Improvement of microwave-dried, protein-enriched, instant noodles by using hydrocolloids

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Abstract The addition of chicken meat, egg yolk and seaweed into instant noodles followed by drying using a continuous microwave oven instead of deep oil frying has been studied to increase the protein content of the protein-enriched, instant noodles (PEIN); however, the product has an inferior quality. This research aimed to improve the quality of the product by the addition of 3 hydrocolloids [guar gum (GG), xanthan gum (XG) and carboxymethyl cellulose (CMC)] alone or in combination at 3 levels (0, 1 and 2 g/100 g flour). The results showed that GG, XG and CMC significantly increased the viscosity of the starch mixture. They also improved the PEIN qualities by significantly decreasing the cooking loss to less than the control. The highest maximum tension force and maximum distance were found with XG addition. Moreover, all hydrocolloids also promoted microstructural improvement with a smooth surface and uniform pore structure. The optimum conditions were the addition per 100 g wheat flour of 1.6 g GG and 1.9 g CMC. Finally, the PEIN was moderately liked by 70 panelists at the moderately like. In conclusion, PEIN with hydrocolloid supplementation had a better quality than without, was convenient to serve, had an acceptable taste, with higher fiber and lower oil contents and higher protein (more than 25% protein) when compared to traditional instant noodle.

Keywords Enrichment · Instant noodles · Hydrocolloid · Microstructure · Microwave

Introduction

Fried instant noodles have become a convenient food because of their easy preparation, acceptable mouth feel and reasonable price. However, the undesirable oil absorbed in noodle strands from deep oil frying and their poor nutritional value are problems with such noodle products. In recent years, there has been an increasing demand for low fat, non-fried food products that also provide additional health benefits. Generally, chicken meat is categorized as a good source of protein (Jayasena et al. 2015) and is an important component of a healthy and well balanced diet due to its nutritional richness (Pereira and Vicente 2013). Egg is a good source of proteins, vitamins, minerals, folic acid and choline that play important roles in basic nutrition (Chang and Wu 2008). Green seaweed is a nutritious vegetable, which is rich in vitamins, minerals and biologically active phytochemicals including chlorophyll, carotenoids and dietary fibers, as well as being low in calories (Mohamed et al. 2012). It can be used to enrich the fiber content in noodles (Prabhasankar et al. 2009). Therefore, this research investigated the development of protein-enriched, instant noodles (PEIN) with good nutrition and functional properties by incorporating chicken meat, egg yolk and seaweed. The product was dried using a continuous microwave oven instead of deep-fat frying to reduce the oil content in the noodle strands, to extend the shelf life and moreover, to provide more open microstructures in the noodles from microwave drying. Other benefits also included space saving, selective heating, and reducing nutritional loss (De Pilli et al. 2008). Therefore, a successful PEIN product could be easily cooked and contain lower fat and higher nutritional value than plain noodle meals (Pongpichaiudom and Songsermpong 2018). However, the physical properties and product

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qualities are generally affected by the addition of new ingredients. Formulating instant noodles with high amounts of chicken meat, egg yolk and seaweed can affect the texture properties of the noodles and cause undesirable texture problems.

Several reports found that the addition of hydrocolloids could be used to modify and control the texture properties and to enhance the overall quality of products (Yalcin and Basman 2008). Hydrocolloids such as guar gum, xanthan gum and carboxymethyl cellulose are frequently used in starch-based food products because they can modify and control physical properties. Guar gum is water soluble and is a non-ionic polysaccharide. Its structure is galactomannan consisting of a β -(1–4)-linked D-mannopyranosyl backbone and substituted with α -(1–6)-linked D-galactopyranosyl side chains. Its properties could enhance the rehydration characteristics and improved the texture of noodles (Parvathy et al. 2016). Xanthan is a branched, anionic hydrocolloid produced by aerobic fermentation of the bacterium *Xanthomonas campestris*. It has a double helix structure by hydrogen bonding with multiple spiral polymer secondary structures, which relate to water-holding behavior. The addition of xanthan to starch could control the pasting and rheological properties of starch, decreasing cooking loss and increasing the maximal breaking force of noodles, which are indicators of noodle quality improvement (Pan et al. 2016). Carboxymethyl cellulose (CMC) is a cellulose derivative with carboxymethyl groups bound with the hydroxyl groups of the glucopyranose monomers, which make up the cellulose backbone. Negatively charged hydrocolloids like CMC and xanthan can interact electrostatically with functional groups on protein or starch. This can increase the dough viscosity, dough extensibility and elasticity, and provide desirable characteristics in the noodle product (Mirhosseini et al. 2015; Silva et al. 2013). As hydrocolloids affect the rheological properties of food systems and their structure, this present study aimed to improve the quality characteristics of protein-enriched, instant noodles and to make improved modifications to the microstructure by the addition of hydrocolloid. Moreover, the effects of guar gum, xanthan gum and CMC on protein-enriched, instant noodle qualities in terms of cooking, texture, pasting and dielectric and sensory properties were investigated. Response surface methodology as used to optimize the suitable formulation to obtain a good quality final product with better health promoting properties.

