Original Article
Food Science and Technology

ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.1590/fst.68720



# Development of fresh and dried noodle products with high resistant starch content from banana flour

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**Abstract**

The functional properties, resistant starch (RS), and glycemic index (GI) of fresh noodles substituted with banana flour (BF) were investigated. When the substitution with BF was increased from 0 to 40%, the viscoelastic properties increased, while tensile strength and elasticity decreased from 53.23 to 26.84 $g_f$ and 44.65 to 15.04 mm, respectively. GI was reduced from 77.05 to 62.62 while RS content increased from 5.56 to 23.31%. This is considered a very high RS content and the modified noodles are classified as intermediate GI food. Furthermore, the effects of xanthan gum (XG), guar gum (GG), and carboxymethyl cellulose (CMC) individually at 1.0% and 1.5% levels on quality of dried noodles substituted with 30% BF (DBF30) were investigated. DBF30 with XG had the shortest rehydration time (6.5 min), while DBF30 with CMC had the slowest rehydration (8.5 min). The added hydrocolloids increased rehydration and decreased the cooking loss of DBF30, also increasing tensile strength and elasticity of DBF30. Furthermore, the hydrocolloids increased RS content and reduced GI of DBF30. The results reveal that adding BF and hydrocolloids to noodle products provides high nutritional quality with enhanced quality characteristics.

**Keywords:** banana flour; fresh noodles; dried noodles; resistant starch.

**Practical Application:** Increase the resistant starch content and reduce the glycemic index of noodle products by adding banana flour.

## 1 Introduction

Negative lifestyle patterns or poor diet play key roles in developing various health problems that lead to diseases. Noodles have been recognized as major wheat products served as the main carbohydrate-based food. They are high glycemic index (GI) foods because carbohydrates directly raise blood sugar levels (Ho & Che Dahri, 2016). This is a main cause of health risks related to several chronic diseases (obesity, cardiovascular disease, diabetes, and cancers). The incorporation of low GI ingredients in noodle products could lower their GI.

Banana (*Musa* spp.) is among the most important well-known tropical fruits consumed all over the world. It is an excellent source of nutrition supporting good health because it is rich in fiber and a source of minerals such as potassium, iron, calcium and magnesium (Singh et al., 2016). An interesting substantial type of starch in a green banana is the resistant starch (RS), which is not digested in the stomach and small intestine, but is passed on to be fermented by microbiota bacteria, producing short-chain fatty acids and other organic acids in the large intestine. RS does not supply glucose to the body, is related to a decreased GI of carbohydrates (Garcia-Santos et al., 2019). A low GI can help keep blood sugar levels stable, and has been associated with weight control and decreased risk of developing diabetes (Annison & Topping, 1994). Due to low cost and nutritional value of the green banana, many studies are utilized as a functional ingredient in various food products such as bread, snacks, pasta, cheese, and smoothie (Santos et al., 2018; Pivetta et al., 2020; Ribeiro et al., 2020).

The aim of this study was to evaluate the effects of banana flour (BF) and hydrocolloids as ingredients on the quality characteristics, RS, and GI of noodle products.

## 2 Materials and methods

### *2.1 Materials*

Unripe bananas of the variety *Musa sapientum* L. or 'Namwa' banana (ABB group) at stage 1 of ripening were purchased from Songkhla, Thailand. BF was prepared by adapting the methods of Tiboonbun et al. (2011). Hydrocolloids (i.e., guar gum GG; xanthan gum XG; and carboxymethyl cellulose CMC) were purchased from Chemipan Corporation Co., Ltd. (Bangkok, Thailand). Other ingredients were also purchased from a local supermarket (Songkhla, Thailand).

### *2.2 Noodle production*

Fresh noodles were prepared using a method similar to Zhou et al. (2015) with some modifications. Four substitution levels were tested for preparing fresh noodle samples, substituting wheat flour with 10% (BF10), 20% (BF20), 30% (BF30) or 40% (BF40) of banana flour. Control noodle (WF100) was prepared from 100% wheat flour. Salt and alkaline salt were dissolved in water. Materials for the noodles were incorporated in a mixer. The dough was passed through a roll nip five times to form a dough sheet and was slit into 2.3 mm wide strands with a

*Received 15 Dec., 2020*
*Accepted 18 Jan., 2021*
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noodle making machine. Afterwards, the noodle strands of each formula were precooked in boiling water for 60 seconds and cooled, prior to further analysis.

