IMPACT OF HYDROCOLLOIDS ON THE PHYSICO-CHEMICAL AND SENSORY PROPERTIES OF GLUTEN-FREE INSTANT NOODLES FROM RICE FLOUR AND MUNG BEAN STARCH

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ABSTRACT

The physico-chemical properties of gluten-free (GF) instant noodles prepared from rice flour and mung bean starch containing hydrocolloids that were carboxymethyl cellulose (CMC), hydroxypropylmethyl cellulose (HPMC), guar gum (GG) and xanthan gum (XG) had been investigated. The results were found that the sample that contained CMC had the least fat uptake and cooking time. Different hydrocolloids had no effect on the gelatinization parameters of the noodle dough. The addition of GG improved the textural properties and cooking yields of the GF instant noodles. The samples that were enriched with HPMC showed a significantly lower cooking loss than the others did. An undesirable characteristic was found in the GF noodles that incorporated XG. Microstructural image of sample containing XG revealed a non-continuous matrix. The addition of either GG or HPMC improved the sensory properties of the GF instant noodles.

Keywords: gluten-free, guar gum, hydrocolloid, instant noodles, sensory evaluation, thermal properties

1. INTRODUCTION

Instant noodles are a popular food consumed in Asian countries due to their convenience, taste, prolonged shelf life, nutrition and low cost. They are an internationally recognized food (GULIA *et al.*, 2014). Moreover, 100 million servings of instant noodles were consumed worldwide in 2017 (WINA, 2018). The main ingredients of instant noodles are wheat flour, water, salt and alkaline salt. However, consuming wheat-containing foods, which contains gluten, may cause an allergenic response, especially in those who have celiac disease. In addition, there is a rising demand for gluten-free (GF) products over the past decade (CHRISTOPH *et al.*, 2018; HOUBEN *et al.*, 2012). One way to develop such a product is by using non-gluten flour, such as rice flour, as a raw material to substitute wheat flour. Rice is hypoallergenic, mild and colorless (GARCIA *et al.*, 2016; WU *et al.*, 2019). It is also a staple food and the most important crop in Thailand.

Rice flour, however, cannot form a cohesive dough structure since rice protein lacks the functionality of wheat gluten (elasticity) (KAWAMURA-KONISHI *et al.*, 2013; SOZER, 2009). Therefore, the application of heat moisture treated rice flour (CHAICHAW *et al.*, 2011), guar gum (GG) (SABBATINI *et al.*, 2014), xanthan gum (XG) (SABBATINI *et al.*, 2014; YALCIN and BASMAN, 2008), locust bean gum (YALCIN and BASMAN, 2008) and hydroxypropylmethyl cellulose (HPMC) (SABBATINI *et al.*, 2014) are added to obtain a viscoelastic dough when preparing the GF noodles.

Hydrocolloids provide a broad range of functional properties that make them suitable for each application (ANTON and ARTFIELD, 2008). Carboxymethyl cellulose (CMC), GG, locust bean gum and alginates are hydrocolloids that widely used in instant wheat noodle processing (GULIA *et al.*, 2014). Hydrocolloids mimic the viscoelastic properties of gluten (ANTON and ARTFIELD, 2008; SUWANNAPORN and WIWATTANAWANICH, 2011) and improve cooking quality and textural properties of gluten-free pasta (MARTI and PAGANI, 2013; PADALINO *et al.*, 2013; SUSANNA and PRABHASANKAR, 2013). The improvement of cooking and textural properties of GF noodles that contains GG has been shown (KUNYANEE *et al.*, 2015; SABBATINI *et al.*, 2014). The incorporation of XG and gelatinized rice flour improved the dough forming ability and the cooking and sensory properties of the rice noodles (YALCIN and BASMAN, 2008). The HPMC and CMC can form thermo-gelling films (MELLEMA, 2003), which result in a reduction of oil absorption in instant fried wheat noodles (REKAS and MARCINIAK-LUKASIAK, 2015) and deep-fried legume snack foods (PRIYA *et al.*, 1996). However, CMC has a small effect on the reduction of fat uptake in instant fried wheat noodles (CHOY *et al.*, 2012). Wheat-rice noodles that contain CMC have an improved textural quality and they possess sensory qualities that are comparable to wheat noodles (SUWANNAPORN and WIWATTANAWANICH, 2011). In addition, CMC and HPMC may have quite different properties i.e. solubility, thermal gelation, thickening capacity that make them adequate as food additives (CORREA *et al.*, 2010).