Materials and methods

Materials

Commercial, all-purpose, wheat flour was purchased from the United Flour Mill Public Co., Ltd., Thailand. Chicken meat, chicken eggs and dried seaweed were purchased from Betagro Public Co., Ltd, Charoen Pokphand Foods Public Co., Ltd, Thailand and Daesang Corporation, Korea, respectively. Guar gum (GG), xanthan gum (XG), and carboxymethyl cellulose (CMC) were purchased from Weinfelderstrasse 13 (Spain), C.E. Roeper (Germany) and Ashland (France), respectively.

Preparation of protein-enriched, instant noodles

The formula for protein-enriched, instant noodles consisted of 100 g of all-purpose wheat flour, 37 g of distilled water, 2 g of sodium chloride, 10 g of chicken meat, 10 g of egg yolk, 2 g of dried seaweed and hydrocolloids (Table 1). The wheat flour, dried seaweed and chicken meat were mixed in the mixing bowl prior to the addition of the egg yolk, 7 g of distilled water, with 30 g of distilled water containing sodium chloride, and the hydrocolloids and guar gum were slowly added to the flour mixture and then mixed thoroughly. All ingredients were mixed by hand for 15 min until the dough was properly and evenly formed and the crumbly dough was placed to rest in a plastic bag for 30 min at room temperature (25 °C). Then, the dough was sheeted to obtain a thickness of 1 mm and cut into noodle strands using a noodle-making machine (Altas 150, Marcato, Italy). Noodle strands were obtained of length 30 cm weighing 15 g per piece and curled in a round-shaped plastic mold with 7.5 cm diameter. The noodle samples were steamed in a steamer for 6 min and dehydrated in a continuous microwave oven (PrimAsia Technology, Bangkok, Thailand) with 8 magnetrons at a microwave power of 800 W per magnetron for 3 min and 30 s drying time.

Protein and moisture content

The crude protein contents of the raw materials, including chicken meat, egg yolk, seaweed, traditional instant noodles and instant noodles supplemented with chicken meat 10 g, egg yolk 10 g and seaweed 2 g per 100 g of wheat flour were determined according to a method of AOAC (2012). The total nitrogen content was evaluated according to the Kjeldahl method method 991.20 (AOAC, 2012). The protein content was calculated using a conversion factor of 6.25. The moisture content was determined according to AACC (2000).

Table 1 Experimental design and levels of factors in the face central composite design

Experiment	g per 100 g wheat flour basis		
	Guar gum (X1)	Xanthan (X2)	Carboxymethyl cellulose (X3)
1	0	0	0
2	2	0	0
3	0	2	0
4	2	2	0
5	0	0	2
6	2	0	2
7	0	2	2
8	2	2	2
9	0	1	1
10	2	1	1
11	1	0	1
12	1	2	1
13	1	1	0
14	1	1	2
15	1	1	1
16	1	1	1
17	1	1	1

Cooking characteristics of protein-enriched instant noodles

The optimal cooking time (OCT) was modified from AACC (2000). A sample (25 g) of dried instant noodles was cooked in 300 ml hot water until the white core in the noodle strand disappeared when squeezed gently between two glass plates. After that, the noodles were rinsed with distilled water for 10 s. The cooking and rinsing water of each sample was collected in a beaker and evaporated at 105 °C in a hot-air oven to dryness. The residue was weighed and reported as a percentage of the weight of the dry starch noodle before cooking to determine cooking loss, which is the amount of solid substance lost in the cooking water (AACC 2000).