### *2.3 Viscoelastic properties of fresh noodle dough*

The viscoelastic properties were measured using a rheometer (Haake, Germany) as described by Li et al. (2013). Parallel plate geometry was selected for the testing. The noodle dough was subjected to a frequency sweep test in the range from 0.1 to 100.0 Hz and the strain amplitude of 0.1% at 25 °C, which was within the linear viscoelastic range (LVR). Noodle dough was weighed to 0.95 g and molded to form a 20 mm diameter disc of 2 mm thickness. The storage modulus (G') and loss modulus (G") were recorded as functions of frequency. The tan δ loss tangent (G"/G') was determined as well.

### *2.4 Dried noodle production*

The fresh BF30 noodles were selected for producing the dried noodles. First, salt and alkaline salt (9:1 ratio of $Na_2CO_3$ and $K_2CO_3$) were dissolved in water and mixed with flour (70% wheat flour and 30% BF). Hydrocolloids (guar gum GG; xanthan gum XG; and carboxymethyl cellulose CMC) were individually added at 1.0% or 1.5% by weight relative to flour and mixed in a mixer. The dough was passed through a roll nip five times to form a dough sheet and was then slit to 2.3 mm wide strands with a noodle making machine. The noodle strands were precooked in boiling water for 60 seconds and cooled. The fresh noodles were weighted and folded to form a block (100 ± 2 g). The noodle block was dried in a baking oven at 80 °C to a final moisture content below 12%.

### *2.5 Texture properties*

The texture properties were measured using a texture analyzer (TA-XT2i, UK) equipped with spaghetti tensile grips (A/SPR) as described by Shan et al. (2013). The fresh noodle strands were measured for tensile strength and maximum distance.

### *2.6 Resistant starch*

Resistant starch content (RS) was determined using a resistant starch assay kit (K-RSTAR) (Megazyme, Ireland) following the method of McCleary & Monaghan (2002).

### *2.7 Glycemic index*

Glycemic index (GI) was determined according to the method of Sopade & Gidley (2009) using the equation established by Goñi et al. (1997). Briefly, a sample (500 mg) was treated with 1 mL of α-amylase (Sigma A-3176 Type VI-B, Germany) for 15-20 seconds before 5 mL of pepsin (Sigma P-6887, Germany) was added, and was incubated at 37 °C for 30 min in a shaking water bath (Memmert, Germany). The solution was neutralized with 5 mL of 0.02 M NaOH, 25 mL of 0.2 M sodium acetate buffer was then added followed by adding 5 mL of an enzyme mix (pancreatin, Sigma P1750, Germany and amyloglucosidase, Sigma A-7420, Germany). The hydrolyzed solution was incubated at 37 °C for 4 hr. in a shaking water bath. The glucose concentration was measured with a glucometer (Accu-Chek, Performa®, Germany) at 0, 10, 20, 30, 45, 60, 90, 120, 150, 180, 210, and 240 min. Digested starch (% db) was calculated according to Sopade & Gidley (2009). Then the area under the curve (AUC) was calculated. The hydrolysis index (HI) was calculated by dividing the AUC of each sample by that for the corresponding reference sample (white bread), and expressed as a percentage. GI was calculated as follows (Equation 1):

$$GI = 39.71 + (0.549 \times HI) \tag{1}$$

### *2.8 Sensory evaluation*

Fresh noodle samples after precooking (100 g) were cut into 10 cm pieces before testing. The sensory attributes of the noodles were evaluated by 30 panelists. The panelists were asked to evaluate attributes each sample included appearance, color, flavor, texture (stickiness and elasticity) and overall acceptability. The samples were rated on a 9-point hedonic scale (ranging from 1 = dislike extremely to 9 = like extremely) according to Choo & Aziz (2010).

### *2.9 Cooking properties of dried noodles*

The rehydration times were measured according to Wang et al. (2012) with some modifications. The noodles (5 g sample) were cut to 5 cm length and boiled in distilled water (60 mL) in a beaker. One of the noodle stands was taken every 30 seconds and squeezed between two pieces of transparent flat glass to evaluate the white core of a noodle strand. The time required for the core to completely disappear was noted as rehydration time of each sample type. After cooking the noodles were drained on a sieve for 1 min. The rehydration (%) was calculated as the weight ratio of cooked noodles to dry noodles. Cooking loss was determined by drying the cooking water at 105 °C overnight and measuring the weight of dry residue. It is expressed as the weight percentage of solids lost to cooking water relative to dry noodle weight.