The ingredients, formulation and processing parameters have an influence on the quality of instant noodles (GULIA *et al.*, 2014). This study, therefore, aims to investigate the effect of hydrocolloids including GG, HPMC, CMC and XG on the qualities of GF instant noodles.

2. MATERIALS AND METHODS

2.1. Materials

Rice flour was purchased from Varavoot Industry Co. Ltd. in Angthong, Thailand. Mung bean starch was purchased from a local market in Nakhon Pathom, Thailand (Tonson, Sitthinan Co. Ltd). The hydrocolloids used in this study included GG (Union Chemical 1986 Co. Ltd., Bangkok, Thailand), HPMC (Methocel K4M, Dow Chemical Co. Ltd., Samut Prakan, Thailand), CMC (Chemipan Corporation Co., Ltd., Bangkok, Thailand) and XG (Thai Food and Chemical Co. Ltd., Bangkok, Thailand).

2.2. Preparation of instant fried noodles

The dough was formulated by mixing 55.6% rice flour and 2.8% mung bean starch, 0.5% salt (NaCl), 0.5% alkaline salt (Sodium carbonate), 5.6% pasteurized liquid whole eggs, 1.7% hydrocolloid and 33.3% water. Rice flour, mung bean starch and hydrocolloid were mixed in a mixer (Kitchen Aid K5SS, USA). The pasteurized liquid whole eggs and water containing dissolved salts and alkaline salt were then added, respectively. The mixer was operated at speed 2 until the resultant dough became crumbly (10 minutes) and then it was manually kneaded to form a dough ball. It was then sheeted using a pasta machine (Marcato ATLAS 150, Italy) to obtain a final thickness of 1.0 mm, and it was cut into strips 15 cm in length and 0.18 cm in width. The noodle strands were steamed for 10 minutes, cooled at room temperature and fried in palm oil (Morakot Industries PCL., Thailand) at 150°C for 45 seconds. The fried noodles were cooled at room temperature and the excess oil was drained. Finally, the instant fried noodles were stored in resealable plastic bags for analysis.

2.3. Chemical analysis

The proximate composition (moisture, protein and ash) of the instant noodles was analyzed using the Association of Official Analytical Chemists method no. 925.10, 920.87 and 923.03, respectively (AOAC, 2000) and each sample was carried out in triplicate. An analysis of fat content was performed using automated Soxhlet extraction according to a modified method that is described by REKAS and MARCINIAK-LUKASIAK (2015). The total carbohydrate content was determined by calculation using the difference method (100 - (weight in grams [protein + fat + ash] in 100 g of food (dry solid))).

2.4. Scanning electron microscopy (SEM)

The cross-section images of the instant fried noodles prior to cooking in boiling water were observed using a Field Emission Scanning Electron Microscopy (FE-SEM, Tescan Mira3, Kohoutovice, Czech Republic) at the operating voltage of 5.0 kV. The instant noodle samples were fractured into pieces of an approximately 1 cm in length and defatted using the automated Soxhlet extraction. The defatted instant fried noodles were attached to a circular specimen stub with double-sided adhesive tape and coated with gold using a sputter coater.