Texture analysis of cooked, protein-enriched, instant noodles

The texture analysis experiments were performed using a texture analyzer TA-XT2 (Stable Micro Systems, Warrington, UK) after cooking the 30 cm lengths of PEIN for the optimum cooking time. Texture parameters were measured under tension using spaghetti tensile grips (A/SPR) with the testing parameters as follows: pre-test, test and post-test speeds of 3, 3 and 5 mm/s, respectively and a trigger force of 5 g. The force (g) and distance (mm) were calculated using TA software (version 1.2, TA software, London, UK).

Pasting properties

The pasting properties of flour or flour-gum mixtures suspended in distilled water were determined using a Rapid Visco Analyzer (RVA, model 4500, Perten Instruments, Macquarie Park, NSW, Australia). The control consisted of wheat flour (3 g) at 14% moisture content and distilled water (25 ml). The samples with hydrocolloids (GG, XG and CMC) contained wheat flour (3 g) and hydrocolloids (2 g/100 g wheat flour) and distilled water (25 ml). Each sample was then poured into a separate aluminum container and stirred manually using a plastic paddle for 1 min before insertion into the RVA machine. The heating and cooling cycles for the pre-programmed profile were: slurry held at 50 °C for 1 min, heated to 95 °C within 7.50 min and then held at 95 °C for 5 min, cooled to 50 °C and then held at 50 °C for 7.50 min, while maintaining a rotation speed of 160 rpm. The peak viscosity, breakdown, final viscosity and the setback were recorded. All tests were performed using three replications (Chaisawang and Suphantharika 2005).

Microstructure

Scanning electron microscopy (SEM) was used to observe the size, shape, and arrangement of the particles, which could be correlated with texture and cooking behavior. In the SEM observation, dried, protein-enriched, instant noodle using both surface and cross section views were fixed onto aluminum stubs and coated with gold. Then, the

stubs were investigated using SEM (JSM-6400 model, JEOL, Tokyo, Japan). The images were obtained at an accelerating voltage of 15.0 kV at 200× magnification.

Dielectric properties

The open-ended, coaxial probe technique and a network analyzer (HP 8510C, Hewlett-Packard, Santa Rosa, CA, USA) were used to measure the dielectric properties of 2 cm-thick noodle dough (120 g) at 2.45 GHz. Each system was measured using 5 replicates at room temperature (25 °C). Calibration was performed using a short, air, and water, with recalibration using water at the measurement temperature before every test. The open-ended coaxial probe provided dielectric property values from the reflection coefficient of the material in contact with the active tip of the probe. The dielectric constant and loss factor were calculated from the phase shift and the magnitude of the reflected signal by the AT software.

Optimization

A face-centered, central composite design was used to develop models for establishing a suitable formulation of objective responses. The calculation of the optimum condition was performed using a multiple response optimization method. Statistical analyses were performed using the MINITAB software (version 12, Minitab Inc., State College, PA, USA).

Sensory evaluation

Protein-enriched, instant noodles with and without hydrocolloids were sampled after cooking for 3 min and subjected to sensory evaluation with serves presented on randomly coded plates with three digit numbers. The 70 untrained panelists were asked to assess their degree of liking by using a nine-point hedonic scale (where 9 = extremely like and 1 = extremely dislike) in terms of color, odor, flavor, texture and overall quality.

Experimental design and statistical analysis

The experimental design used a face-centered central composite design with three variables (guar gum, xanthan gum and carboxymethyl cellulose) and three levels (0, 1 and 2 g per 100 g of wheat flour) which are presented in Table 1. Response surface plots were generated to design tests for the moisture content, cooking and textural properties. A second-order polynomial model was fitted to each of these variables (Y) according to the following equation:

$$Y = \beta_0 + (\beta_1 \times GG) + (\beta_2 \times XG) + (\beta_3 \times CMC) + (\beta_4 \times GG^2) + (\beta_5 \times XG^2) + (\beta_6 \times CMC^2) + (\beta_7 \times GG \times XG) + (\beta_8 \times GG \times CMC) + (\beta_9 \times XG \times CMC)$$

where GG, XG and CMC are the levels of additional guar gum, xanthan gum and carboxymethyl cellulose, respectively, and $\beta_0, \beta_1, \beta_2 \dots \beta_9$ represent the estimated regression coefficients. The determination coefficient (R^2) was obtained to fit each model of experimental data from the MINITAB software (version 12, Minitab Inc., State College, PA, USA). The analysis of variance and Duncan's multiple range test were used to determine the difference of means at a significance level of $P \leq 0.05$ using the SPSS for Windows software (version 16, SPSS Inc., Chicago, IL., USA).

