological properties. Sungsinchai et al [32] reported that food at a Level 3 in the IDDSI framework had shown a viscosity of more than 1500 mPa.s and a hardness of under $2x10^4$ N/m^2. Different protein mixtures have various impacts upon the viscosity of food systems as previously described [23,24].

3.4 Acceptance scores

The effect of various proteins on the liking scores of plant-based soups was evaluated using the hedonic scale as shown in Table 3. Although, the protein blends generally affected the L^*, a^*, and b^* values (Table 2), the samples' appearance and color liking scores had not been significantly different ($p > 0.05$). In addition, although the types and concentration of proteins had influenced the odor and flavor, they did not have an impact on liking with the odor and flavor ($p > 0.05$). The attribute of texture is the most important factor for elderly patients and individuals with dysphagia. From the results of the viscosity and the rheological properties, the types of protein used and their concentrations had affected their consistency (Tables 2 and 3) and also the liking scores for texture ($p \leq 0.05$). Interestingly, the sample soup with 1.92% WP and 1.92% SP obtained the highest liking score for texture (7.60) ($p \leq 0.05$). Generally speaking, various attributes of texture (i.e., smoothness, consistency, and coating the mouth, etc.) might be used by the consumer to judge their satisfaction with the texture. It was observed that due to a moderate to high viscosity in the mouth, the texture scores that were the lowest (6.57) had corresponded to the plant-based soup made with 2.56% EP, 0.64% WP, and 0.64% SP ($p \leq 0.05$). As a whole, elderly consumers prefer soups that are moderately viscous and the most consistency in-mount by panelists. This result consistent with Ribes et al [34]. Moreover, the overall liking scores for all the mixed protein plant-based soups had not been different and had ranged from 7.53 to 7.93.

Table 2 The **c**olor, viscosity, consistency values, and the IDDSI levels of plant-based soups with various protein mixtures.

Treatments	Colors			Viscosity by viscometer (cP)	Consistency		Drop test
	L^{*}	a^{*}	b^{*}		Consistency (g/mm)	Viscosity index (g/mm)	
Tr1	80.64 ± 0.01^{a}	-0.17 ± 0.00^{b}	16.15 ± 0.01^{de}	534.13 ± 4.35^{j}	624.13 ± 14.97^{fg}	-10.76 ± 0.51^{a}	2
Tr2	63.75 ± 0.01^{k}	-0.95 ± 0.00^{d}	15.94 ± 0.01^{e}	533.33 ± 29.5^{j}	724.70 ± 84.95^{ef}	-73.51 ± 4.61^{bcd}	3
Tr3	71.65 ± 0.03^{f}	-2.51 ± 0.14^{g}	17.51 ± 0.01^{ab}	2829.33 ± 37.81^{b}	1383.13 ± 177.85^{a}	-126.08 ± 26.22^{e}	4
Tr4	69.18 ± 0.01^{g}	-0.44 ± 0.01^{c}	16.51 ± 0.01^{d}	791.53 ± 4.50^{i}	554.78 ± 58.82^{fg}	-55.57 ± 3.60^{b}	3
Tr5	76.86 ± 0.04^{c}	-1.43 ± 0.01^{e}	15.37 ± 0.05^{f}	1773.33 ± 54.42^{f}	990.34 ± 90.55^{cd}	-108.97 ± 14.81^{de}	3
Tr6	66.03 ± 0.17^{i}	-1.31 ± 0.03^{e}	17.63 ±0.15^{ab}	2269.33 ± 22.74^{d}	1169.75 ± 107.27^{b}	-96.48 ± 17.56^{cde}	4
Tr7	67.26 ± 0.35^{h}	-1.51 ± 0.16^{e}	17.01 ± 0.24^{c}	1880.67 ± 26.63^{e}	1277.65 ± 43.61^{ab}	-87.44 ± 39.98^{cde}	3
Tr8	75.42 ± 0.16^{d}	-0.94 ± 0.27^{d}	17.67 ± 0.38^{ab}	1537.33 ± 25.00^{g}	723.82 ± 32.56^{ef}	-73.88 ± 6.60^{bcd}	3
Tr9	65.59 ± 0.05^{j}	-1.02 ± 0.06^{d}	17.31 ± 0.08^{bc}	1258.67 ± 11.01^{h}	844.35 ± 62.62^{de}	-91.21 ± 10.53^{bcde}	3
Tr10	69.35 ± 0.10^{g}	-2.13 ± 0.18^{f}	16.38 ± 0.06^{d}	2444.00 ± 166.71^{c}	1280.74 ± 38.01^{ab}	-87.44 ± 5.64^{bc}	3
*Tr11	80.31 ± 0.19^{b}	0.12 ± 0.11^{a}	16.20 ± 0.15^{de}	567.40 ± 5.10^{j}	466.01 ± 48.53^{g}	-20.43 ± 5.32^{a}	2
*Tr12	63.66 ± 0.14^{k}	-0.85 ± 0.13^{d}	17.75 ± 0.58^{a}	1209.33 ± 5.03^{h}	615.11 ± 141.24^{fg}	-78.77 ± 7.98^{bcd}	3
*Tr13	71.95 ± 0.18^{e}	-2.20 ± 0.03^{f}	16.24 ± 0.10^{de}	2974.67 ± 63.29^{a}	1132.84 ± 33.57^{bc}	-97.73 ± 25.92^{cde}	4