2.5. Thermal properties

An analysis of the thermal properties of the fresh noodles before they were steamed and fried was conducted using a Differential Scanning Calorimeter (DSC8000, Perkin Elmer, Shelton, CT, USA). An empty stainless steel pan was used as a reference and each noodle dough sample was weighed in a stainless steel pan. Distilled water was added into the sample pan to bring the water content to 70%. The sample pan was sealed hermetically and equilibrated for 1 hour at room temperature before the DSC measurement. The sample pan was heated from 25°C to 130°C at a ramp rate of 10°C/min to obtain the characterization of gelatinization. The onset temperature (T_o), peak temperature (T_{p1} and T_{p2}), final temperature (T_f), and enthalpy of gelatinization (ΔH) were determined.

2.6. Cooking properties

The optimum cooking time, cooking loss and cooking yield (or water absorption) of the instant noodles were determined according to the American Association of Cereal Chemists Official Methods (AACC, 2000) with slight modification. The noodle samples, which was approximately 10g were broken into pieces with an approximate lengths of 5 cm, they were placed in a beaker that contained 120ml of boiling distilled water and then the timing started. The noodle strands were removed from the cooking water at 10 seconds time intervals and they were squeezed between two pieces of glass plates. The time required to the sample as having an "optimum cooking time" was when the opaque central core of the sample disappeared. Samples that were 15g were cooked at optimum cooking time in 180 ml of boiling distilled water. After cooking, the samples were rinsed with 50 ml of distilled water, placed in the water at room temperature for one minute and drained before the weight was recorded. The results were calculated for percentage of "cooking yield." The cooking loss was the amount of solid loss in the cooking water. The cooking water was added to a pre-weighed beaker and evaporated over a steamed bath, and then it was put into hot air oven at a temperature of 105°C until a constant weight was obtained and reported as a percentage of "cooking loss." The analysis was performed in triplicate for each sample.

2.7. Texture profile analysis

The texture measurements of the cooked instant noodles were evaluated using a TA-XT2 texture analyzer (Stable Micro System, London, England) and the procedure described by CHOY *et al.* (2012) with modifications. The samples were cooked for the optimum cooking time as described above and cooled in tap water (~17°C) for 1 minute. Then, the cooked noodles were retained at room temperature in a covered plastic container. The noodles were compressed using a cylinder probe (P/50) at 2.00 mm/s speed (pre-test, test and post-test) and 75% strain. The parameters that were obtained from the force-time curve of the texture profiles analysis (TPA) were hardness, adhesiveness, springiness, cohesiveness and chewiness.

2.8. Sensory evaluation

The instant noodles were served after cooking and evaluated by fifty untrained panelists who like eating instant noodles (48 females and 2 males). The sensory evaluations were performed using a 9-point hedonic scale. The panelists scored each sample and assigned scores on a scale of 1 (extremely disliked) to 9 (extremely liked) for appearance, color, firmness, springiness and overall acceptability.

2.9. Statistical analysis

A statistical analysis was conducted on the experimental data using a one-way analysis of variance (ANOVA), and a comparison of the means was completed by Tukey's test with a significance level of $p<0.05$. Analysis of variance (ANOVA) was carried out using the SPSS 10.0 (SPSS Inc., USA).

3. RESULTS AND DISCUSSION

3.1. Proximate composition of instant noodles

The chemical composition of the GF instant noodles are shown in Table 1. Moisture, fat, ash and carbohydrate contents of all samples were 5.01-7.80%, 14.09-18.09%, 1.56-1.94% and 73.98-77.83%, respectively. The moisture content of the noodles was reduced from around 40% to 5-8% when they were fried in oil. The fat content of the fried noodles was generally in a range of between 15-20% (GULIA *et al.*, 2014). All the samples met the standard requirements as specified by the Notification of Ministry of Industry, Thailand. Hydrocolloid type had an influence on moisture and fat contents of the final products. The GF instant noodles that contained GG had the lowest moisture content ($p<0.05$). The lowest fat content was obtained in the sample containing CMC. Fat uptake are related to two main mechanisms: condensation and capillary mechanisms; in both, oil penetrates through the pores inside the product (MELLEMA, 2003). The differences in fat content of instant fried noodles come from the microporous structure of the product and from the amount of water absorbed in the evaporation process (MARCINIAK-LUKASIAK *et al.*, 2019; MELLEMA, 2003). The ability of CMC to reduce oil absorption was linked to its hydrophilic character (ANG and MILLER, 1991) and the final product porosity (PINTHUS *et al.*, 1995).