Results and discussion

Protein content analysis

Generally, most noodles are made from wheat flour, which contained 8–10% protein and 0.36–0.4% ash content (Vijayakumar and Boopathy 2014). They are rich in carbohydrates but deficient in protein and lack an amino acid balance. After the addition of chicken meat (10 g), egg yolk (10 g) and seaweed (2 g per 100 g wheat flour basis), the protein content was significantly ($P \leq 0.05$) increased from 11.42 g per 100 g dry matter to 16.73 g per 100 g dry matter. This was due to the higher protein in chicken meat (approximately 93.47 g per 100 g dry matter), while the protein content of egg yolk and seaweed were found to be 33.56 and 23.73 g per 100 g dry matter, respectively. Accordingly, protein content of microwave-dried, instant noodles supplemented with chicken meat, egg yolk and seaweed was significantly ($P \leq 0.05$) increased by more than 25% compared to traditional instant noodles. Therefore, the supplemented noodles could be claimed as a protein-enriched product according to the nutrition labeling notification of the Ministry of Public Health of Thailand. Regardless, consumers not only expect higher nutritional value in the product, but they also expect it to have the best texture qualities. Therefore, the addition of hydrocolloids might be able to improve the qualities of instant noodles to achieve a product balance between higher nutritional aspects and good sensory qualities.

Effect of hydrocolloids on protein-enriched, instant noodles cooking qualities

Cooking qualities are very important parameters in the determination of the acceptability of noodles by consumers, and have been connected to low cooking loss (Zhou et al. 2013). The optimal cooking time (OCT) was determined as the time required for the disappearance of the white core in the noodle strand. It depended on the hydration rate of the major components such as starch and protein. A response surface plot of the hydrocolloid interaction on OCT showed that it increased when all hydrocolloid concentrations were increased (Fig. 1a and 1b) similar to the result of Padalino et al. (2013). The longer cooking time in the presence of gums was due to the limited availability of water to the starch granules due to competition from other macromolecules which caused a delay in the swelling and gelatinization of granules (Shittu et al. 2009). Chaisawang and Supphantharika (2005) explained that the presence of gum protected the starch granules from swelling and influenced the gelatinization characteristics of starch by increasing the onset gelatinization temperature. The highest OCT condition was found with the addition of xanthan gum due to its anionic charge and branch structure, which meant it could inhibit starch swelling and starch gelatinization and prevent amylose leaching better than a neutral gum such as guar gum (Silva et al. 2013).

The cooking loss parameters could indicate the structural strength of noodles because a strong protein-starch matrix can inhibit the diffusion of amylose into the cooking water during cooking (Bustos et al. 2011). A high loss of solids during cooking of the noodles results in poor quality noodles due to their less firm structure (Kaur et al. 2015). Therefore, less than 10% cooking loss of cooked noodles is required. In the current study, the highest cooking loss was found in the control which could be explained in terms of the weak interactions between the fiber and the protein starch matrix to encapsulate the native starch. The results also showed that the noodles prepared with all hydrocolloids had significantly ($P \leq 0.05$) lower cooking losses than the control. The response surface plots indicated that the addition of hydrocolloid at 2 g concentration had a lower cooking loss than at 1 g concentration (Fig. 1c), which was similar to the result of Lü et al. (2014) who reported the cooking loss reduced with the addition of guar gum. Silva et al. (2013) explained the lower cooking loss of noodles containing hydrocolloids by noting that the hydrated polysaccharide network could encapsulate the starch granules and this created stable-starch granules in the matrix system (Zhou et al. 2013). Menon et al. (2015) offered supporting evidence that hydrocolloids created a strong association of soluble starch such as amylose and

increased the stability and viscosity which led to lower leaching of amylose into the cooking water. The lowest cooking loss was found with the addition of CMC (Fig. 1d) because an electrostatic complex with gluten proteins was formed by the addition of CMC that increased the gluten network strength and reduced the cooking loss (Kishk et al. 2011).