Table 3 The Rheological properties and liking scores of the plant-based soups with various protein mixtures.

Treatments	Rheological properties				Liking Scores					
	Consistency coefficient, *K* (Pa.s^{n})	Flow behavior index, *n*	R^2	RMSE	Appearance	Color	Odor	Flavor	Texture	Overall
Tr1	7.633 ± 0.285^{fg}	0.468 ± 0.028^{bcd}	0.9146	1.082	7.73±1.20^{a}	7.10±1.32^{a}	7.00±1.23^{a}	7.00±1.53^{a}	6.93±1.64^{abc}	7.83±1.02^{a}
Tr2	9.722 ± 1.350^{de}	0.474 ± 0.024^{bcd}	0.9329	0.939	7.30±1.64^{a}	7.47±1.63^{a}	6.97±1.85^{a}	7.00±1.64^{a}	7.37±1.79^{ab}	7.90±1.45^{a}
Tr3	18.180 ± 0.536^{a}	0.449 ± 0.019^{cdef}	0.9408	0.816	7.53±1.55^{a}	7.20±1.71^{a}	7.13±1.72^{a}	7.30±1.70^{a}	7.40±1.38^{ab}	7.87±1.57^{a}
Tr4	6.524 ± 0.891^{g}	0.420 ± 0.013^{f}	0.9104	1.001	7.20±2.06^{a}	7.20±1.35^{a}	7.07±1.26^{a}	7.60±1.10^{a}	7.60±1.35^{a}	7.53±1.17^{a}
Tr5	15.447 ± 1.504^{b}	0.423 ± 0.009^{f}	0.9426	0.799	7.73±1.20^{a}	7.07±1.11^{a}	7.07±1.36^{a}	7.13±1.57^{a}	6.97±1.45^{abc}	7.70±1.34^{a}
Tr6	13.647 ± 0.626^{c}	0.447 ± 0.002^{def}	0.9187	2.023	7.77±1.63^{a}	7.57±1.45^{a}	7.30±1.39^{a}	7.33±1.27^{a}	7.17±1.37^{abc}	7.70±1.42^{a}
Tr7	10.493 ± 1.813^{d}	0.467 ± 0.034^{bcd}	0.9326	0.812	7.60±1.65^{a}	7.03±1.69^{a}	7.03±1.43^{a}	7.30±1.49^{a}	7.20±1.40^{abc}	7.70±1.60^{a}
Tr8	12.950 ± 0.550^{c}	0.432 ± 0.011^{df}	0.9436	0.768	7.47±1.25^{a}	7.43±1.17^{a}	7.20±1.37^{a}	7.20±1.81^{a}	7.00±1.86^{abc}	7.63±1.30^{a}
Tr9	8.633 ± 0.724^{ef}	0.492 ± 0.018^{ab}	0.9509	0.696	7.40±1.83^{a}	7.00±1.66^{a}	6.77±1.48^{a}	7.47±1.38^{a}	7.23±1.30^{abc}	7.57±1.33^{a}
Tr10	13.753 ± 0.474^{c}	0.511 ± 0.005^{a}	0.9625	0.625	7.37±1.63^{a}	7.27±1.64^{a}	7.00±1.72^{a}	7.03±1.75^{a}	6.57±1.74^{c}	7.93±1.26^{a}
*Tr11	7.072 ± 0.381^{fg}	0.460 ± 0.014^{bcde}	0.9141	0.972	7.67±1.45^{a}	7.60±1.45^{a}	7.17±1.29^{a}	7.13±1.43^{a}	7.10±1.47^{abc}	7.63±1.25^{a}
*Tr12	9.402 ± 0.796^{de}	0.482 ± 0.009^{abc}	0.9333	0.823	7.70±1.62^{a}	7.10±1.27^{a}	7.33±1.40^{a}	7.13±1.70^{a}	6.90±1.35^{bc}	7.63±1.17^{a}
*Tr13	17.270 ± 0.505^{a}	0.451 ± 0.017^{cdef}	0.9474	0.788	7.73±1.72^{a}	7.20±1.35^{a}	7.30±1.42^{a}	7.10±1.77^{a}	7.10±1.77^{abc}	7.83±1.39^{a}