### *2.10 Statistical analyses*

The data are expressed as mean ± standard deviation based on triplicates. Data were analyzed using one-way analysis of variance (ANOVA) and data from the sensory evaluation were arranged in a randomized complete block design (RCBD). Duncan's multiple-range test was applied to a means comparison when the analysis of variance showed a significant difference at $p < 0.05$.

## 3 Results and discussion

### *3.1 Functional properties, Resistant Starch (RS) and Glycemic Index (GI) of fresh noodles*

*Viscoelastic properties of fresh noodle doughs*

The rheological characteristic of noodle dough inform about the structure and properties of dough, and are associated with texture and quality of the final products (Zhou et al., 2015). The doughs are viscoelastic materials that exhibit behavior intermediate between a viscous liquid and an elastic solid, and this was affected by the level of BF substitution (Table 1). On increasing BF substitution from 0 to 40%, both G' and G" significantly ($p < 0.05$) increased.

**Table 1**. Storage modulus (G'), loss modulus (G"), and tan δ at ω = 10 rad/s frequency and 25 °C, for the noodle doughs with various banana flour substitution levels before precooking.

| Sample | G' (Pa) | G" (Pa) | tan δ |
|---|---|---|---|
| WF100 | 27500.63 ± 87.23$^{c}$ | 20613.33 ± 772.65$^{d}$ | 0.75 ± 0.03$^{d}$ |
| BF10 | 27326.91 ± 719.77$^{c}$ | 21618.97 ± 365.72$^{d}$ | 0.79 ± 0.01$^{cd}$ |
| BF20 | 29838.70 ± 709.96$^{b}$ | 24352.73 ± 991.68$^{c}$ | 0.82 ± 0.02$^{bc}$ |
| BF30 | 30730.37 ± 848.08$^{ab}$ | 26420.47 ± 800.74$^{b}$ | 0.86 ± 0.01$^{b}$ |
| BF40 | 31315.20 ± 149.23$^{a}$ | 28931.23 ± 677.10$^{a}$ | 0.92 ± 0.03$^{a}$ |

Each value is mean ± SD of triplicate measurements. Different superscripts in a column indicate significant differences at $p < 0.05$. Abbreviated labels are WF100: 100% wheat flour; BF10: 10% banana flour; BF20: 20% banana flour; BF30: 30% banana flour; and BF40: 40% banana flour.

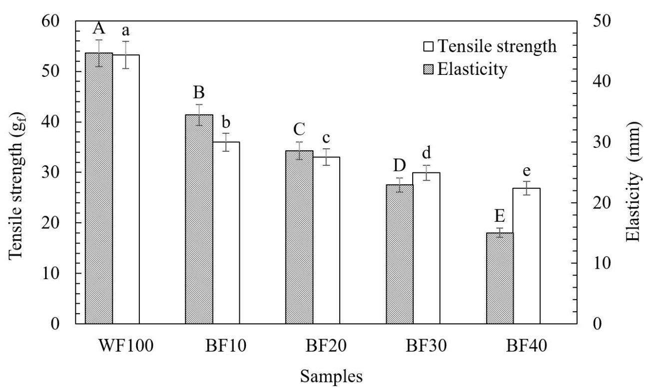


**Figure 1**. Tensile strength and elasticity of fresh noodles at various levels of banana flour content after precooking. The columns indicate means and the error bars show SD based on triplicates. Different lowercase letters (or capital letters) indicate significant differences in tensile strength (elasticity) at $p < 0.05$. Abbreviated labels are WF100: 100% wheat flour; BF10: 10% banana flour; BF20: 20% banana flour; BF30: 30% banana flour; BF40: 40% banana flour.