Effect of hydrocolloids on protein-enriched, instant noodles textural properties

Texture is an important attribute of food acceptance by consumers, which is defined by a smooth surface, firm texture and good mouth feel (Zhou et al. 2013). In the current study, the maximum tension force indicated the noodle tensile strength and the maximum distance indicated noodle extensibility. All conditions of added hydrocolloids significantly ($P \leq 0.05$) increased the maximum tension force and maximum distance when compared to the control. Moreover, higher concentrations resulted in concomitant increases (Fig. 1e) due to the interaction between the hydrocolloids and wheat protein to improve the gluten network strength and the increase in the wheat starch viscosity during gelatinization (Ribotta et al. 2005). The highest maximum tension force conditions resulted from the addition of 2 g xanthan gum because of the rigid, ordered conformational structure of the xanthan gum molecules compared with the extended conformational structure of guar gum molecules. Xanthan gum could reinforce the three-dimensional network structure of the starch pastes better than guar gum (Chaisawang and Supphantharika 2006). Therefore, the addition of 2 g xanthan gum in the EPIN resulted in the highest tensile strength. These results paralleled those obtained by Pan et al. (2016) and Yalcin and Basman (2008), who indicated that the improvement in texture properties was maximized with xanthan gum which improved the structure of noodles by ionic charges of the hydrophilic component interacting with proteins (Gull et al. 2016).

The maximum distance significantly ($P \leq 0.05$) increased with the addition of all hydrocolloids (Fig. 1f) because the wheat starch viscosity was increased with the addition of hydrocolloids during gelatinization. However, at high concentration, they decreased the noodle extensibility because their high hydrophilicity competed with the wheat protein and starch for water. The high molecular weight of hydrocolloids could interfere with gluten network formation. Similar observations were reported by Silva et al. (2013) as xanthan gum, with its high water binding capacity, could increase the strength and stiffness of cooked broccoli powder noodles by interaction between its polar groups and the peptide chains of the gluten (Ribotta et al. 2005).

Optimum cooking time

Cooking loss

Texture properties

Fig. 1 Response surface plots of protein-enriched, instant noodles on **a** Optimum cooking time by GG and CMC and **b** by XG and CMC, **c** Cooking loss by GG and XG and **d** XG and CMC, **e** Maximum tension force by GG and XG, and **f** Maximum distance by GG and XG. GG guar gum, XG xanthan gum, CMC carboxymethyl cellulose

Based on the experimental results of the response surface methodology, the significant effects on the cooking and texture quality due to the hydrocolloid components were modeled using regression analysis. R^2 indicates the fraction of the variation of the response explained by the model. Regression analyses for the moisture content, cooking loss, maximum tension force and maximum distance indicated that the models provided statistically good fits for more than 80% of the variation in the experimental data and as such, the models could be considered reliable and suitable for explaining the effect of noodle quality as a function of the three hydrocolloids as follows:

Moisture content (% wet basis)

$$= 9.94 + 0.89GG + 0.60XG + 0.20XG^2 + 0.18CMC^2 \\ - (0.26GG \times XG) - (0.25GG \times CMC) \\ - (0.43XG \times CMC) \\ (\text{Adjusted } R^2 = 0.91)$$

$$\text{Cooking loss (\%)} = 8.50 - 0.58GG + 0.37XG \\ + 0.73CMC - 0.33XG^2 - 0.60CMC^2 \\ + (0.16GG \times XG) + (0.23GG \times CMC) \\ + (0.03XG \times CMC) \\ (\text{Adjusted } R^2 = 0.97)$$

$$\text{Maximum tension force (g force)} = 8.80 + 1.56GG \\ + 7.32XG - 1.70XG^2 + 1.31CMC^2 \\ - (1.96GG \times XG) + (0.43GG \times CMC) \\ - (1.22XG \times CMC) \\ (\text{Adjusted } R^2 = 0.92)$$

$$\text{Maximum distance (mm)} = 11.80 + 6.56XG \\ + 3.16CMC - 1.83XG^2 - 1.81CMC^2 \\ - (1.53GG \times XG) + (0.82GG \times CMC) \\ - (1.16XG \times CMC) \\ (\text{Adjusted } R^2 = 0.84)$$

where GG is guar gum, XG is xanthan gum and CMC is carboxymethyl cellulose.