Table 1. Proximate composition of the GF instant fried noodles containing different hydrocolloids.

Samples	Content (g/100 g of dry basis)				
	Moisture	Protein^{NS}	Fat	Ash	Carbohydrate
GG	5.01±0.09^{c}	6.16±0.02	18.09±0.19^{a}	1.56±0.02^{b}	74.19±0.16^{b}
HPMC	7.80±0.02^{a}	6.29±0.01	18.09±0.08^{a}	1.67±0.02^{b}	73.96±0.07^{b}
CMC	7.72±0.07^{a}	6.15±0.04	14.09±0.81^{b}	1.94±0.03^{a}	77.83±0.80^{a}
XG	5.97±0.08^{b}	6.20±0.09	16.74±0.65^{a}	1.86±0.04^{a}	75.21±0.51^{b}

Guar gum (GG), hydroxypropylmethyl cellulose (HPMC), carboxymethyl cellulose (CMC) and xanthan gum (XG) were used in this study.
Results are expressed as mean values ± standard deviations.
Means with same superscripts in a row are not significantly different ($p\geq0.05$) as assessed by Tukey's test.
^{NS} = values in the same column are not significantly different (*probability value,* $p\geq0.05$).

In addition, CMC had greater hydrophilicity than HPMC (ADEDEJI A.A. and MO, 2011). The thermal gelation of this hydrocolloid also created an oil-resistant film around the fried product and resulted in an increased in its water holding capacity because it entrapped the food moisture inside and lowered the fat absorption (ANG and MILLER, 1991; SAKHALE *et al.*, 2011; YAZDANSETA *et al.*, 2015).

3.2. SEM

The microstructure in the cross section of the GF instant noodle strands (after frying) is shown in Fig. 1. Generally, during the frying process, many microporous were created as the water was quickly removed, which left empty spaces in the hole structures of the noodles that were replaced by oil (HOU, 2001; ZIAIIFAR *et al.*, 2008). The cross-section structure of the GF instant fried noodles that were incorporated with different hydrocolloids had many pores with various sizes and thicknesses. The structure of the instant fried noodles with CMC (Fig. 1c) presented small pore sizes and a fewer number of voids and hollows compared to the others. The sample with XG (Fig. 1d) showed a non-continuous matrix noodle structure, a more open area and a large voids and hollows.