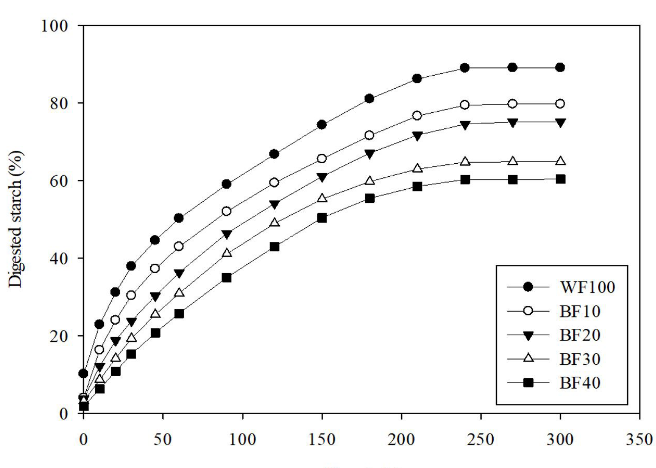


**Figure 2**. *In vitro* starch digestibility (%) of fresh noodles with various substitution levels of banana flour. Abbreviated labels are WF100: 100% wheat flour; BF10: 10% banana flour; BF20: 20% banana flour; BF30: 30% banana flour; BF40: 40% banana flour.

The BF40 noodle dough had the highest G' and G" (31315.20 Pa and 28931.23 Pa) among the cases tested, indicating that BF content contributed to deformation resisting gel structures. Therefore the dough samples with BF were firmer than WF100, and BF40 noodles had the most firm texture. It was observed that G' values were distinctly higher than G", indicating that the materials were by their character more elastic than viscous. This was tentatively attributed to inter-molecular interactions and strengthened structure that contributed to elastic characteristics. The tan δ (loss tangent) also increased with BF substitution level in the noodle formulas, indicating that the noodle doughs became stronger. The tan δ values remained below 1, because G' was dominant in the doughs and they behaved solid-like (Romero et al., 2017). The WF100 noodle dough had the lowest tan δ while the BF40 noodle dough had the highest. This indicates that increasing the BF substitution level contributed more to viscous than elastic character of the dough, making the texture of noodles stiffer and less extensible.

### *Texture properties of fresh noodles*

Tensile strength and elasticity of fresh noodles substituted with BF reflect the eventual texture of noodles (Figure 1). Increasing the level of BF substitution significantly ($p < 0.05$) decreased tensile strength and elasticity. This decrease might be explained by BF being a non-gluten flour, thereby reducing the proportion of (wheat) gluten. Therefore the gluten matrix was impaired during dough formation, leading to softness and weak internal structure in the noodles (Sirichokworrakit et al., 2015). A high level of substitution interrupted and weakened the gluten network more, which made it eventually impossible to form a network in the dough. According to prior literature, gluten is responsible for dough extensibility (viscosity) and strength (elasticity) (Kovacs et al., 2004). There is a positive correlation between viscoelastic properties of dough and texture properties of the noodles. It could be seen that the noodles with BF content lost their viscoelastic properties, making the noodles less elastic and easily broken by stretching. Ritthiruangdej et al. (2011) also reported similar results for wheat noodles supplemented with BF.

### *Starch digestibility of fresh noodles*

The results of *in vitro* starch digestibility rate in the fresh noodles substituted with BF at various levels, after 240 min, are shown in Figure 2. The starch digestion curves ascend over the first 60 min and then the curve gradually levels at 60 to 240 min, and at 240 min an equilibrium level has been reached in digestion. These are similar to the prior results of Zhang et al. (2019). The fast digestion affected the rapidly digestible starch (RDS) fraction in the sample. Among all the noodle products, the WF100 case was digested more rapidly than those made with BF. The rates decreased with increasing BF substitution level, and especially the BF40 noodle had the lowest digestion rate. The slow digestion of BF in noodles was probably related to the presence of RS in BF. RS has compact structure making it less susceptible to enzymatic digestion. This indicates that the noodles containing BF had a strong resistance to hydrolysis by the digestive enzymes. There are several prior reports with similar observations to this current study (Ovando-Martinez et al., 2009; Saifullah et al., 2009).

In addition, the starch fractions could be calculated from the rate of starch digestion by single-point measurements, as defined by Englyst et al. (1992). These results were classified into RDS as that starch which was digested within 60 min, slowly digestible starch (SDS) as that starch which was digested during 60 to 150 min, and RS that was not digested in 150 min. RDS content significantly ($p < 0.05$) decreased as the level of BF substitution increased. BF40 noodles had the least (25.90%) RDS, while WF100 noodle had the most (49.13%). There was no significant ($p < 0.05$) difference in the SDS content of fresh noodles between the BF levels. In contrast, the content of RS significantly ($p < 0.05$) increased with BF substitution level. BF40 had the most RS (23.85%) and WF100 noodle had the least (4.41%). This indicates that the starch fractions in wheat flour, especially RSD, were replaced by RS content in BF that was substituting for the wheat flour as a noodle ingredient.