Pasting properties

The pasting characteristics of wheat flour and wheat flour-gum mixtures determined using RVA analysis are

summarized in Table 2. The addition of hydrocolloids significantly ($P \leq 0.05$) changed the viscosity values. Wheat flour–water had the lowest viscosity, while wheat flour-hydrocolloid increased the peak, break down, final, and setback viscosities compared to the wheat flour alone, which was similar to the results of Huang (2009). The increase in the peak viscosity by the addition of hydrocolloid could have been due to the addition of thickening gums enhancing the forces exerted on the swollen granules in the shear field, which were larger than for the starch-alone system (BeMiller 2011). However, the result showed that the effects on the viscosity of guar gum were less pronounced than of xanthan gum and CMC due to the interaction between the hydrocolloid and protein being attracted by repulsive interactions between biopolymers. Anionic hydrocolloids, such as xanthan gum and CMC, could form an electrostatic complex with some fractions of gluten proteins better than neutral hydrocolloids. Moreover, the rigid, ordered, conformational structure of xanthan molecules could reinforce the three-dimensional network structure of the starch pastes better than guar gum. These results corresponded well with the longer cooking time of noodles with the addition of xanthan gum as the gum protected the starch granules from swelling (Rojas et al. 1999). The interactions between xanthan and guar gum can have synergistic effects as the peak viscosities of wheat flour-GG and wheat flour-XG were enhanced from 1625.67 and 2024.33 Cp, respectively, to 2499.33 Cp. When xanthan interacted with galactomannan molecules, the interactions occurred between the xanthan helix and the smooth region of the galactomannan, which resulted in a higher viscosity in the mixture. The addition of CMC increased the peak, break down, final, and setback viscosities due to the interaction between free carboxyl groups and the amino groups of protein. The higher peak viscosity suggested that the addition of CMC could assist the swelling of the starch granules. These results indicated that the addition of guar gum, xanthan gum and CMC could improve the quality of noodles by increasing the viscosity that related to the reduction of amylose leaching from the granules (Mohammadia et al. 2014), which had a positive effect on the cooking and texture properties of noodles.

Microstructure of dried, instant noodles with and without hydrocolloids

SEM was used to investigate the structural integrity of the surface and cross section of dried, protein-enriched, instant noodles with and without hydrocolloids as shown in Fig. 2. Supplementing instant noodles with chicken meat, egg yolk and seaweed without hydrocolloid showed a rough surface and discontinuities in the protein network (Fig. 2a) which could be explained by the fiber supplements disrupting the

Table 2 Effect of guar gum, xanthan gum and carboxymethyl cellulose on the pasting properties of wheat flour

	Pasting parameters (Cp)			
	Peak viscosity	Break down	Final viscosity	Setback
Wheat flour	1177.33 ^a ± 13.20	82.33 ^a ± 0.58	1607.00 ^a ± 72.27	1518.33 ^a ± 75.87
Wheat flour + GG	1625.67 ^b ± 48.18	92.67 ^{ab} ± 9.71	2145.33 ^b ± 62.42	2005.67 ^b ± 64.27
Wheat flour + XG	2024.33 ^{cd} ± 161.66	125.00 ^b ± 13.89	2440.67 ^c ± 184.35	2018.67 ^b ± 113.29
Wheat flour + GG, XG	2499.33 ^f ± 60.93	196.67 ^{cd} ± 27.32	2794.00 ^{de} ± 120.55	2278.33 ^{bc} ± 103.55
Wheat flour + CMC	1845.00 ^c ± 54.67	83.00 ^a ± 1.73	2316.67 ^{bc} ± 82.57	2133.33 ^b ± 62.05
Wheat flour + GG, CMC	2234.00 ^{de} ± 189.07	115.67 ^{ab} ± 6.43	2671.33 ^d ± 162.24	2419.33 ^c ± 126.75
Wheat flour + XG, CMC	2252.00 ^e ± 175.19	170.00 ^c ± 34.39	2907.33 ^e ± 136.69	2482.00 ^c ± 233.41
Wheat flour + GG, XG, CMC	3040.00 ^f ± 139.77	216.00 ^d ± 41.51	3221.67 ^f ± 147.45	2529.33 ^c ± 283.66