* Tr11, Tr12 and Tr13 were the replicated design points of Tr1, Tr2 and Tr3, respectively. Different superscripts in the same column indicate a significant difference ($P \leq 0.05$).

3.5 Formulation optimization of proteins in plant-based soups

The predicted model, probability of equations, lack of fit of models, and the coefficients of determination (R^2), which were obtained for color, rheological properties, and for the sensory liking scores, are shown in Table 4. The models were linear, quadratic, and cubic equations. The predicted regression equations with $p \leq 0.05$, no lack of fit, and R^2 values >0.7 were used to generate the mixture response surface contour plot as depicted in Figure 1. From the results (Table 4), it was not possible to apply a predicted model to the drop test and the sensory satisfaction of all attributes given that the probability of the model had been > 0.05. This indicated that the studied factors had not affected the responses. However, all obtained samples were rated on the range of 'moderately liked' which was acceptable for the consumer. Moreover, the probability of lack-of-fit of L^* had been significant ($p \leq 0.05$). Therefore, the model did not fit the data well. Consequently, the model did not explain most of the direction of the L^* and the sensory satisfaction responses. EP was the most important variable determining the viscosity and is shown as the highest coefficient in Table 4.

To obtain the optimum region, a contour plot with predicted consistency, index viscosity, a^*, and viscosity ranging from 493.45 - 1347.33 g/mm, (-115.58) - (-10.7) g/mm, (-2.51) - (-2.12), and 533.33 - 2974.67 cP, respectively, was selected to drive the predicted optimum formulation in response to the IDDST Level 3 (the beginning of food texture for the practice of rehabilitation). The optimum area, which consisted of WP, SP and EP, is shown in Figure 1F (shaded region). The optimized formulation with the highest desirability (1.00) that was obtained from software calculations had been comprised of 2.56% WP, 0.64% SP, and 0.64% EP. To validate the predicted model, the calculated and observed values for consistency, index viscosity, a^*, and the viscosity of the optimized formulation were compared. To validate the predicted model, the calculated and observed values for consistency, index viscosity, a^*, and the viscosity of the optimized formulation were compared. The experimental errors for all values ranged between 0.41-8.41%. Say et al [35] reported that the experimental error with lower than 10% meant eventually good fit between the predicted and observed values.