*Resistant Starch content (RS) and Glycemic Index (GI) of fresh noodles*

The RS contents of fresh noodles substituted with BF are shown in Table 2. A significant ($p < 0.05$) increase in RS content was observed with increasing substitution level of BF. A similar pattern was previously found by Tiboonbun et al. (2011) and by Osorio-Díaz et al. (2014). The BF40 noodle had the most RS (23.31%), while the WF100 noodle had the least (5.56%). By RS content the fresh noodles can be divided into 2 categories according to the classification of Goñi et al. (1997), as follows: high RS noodles (WF100, BF10, and BF20), and very high RS noodles (BF30 and BF40). This is related to the high RS content source, namely BF. The RS found in BF is of type 2 (RS2). RS2 is a native starch type that limits the accessibility of digestive enzymes by its crystalline granular structure, making it resist hydrolysis (Ovando-Martinez et al., 2009).

Fresh noodles containing various BF levels had significant ($p < 0.05$) decreases in HI and GI (Table 2). This was due to the slow hydrolysis of RS content from BF as an ingredient. The high RS content of BF can potentially reduce the rate of starch digestion (Choo & Aziz, 2010; Srikaeo et al., 2011). The HI was the highest for WF100 noodle (68.02%) causing the highest GI (77.05). Then 10 to 40% substitution of BF significantly ($p < 0.05$) reduced both HI and GI of the noodles. This is because both HI and GI were influenced by both physical (structural) characteristics and physicochemical properties of starch (Segundo et al., 2017). The GI values ranged between 72.74 and 62.62, and the noodles are classified as "intermediate GI" foods (56-69) except for WF100 and BF10 noodles that were "high GI" foods (>70) according to the report of Goñi et al. (1997). These moderate glycemic responses of the noodles substituted with BF were related to slow digestion rate, which controls postprandial blood glucose and insulin responses.

*Sensory evaluation of fresh noodles*

The sensory evaluation of fresh noodles is presented in Table 3. Increasing BF substitution of fresh noodles affected in all sensory attributes except for the flavor. The WF100 showed the highest liking score of appearance and color because of yellow bright color and no dark spots. The scattered dark spots were increased with increasing BF substitution levels due to the nature of BF. The darker color of BF noodles had indicated the Maillard reaction, in which protein and sugar of the flours react with each other during the cooking process (Anggraeni & Saputra, 2018). However, as the level of BF substitution increased, it was no significantly ($p < 0.05$) different in the liking score of flavor and texture among samples. Considering overall liking score results, the substitution of BF with 10 to 30% gives highly acceptability scores like WF100 noodle that still accepted by consumers. This can consider that the BF30 noodle was suitable for the manufacture of noodles. This was due to it was considered more acceptable (in terms of texture and overall acceptability) than BF40 noodle and its nutritional value without difference from BF40 noodle.

### *3.2 The effects of hydrocolloids on quality of dried noodles*

*Cooking quality of dried noodles*

The effects of hydrocolloids on cooking quality of the DBF30 noodles are shown in Table 4. These cooking quality measures are important factors predictive of the cooking performance of noodles as perceived by the consumers. The rehydration time of DBF30 showed differences by sample type, and varied from 6.5 to 8.5 min. It was observed that the rehydration time of DBF30 became shorter with hydrocolloids than that without any hydrocolloid, except for the case with CMC. The rehydration times of all samples were higher than that of commercial instant noodles (less than 5 min) (Thailand, Ministry of Industry, 2005). This may be because the DBF30 was produced like Hokkien noodles, with diameter larger than that of commercial ones. The hydrocolloids improved the rehydration time because they are binders retaining water and aid gelatinization within the noodle stands (Hymavathi et al., 2019). The rehydration time of DBF30 with XG was the shortest, because the structure had an anionic charge and highly branch chains (Pongpichaiudom & Songsermpong, 2018a), while the slowest rehydration time with CMC was associated with the linear structure of this additive, decreasing the breakdown viscosity and requiring a longer time for water penetration.