Means with different, lowercase superscripts in the same column are significantly different ($P \leq 0.05$)

GG guar gum, XG xanthan gum, CMC carboxymethyl cellulose

Surface

a Without hydrocolloid

b 2 g GG

c 2 g XG

d 2 g CMC

Cross section

e Without hydrocolloid

f 2 g GG

g 2 g GG and 2 g CMC

Fig. 2 SEM micrographs of dried instant noodles. **a** Surface without hydrocolloid, **b** surface with 2 g of GG, **c** surface with 2 g XG, **d** surface with 2 g CMC, **e** porosity without hydrocolloid, **f** porosity

with 2 g GG, **g** porosity with 2 g GG and 2 g CMC. GG guar gum, XG xanthan gum, CMC carboxymethyl cellulose

protein-starch matrix, diluting the gluten strength and weakening the overall structure of instant noodles. This interference agreed with the negative results observed in cooking behavior and texture measurements. Moreover, many empty spaces were generated in protein-enriched, instant noodles without the addition of hydrocolloid (Fig. 2e) due to the non-uniform distribution of the chicken meat, which contained a high moisture content and had high dielectric properties. Subsequent microwave cooking

caused the conversion of water in the food to vapor, creating large voids and a porous structure. Therefore, this provided evidence of a less optimum cooking time in this condition.

SEM confirmed the changes in the noodle microstructure as hydrocolloid supplementation affected the gluten network development to produce a smooth surface and a continuous matrix (Fig. 2b–d). Bárcenas et al. (2009) explained that the gluten network was formed by hydrogen

and disulphide bonds between gliadins and glutenins. Then, the electric charge of the hydrocolloid could increase the interaction with gluten proteins and improved the gluten network formation and texture properties of instant noodles. Moreover, the hydrocolloid created a more uniform water distribution in the noodle system due to binding of water-soluble starch by hydrocolloids (Menon et al. 2015). When fresh noodles were subjected to microwave heating, they produced a more uniform, porous structure than without hydrocolloids (Fig. 2f). The micrographs for the addition of 2% GG and 2% CMC showed a denser continuous phase (Fig. 2g), which might have been due to the interaction between the hydrocolloids and the protein gluten filled in the network space (Choy et al. 2012). Thus, the protein-starch matrix appears to be developed with strong and continuous protein. This may explain both the reduced cooking loss and the significantly altered textural characteristics. Therefore, it indicated the potential for improving the texture of EPIN with the addition of the hydrocolloid.

Moisture content and dielectric properties of hydrocolloids

The regression analysis of the moisture content indicated that the ratio of hydrocolloids had a greater, positive, linear relationship on the moisture content because of the water binding and holding properties of the hydrocolloid (Škara et al. 2013). According to Ministry of Public Health Thailand (2000), the final moisture content of dried, instant noodles should be less than 12% to provide microbial stability and a shelf life longer than 1 year. The highest moisture content was found with the addition of xanthan which has a high water-holding capacity attributed to the presence of hydroxyl groups, and this allows more water interactions through hydrogen bonding (Burešová et al. 2016).

An understanding of ingredient behavior with microwave heating is important in choosing the ingredients and to develop the best performance. Dielectric properties determine the interaction between the electromagnetic energy and the materials. The dielectric constant quantifies the capacity of a material to store energy when subjected to an electric field while the loss factor is related to the amount of energy transformed into heat. The addition of guar gum and xanthan gum significantly ($P \leq 0.05$) increased the dielectric constant of the noodle dough (Fig. 3). The dielectric properties varied depending on the moisture content. Increasing the amount of hydrocolloid in the system caused greater water retention and a change in the amount of free water in the noodle system which affected the dielectric properties. In addition, all hydrocolloids significantly ($P \leq 0.05$) increased the dielectric loss factor due to the high moisture content. Free water is

Fig. 3 Dielectric constant and loss factor of the addition of guar gum, xanthan gum and carboxymethyl cellulose of protein-enriched noodle dough. GG guar gum, XG xanthan gum, CMC carboxymethyl cellulose

the major factor controlling the rate of microwave heating in a hydrocolloid-thickened system. The binding water molecules changed their hydration and viscosity properties, which affects the dielectric properties. Guar gum with its neutral charge had a lower dielectric loss factor than either xanthan or CMC. Dielectric properties are highly dependent on the charge of the hydrocolloid (Guardeño et al. 2010). Therefore, anionic gum seems to be suitable as a product ingredient for microwave heating.