Table 4 The predictive regression models and the goodness-of-fit for the physical properties and sensory analysis of plant-based soups with various protein mixtures for the elderly.

Responses (Y)	Regression models	R^2	Probability of model	Lack of fit (p)
Consistency	Y = 541.48A+655.98B+1220.76C-305.89AB +402.41AC+918.12BC+ 8323.83ABC	0.9318	0.0029	0.2839
Viscosity index	Y =-14.27A–75.65B–106.17C–28.56AB–187.21AC-14.49BC–1987.40A^{2}BC-2099AB^{2}C+5018.02ABC^2	0.9680	0.0096	0.1924
Color L^*	Y = 80.52A+63.75B+71.84C-11.15AB+3.38AC-6.40BC+32.89A^{2}BC–35.15AB^{2}C–196.97ABC^2	0.9964	0.0001	0.0080
Color a^*	Y = -0.15A-0.88B-2.38C+0.43AB-0.88AC+1.23BC-13.84ABC	0.9855	< 0.0001	0.5635
Color b^*	Y = 16.74	0.0000	-	0.7263
Viscosity	Y = 698.92A+998.84B+3056.80C	0.9220	< 0.0001	0.6298
K	Y = 16.3A+11.23B+11.70C-2.27AB-32.16AC-1.55BC	0.5722	0.2176	0.6439
Drop test	Y=3.61A+3.21B+2.41C	0.3792	0.0922	0.2788
Appearance	Y = 7.71A+7.5B+7.6C-1.6AB+0.01AC+0.53BC	0.5511	0.2483	0.6502
Color	Y=7.25	0.0000	-	0.7964
Odor	Y=7.10	0.0000	-	0.6825
Flavor	Y=7.06A+7.09B+7.18C+1.97AB-0.44AC+0.53BC	0.7294	0.0562	0.4090
Texture	Y=7.02A+7.16B+7.20C+1.83AB-1.36AC-0.68BC	0.4653	0.3910	0.4566
Overall liking	Y=7.66A+7.67B+7.84C	0.2629	0.2176	0.6703

A: Whey protein isolate, B: Soy protein isolate, and C: Egg white powder.

The optimized plant-based soup had a protein content of 5.07%, which was 10.14g per serving (200g). Therefore, it could be determined that the plant-based soup is an excellent source of protein product. The L^*, a^*, and b^* values of the optimized formulation soup were 75.11, -0.92, and 16.03, respectively. The soup had a viscosity and consistency of 1238 cP and 823.51 g/mm, respectively, and it exhibited a Level 3 on the IDDSI framework. Regarding the sensory liking scores, appearance, flavor, and the overall liking scores for the optimized soup were higher than 7 ('moderately liked' to 'liked very much'). Satisfaction scores for the attributes of color, aroma, and texture ranged from 6.67 to 6.97. Therefore, plant-based soups, which consist of 2.56% WP, 0.64% SP and 0.64% EP, could be successfully used to produce a high protein soup for elderly.