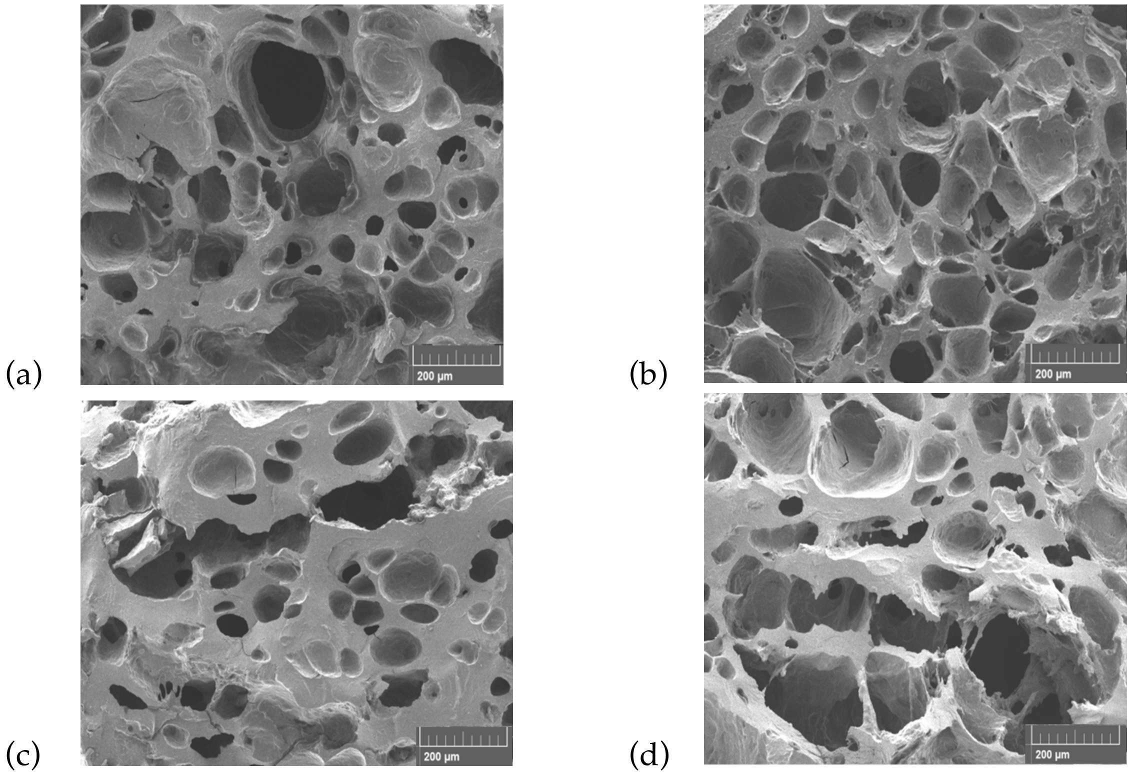

Figure 1. Scanning electron microscopy (SEM) of the GF instant fried noodles that contained **(a)** guar gum (GG), **(b)** hydroxypropylmethyl cellulose (HPMC), **(c)** carboxymethyl cellulose (CMC) and **(d)** xanthan gum (XG).

3.3. Thermal properties

The gelatinization temperature and enthalpy changes of the dough are important for an understanding of these phenomena during the thermal process (SABANIS and TZIA, 2011). All the GF instant fried noodles did not observe an endothermic peak of gelatinization, which indicates that the starches in those samples were fully gelatinized after frying (data not shown). DSC thermograms of the fresh noodles (before steaming and frying) with different hydrocolloids showed biphasic endotherm referred to as G and M1 endotherms, which is in accordance with the finding of PRAKAYWATCHARA *et al.* (2018). The first peak (Tp_1 or G endothermic peak) is attributed to the swelling of partially degraded starch chains and the second peak (Tp_2 or M1 endothermic peak) reflects the ''melting'' of the remaining crystallites (KIM *et al.*, 2014; XING *et al.*, 2017). The samples with different hydrocolloids were not significantly changed in all thermal properties (p≥0.05) (Table 2). It indicated that the hydrocolloids used in this study had no effect on the thermal properties of the noodle dough.

Table 2. Thermal properties of fresh GF noodles that contained different hydrocolloids.

Samples	T_o (°C)^{NS}	T_{p1} (°C)^{NS}	T_{p2} (°C)^{NS}	T_f (°C)^{NS}	ΔH (J/g)^{NS}
GG	68.57±0.15	74.10±0.01	82.96±0.04	90.43±0.10	9.31±0.41
HPMC	68.55±0.10	74.39±0.09	82.86±0.29	90.35±0.03	8.08±0.64
CMC	68.66±0.13	74.33±0.01	83.29±0.08	90.49±0.08	8.60±0.05
XG	68.54±0.06	74.10±0.16	82.72±0.23	90.43±0.07	8.26±0.23

Guar gum (GG), hydroxypropylmethyl cellulose (HPMC), carboxymethyl cellulose (CMC) and xanthan gum (XG) were used in this study.
Results are expressed as mean values ± standard deviations.
^{NS} = values in the same column are not significantly different (*probability value, p*≥0.05).