Optimization of hydrocolloids dosage

The calculation of the optimum conditions was performed using a multiple response optimization method. Five target conditions (the final moisture content not over 12% wet basis, optimum cooking time less than 3 min, cooking loss less than 10%, maximum tension force of 15–18 g force and maximum distance of 13–18 mm) were utilized to optimize the formulation for protein-enriched, instant noodles. To predict the results with higher reliability, the optimization was carried out within limits for the chosen ranges. Finally, the optimum conditions were identified as the addition of 1.60 g GG and 1.90 g CMC per 100 g wheat flour. The predicted values under the optimum conditions were a moisture content of 11.25% wet basis, a cooking loss of 7.49%, a maximum tension force of 17.33 g force and a maximum distance of 13.76 mm. To validate this model, the addition of 1.60 g guar gum and 1.90 g CMC per 100 g wheat flour was used to prepare

instant noodles in triplicate for experimental assessment. The experimental values obtained were: a moisture content of $11.22 \pm 0.03\%$ wet basis, a cooking loss of $7.52 \pm 0.02\%$, a maximum tension force of 17.29 ± 0.07 g force and a maximum distance of 13.78 ± 0.07 mm, which were in good agreement with the predicted values. This indicated the suitability of the model employed in optimizing the ingredients of protein-enriched, instant noodles, which will be useful in identifying the gums for improving the noodle characteristics.

Sensory characteristics of cooked, protein-enriched, instant noodles with and without hydrocolloid

Sensory analysis gives a perspective of the potential consumer's acceptance which can impact future commercialization. Generally, consumers expect a firmer texture, non-sticky surface, good mouth feel, color and appearance. The results of the hedonic test on parameters such as color, odor, flavor, texture and overall quality of cooked, protein-enriched, instant noodle with and without hydrocolloid (1.60 g guar gum per 100 g wheat flour and 1.90 g CMC per 100 g wheat flour) are presented in Fig. 4. The sensory evaluation results of the product showed that protein-enriched, instant noodle with hydrocolloid received a significantly higher score than the control in terms of color, flavor and overall acceptability. Overall acceptability was scored as moderately like, whereas the protein-enriched, instant noodle without hydrocolloid was scored as slightly like. Therefore, the addition of hydrocolloid could have great potential to improve the qualities of protein-enriched, instant noodle which has a higher nutritional value in terms of protein and fiber and was accepted by consumers.

Fig. 4 Sensory evaluation of PEIN with and without hydrocolloid added. GG guar gum, XG xanthan gum, CMC carboxymethyl cellulose

Conclusion

Protein-enriched, instant noodle was supplemented with chicken meat, egg yolk and seaweed and dried using a continuous microwave oven to provide a higher protein content in the product and reduce undesirable oil in the noodle strands. Further supplementation with hydrocolloid significantly increased the viscosity of the wheat flour mixture, which was related to an improvement in the textural characteristics due to the higher tensile strength and extensibility of the added xanthan gum and an improvement in the cooking quality due to the lower cooking loss of noodles with the addition of CMC, which related to the uniform surface of the microstructure. Anionic gums such as xanthan and CMC significantly increased the dielectric properties of the noodle dough which in turn provided more interaction of the food during microwave heating. However, xanthan gum resulted in a longer optimum cooking time. Therefore, 1.60 g guar gum and 1.90 g CMC per 100 g wheat flour were chosen as the optimum conditions and there was good acceptance of the developed products. From the overall results, it could be concluded that the addition of guar, xanthan and CMC produced a very good quality product of protein-enriched, instant noodles owing to the modifications to the cooking loss and texture properties, which were confirmed by the smooth surface microstructure. Therefore, the product was accepted by panelists and is suitable for the modern-day, rushed lifestyle where the product has the desirable attributes of convenient to prepare, acceptable taste, higher protein and fiber and a lower oil content.

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