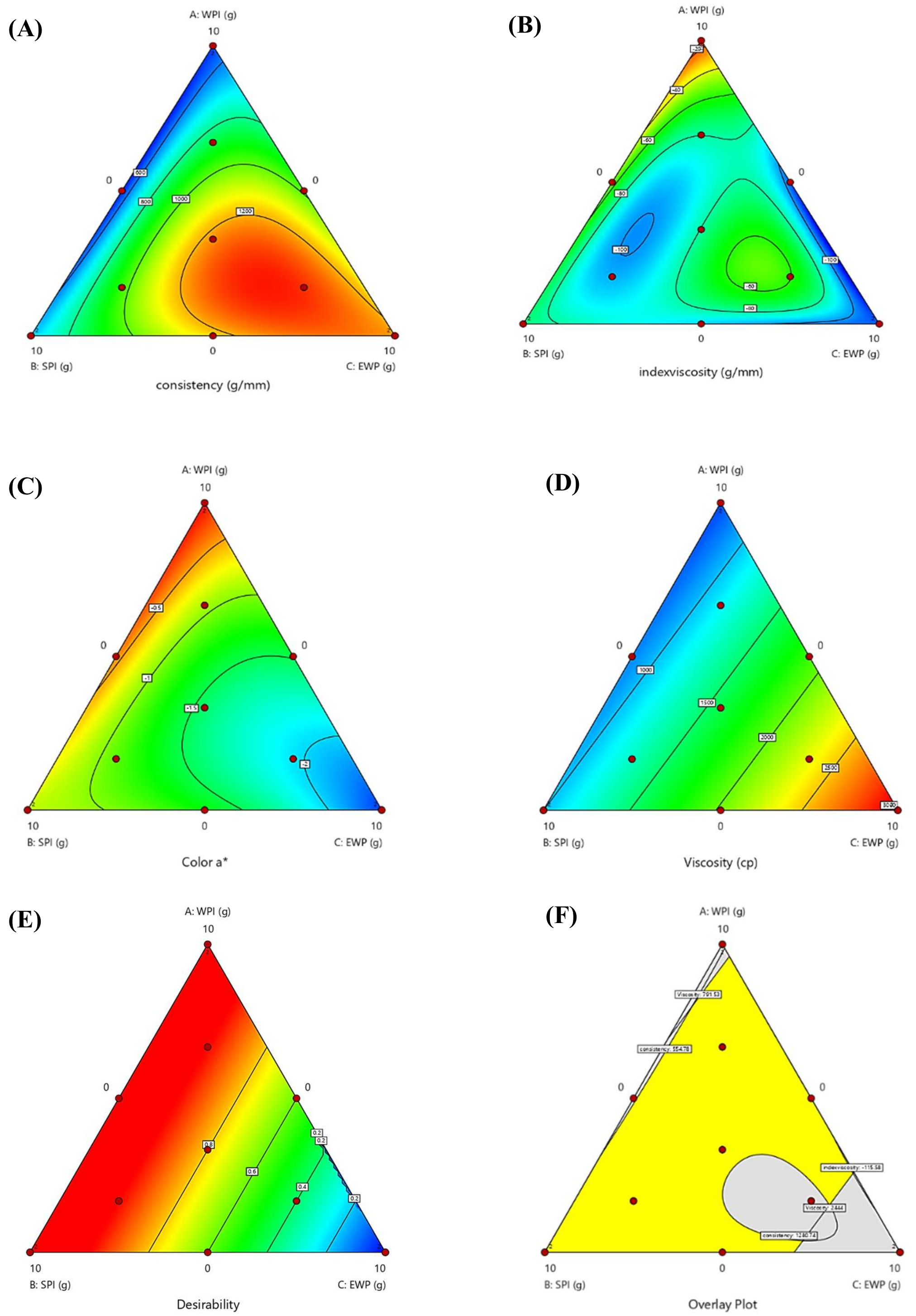

Figure The mixture response surface contour plots displaying the combined effects of whey protein isolate, soy protein isolate, and egg white protein on consistency (A), viscosity index (B), a* (C), viscosity (D), desirability (E), and optimum region (yellow shade) (F) that had obtained a moderate consistency, index viscosity, a*, viscosity, and a high desirability value.

4. Conclusion

Regarding the development plant-based soup mixtures, the elderly consumers had greatly accepted them. The different mixtures of WP, SP, and EP had mainly influenced the textural properties of the obtained soup. However, it was shown that the appearance, color, odor, flavor, and the overall liking with the soup had not been impacted. The optimized formula with the maximum liking score for texture and with a moderate consistency and index viscosity had consisted of 2.56% WP, 0.64% SP, and 0.64% EP. The plant-based soup, which had been produced with the optimized protein mixture, was able to be claimed as an excellent source of protein, which possessed a desirable viscosity and provided an overall degree of acceptability for the elderly.

5. Ethical approval

Ethical approval to perform the study (No. HE633117) was obtained from the Center for Ethics in Human Research of Khon Kaen University.

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