3.4. Cooking qualities of the instant noodles

The cooking quality characteristics of the GF instant fried noodles, including optimum cooking time, cooking loss and cooking yield, are presented in Table 3. The optimum cooking times of all the samples ranged from 2.50 to 3.10 minutes. The samples that contained XG had the longest optimum cooking time. The longer optimum cooking times may be attributed to the limited availability of water to the starch granules, which resulted in the retardation of starch swelling (KAUR *et al.*, 2015). On the other hand, the noodles that were incorporated with CMC had the shortest optimum cooking time. This may be due to the carboxyl and hydroxyl groups in the structure of the gum, which allowed them to bind with the readily available water and caused an increment in the swelling index and water absorption (GULL *et al.*, 2016).
Cooking loss was related to the structural strength of the noodles, and a higher value indicated a lower structural strength. Because the soluble starch and other soluble components, including non-starch polysaccharides, leached out into the water during cooking (GULL *et al.*, 2016). The cooking loss for a good quality noodle should be lower than 12% (UGARCIC-HARDI *et al.*, 2007). In this study, the cooking loss of the GF instant noodles was between 8.50 and 14.46% (Table 3). The sample that contained HPMC was the

most effective for reducing the cooking loss because the hydrated HPMC network may have been surrounded in the starch-protein matrix and confined the excessive swelling and diffusion of the amylose content (PURNIMA *et al.*, 2012). Finally, the noodles that contained XG had the highest cooking loss, perhaps because the XG interfered with the gel compactness (HAN *et al.*, 2011) as observed in Fig. 1(d).
The cooking yield explains the ability of the noodles to absorb water during the cooking process (TAN *et al.*, 2016). The highest cooking yield was observed in the samples in which GG was added, followed by CMC, HPMC and XG, respectively. This result may be due to the ability of the GG to absorb water in its interrelated network and interact with starch granules (RODGE *et al.*, 2012).

Table 3. The cooking qualities of the GF instant fried noodles incorporating different hydrocolloids.

Samples	Optimum cooking time (min)	Cooking loss (%)	Cooking yield (%)
GG	3.00	10.84±0.86[b]	297.26±6.13[a]
HPMC	3.00	8.50±0.79[c]	270.32±5.43[c]
CMC	2.50	10.34±0.59[bc]	281.11±5.29[b]
XG	3.10	14.46±1.70[a]	228.79±7.49[d]

Guar gum (GG), hydroxypropylmethyl cellulose (HPMC), carboxymethyl cellulose (CMC) and xanthan gum (XG) were used in this study.
Results are expressed as mean values ± standard deviations.
Means with same superscripts in a row are not significantly different (*probability value*, $p \geq 0.05$) as assessed by Tukey's test.

3.5. Textural properties of the instant noodles

Textural characteristics are an important parameter that determines the acceptance of the noodles (WU *et al.*, **2015**). Hardness, springiness, cohesiveness and chewiness of the instant GF noodles with GG addition presented the highest values (Table 4). These results indicated that a strong network could be formed by an interaction between amylose in the molecules of starch and GG, resulting in a three-dimensional structure and an increase in gel hardness (KUNYANEE *et al.*, 2015). The springiness referred to the elasticity of the noodles and assessed the ability of the noodle to regain its original shape after compression (EPSTEIN *et al.*, 2002). The addition of XG presented the lowest amount of springiness in the instant noodles. Similar results have been reported by SUWANNAPORN and WIWATTANAWANICH (2011). XG did not enhance the elasticity of wheat-rice noodles (SUWANNAPORN and WIWATTANAWANICH, 2011) and increase the dough resistance during extension (COLLAR *et al.*, 1999). HPMC was effective for reducing the cooking loss of the instant GF noodles, but it showed a relatively high adhesiveness in the cooked samples. Similarly, HAN *et al.* (2011) also observed the same trend in noodles that contained locust bean gum and they reported that the soluble starch that resided on the noodle surface directly affected their adhesiveness. Finally, they found that this hydrocolloid was also effective for the promotion of a gel matrix formation (HAN *et al.*, 2011).