The results exhibited significant ($p < 0.05$) effects of hydrocolloid additives on the rehydration of DBF30. DBF30 with hydrocolloids rehydrated with more water than without

**Table 2**. Resistant starch content (RS) and glycemic index (GI) of fresh noodles substituted with various banana flour contents.

| Sample | Resistant starch (%) | Hydrolysis index (%) | Glycemic index |
|---|---|---|---|
| WF100 | 5.56 ± 0.14$^{e}$ | 67.89 ± 0.47$^{a}$ | 76.98 ± 0.26$^{a}$ |
| BF10 | 9.54 ± 0.12$^{d}$ | 60.15 ± 0.50$^{b}$ | 72.73 ± 0.27$^{b}$ |
| BF20 | 13.37 ± 0.16$^{c}$ | 53.40 ± 0.50$^{c}$ | 69.03 ± 0.28$^{c}$ |
| BF30 | 18.03 ± 0.40$^{b}$ | 47.80 ± 0.62$^{d}$ | 65.95 ± 0.34$^{d}$ |
| BF40 | 23.31 ± 0.29$^{a}$ | 41.72 ± 0.60$^{e}$ | 62.61 ± 0.33$^{e}$ |

Each value is mean ± SD of triplicate measurements. Different superscripts in a column indicate significant differences at $p < 0.05$. Abbreviated labels are WF100: 100% wheat flour; BF10: 10% banana flour; BF20: 20% banana flour; BF30: 30% banana flour; and BF40: 40% banana flour.

**Table 3**. Sensory evaluation of fresh noodles substituted with various banana flour contents.

| Sample | Sensorial attributes | | | | |
|---|---|---|---|---|---|
| | Appearance | Color | Flavor | Texture | Overall |
| WF100 | 8.13 ± 0. 43$^{a}$ | 7.97 ± 0.71$^{a}$ | 6.70 ± 0.90$^{a}$ | 7.10 ± 0.83$^{ab}$ | 7.07 ± 0.63$^{ab}$ |
| BF10 | 7.77 ± 0.67$^{b}$ | 7.80 ± 0.70$^{ab}$ | 6.57± 0.96$^{a}$ | 7.13 ± 0.85$^{ab}$ | 7.20 ± 0.79$^{a}$ |
| BF20 | 7.83 ± 0.69$^{b}$ | 7.73 ± 0.73$^{ab}$ | 6.80 ± 0.87$^{a}$ | 7.20 ± 0.83$^{ab}$ | 7.30 ± 0.86$^{a}$ |
| BF30 | 7.60 ± 0.66$^{b}$ | 7.43 ± 0.84$^{b}$ | 6.90± 0.87$^{a}$ | 7.37 ± 0.76$^{a}$ | 7.37 ± 0.60$^{a}$ |
| BF40 | 7.30 ± 0.94$^{c}$ | 6.77 ± 0.84$^{c}$ | 6.83 ± 0.90$^{a}$ | 6.90 ± 0.83$^{a}$ | 6.80 ± 0.79$^{b}$ |

Each value is mean ± SD of triplicate measurements. Different superscripts in a column indicate significant differences at p < 0.05. Abbreviated labels are WF100: 100% wheat flour; BF10: 10% banana flour; BF20: 20% banana flour; BF30: 30% banana flour; and BF40: 40% banana flour.

**Table 4**. Cooking quality indicators of dried noodles substituted with 30% BF (DBF30) improved by various hydrocolloid at 0.5% or 1% levels.

| Sample | Rehydration time (min) | Rehydration (%) | Cooking loss (%) |
|---|---|---|---|
| DBF30 | 7.5 min | 107.21 ± 1.49$^{f}$ | 4.34 ± 0.05$^{a}$ |
| DBF30 + 1.0% XG | 6.5 min | 118.71 ± 1.48$^{d}$ | 3.93 ± 0.06$^{d}$ |
| DBF30 + 1.5% XG | 6.5 min | 127.67 ± 1.93$^{c}$ | 3.65 ± 0.04$^{e}$ |
| DBF30 + 1.0% GG | 7.0 min | 111.35 ± 0.79$^{e}$ | 4.02 ± 0.08$^{cd}$ |
| DBF30 + 1.5% GG | 7.0 min | 118.03 ± 2.04$^{d}$ | 3.71 ± 0.03$^{e}$ |
| DBF30 + 1.0% CMC | 8.5 min | 145.05 ± 2.26$^{b}$ | 4.23 ± 0.03$^{b}$ |
| DBF30 + 1.5% CMC | 8.5 min | 151.10 ± 1.75$^{a}$ | 4.12 ± 0.05$^{c}$ |