Table 4. The textural characteristics of the GF instant noodles containing different hydrocolloids.

Samples	Hardness (N)	Adhesiveness (N.sec)	Springiness	Cohesiveness	Chewiness
GG	34.12±2.19^{a}	0.78±0.13^{b}	0.88±0.02^{a}	0.71±0.02^{a}	21.17±1.94^{a}
HPMC	30.18±2.63^{b}	1.02±0.16^{a}	0.85±0.05^{ab}	0.64±0.02^{b}	16.52±2.13^{b}
CMC	25.86±2.73^{c}	1.07±0.10^{a}	0.84±0.05^{ab}	0.69±0.04^{a}	15.02±2.23^{bc}
XG	27.70±2.60^{c}	0.67±0.13^{c}	0.82±0.05^{b}	0.61±0.03^{b}	13.86±2.17^{c}

Guar gum (GG), hydroxypropylmethyl cellulose (HPMC), carboxymethyl cellulose (CMC) and xanthan gum (XG) were used in this study.
Results are expressed as mean values ± standard deviations.
Means with same superscripts in a row are not significantly different (*probability value*, $p \geq 0.05$) as assessed by Tukey's test.

3.6. Sensory evaluation

The results of the sensory evaluation of the cooked GF instant noodles with mixed hydrocolloids are presented in Table 5. The instant noodle that contained GG and HPMC had significantly higher ($p<0.05$) scores for color, firmness, springiness and overall acceptability. The scores for springiness of the cooked instant noodles were improved with the addition of GG and HPMC. They have medium correlation with hardness (r = 0.621, p<0.05), springiness (r = 0.588, p<0.05) and chewiness (r = 0.631, p<0.05) evaluated by instrument (Table 3). The samples that contained GG and HPMC exhibited the highest overall acceptability scores. On the other hand, the samples that contained CMC and XG showed lower overall qualities, namely that they possessed less elasticity and softer texture than the others.

Table 5. The sensory evaluation of the GF instant noodles containing different hydrocolloids.

Samples	Appearance^{NS}	Color^{NS}	Firmness	Springiness	Overall acceptability
GG	6.58±1.18	6.92±1.07	6.34±1.38^{ab}	6.18±1.41^{a}	6.58±1.11^{ab}
HPMC	6.90±1.22	7.00±1.07	6.58±1.07^{a}	6.18±1.55^{a}	6.70±1.22^{a}
CMC	6.64±1.10	6.68±1.08	5.92±1.61^{b}	5.56±1.77^{ab}	6.14±1.37^{bc}
XG	6.52±1.30	6.78±1.15	6.08±1.58^{ab}	5.20±1.71^{b}	5.98±1.44^{c}

Guar gum (GG), hydroxypropylmethyl cellulose (HPMC), carboxymethyl cellulose (CMC) and xanthan gum (XG) were used in this study.
Results are expressed as mean values ± standard deviations.
Means with same superscripts in a row are not significantly different (*probability value*, $p \geq 0.05$) as assessed by Tukey's test.
^{NS} = values in the same column are not significantly different (*probability value*, $p \geq 0.05$).

4. CONCLUSIONS

The GF instant noodles that consisted of GG and HPMC provided a comparable sensory score. Compared with HPMC, the sample with GG had a significantly higher cooking yield, cooking loss, hardness, cohesiveness and chewiness, and it also presented a significantly lower adhesiveness. CMC was effective for the reduction of fat uptake and required the least cooking time. Thermograms of the fresh noodles with different hydrocolloids before they were steamed and fried showed no significant difference.

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