Each value is mean ± SD of triplicate measurements. Different superscripts in a column indicate significant differences at p < 0.05. Abbreviated labels are DBF30: dried noodle substituted with 30% banana flour; XG: xanthan gum; GG: guar gum; CMC: carboxymethyl cellulose.

hydrocolloid. This suggests that the hydrophilic groups in hydrocolloids (containing many hydroxyl groups) increased the water-binding, which increased the swelling capacity of starch granules (Jang et al., 2015). Similar results were found by Kraithong et al. (2019) when rice noodles were made with GG, CMC and XG. The rehydration of DBF30 made with hydrocolloids had the following rank order: CMC > XG > GG. The large effect of CMC stemmed from the interactions between free carboxyl groups and the amino groups of proteins in the noodles (Pongpichaiudom & Songsermpong, 2018b). Besides, the % rehydration was dependent on the content of hydrocolloids. The rehydration with 1.5% of hydrocolloids was significantly ($p < 0.05$) higher than with 1%, so the effects of the hydrocolloids were dose dependent as would be expected. The ability to absorb water during cooking is important to cooking quality.

Cooking loss measures the amount of solids lost from the noodles to the cooking water, and a high cooking loss is undesirable. According to Tan et al. (2009), acceptable cooking losses of starch noodles should not exceed 10%. In this study, the cooking loss of DBF30 ranged from 3.65 to 4.34% and was significantly ($p < 0.05$) reduced by added hydrocolloids, except for CMC. Complex network formation occurred between starch and a hydrocolloid through hydrogen bonding and hydrophilic interactions. This might encapsulate starch granules during the cooking and thereby reduce the cooking losses (Hymavathi et al., 2019). Hymavathi et al. (2014) reported that very high rehydration led to the softening of noodles, resulting in more cooking loss. This suggests that added CMC weakened the noodles permitting the leaching of solids. Increasing the amount of a hydrocolloid tended to decrease cooking loss, by enhancing swelling and gelatinization of starch granules, which reduced the leaching of amylose during cooking.

*Texture properties of dried noodles*

The texture properties of DBF30 were improved by a hydrocolloid at 1% or 1.5% level, when compared with DBF30 without hydrocolloids (Figure 3). This is probably due to the strong network in the noodle structure, formed by hydrogen bond interactions between starch granules and hydrocolloid (Han et al., 2011). A similar trend was found by Kraithong et al. (2019), who reported increased tensile strength and elasticity of gluten-free noodles when using hydrocolloids. The tensile strength was significantly ($p < 0.05$) increased by increasing the addition level of hydrocolloid. DBF30 with 1.5% GG showed the highest value (71.70 $g_f$), while DBF30 without hydrocolloid had the lowest tensile strength (39.44 $g_f$). On the other hand, some hydrocolloids did not affect the elasticity of DBF30. Furthermore, there was a difference observed in the textural properties when the hydrocolloid level was increased from 1.0 to 1.5%. In particular, an increase in the tensile strength. The higher strengths of DBF30 with GG and XG could be explained by the linear additive molecules with a branched structure. The strength of the network provided high texture properties to the noodles. In contrast, the CMC is a linear polymer that might exhibit lower polymer strength and hence gave the poor texture properties (Chang & Wu, 2008). In another sense, rehydration is one of the major factors associated with texture characteristics of noodles. A high degree of rehydration results in soft and sticky texture, while lesser rehydration results in noodles with a coarse and hard texture (Hymavathi et al., 2019).

*Resistant Starch content (RS) and Glycemic Index (GI) of dried noodles*

The RS contents of DBF30 made with different hydrocolloids are shown in Table 5. The RS contents of DBF30 with hydrocolloids were significantly ($p < 0.05$) higher than that of DBF30 without any hydrocolloids. There was no significant ($p < 0.05$) difference by the type or the level of hydrocolloid. The hydrocolloids helped form a gel matrix encasing the starch granules, retarding enzymatic digestion. This shifted some starch between digestible and non-digestible fractions, and the effect is dependent on the type of starch (Gularte & Rosell, 2011). However, these samples were found to be "very high RS" foods, because the RS contents exceeded 15% (Goñi et al., 1997).

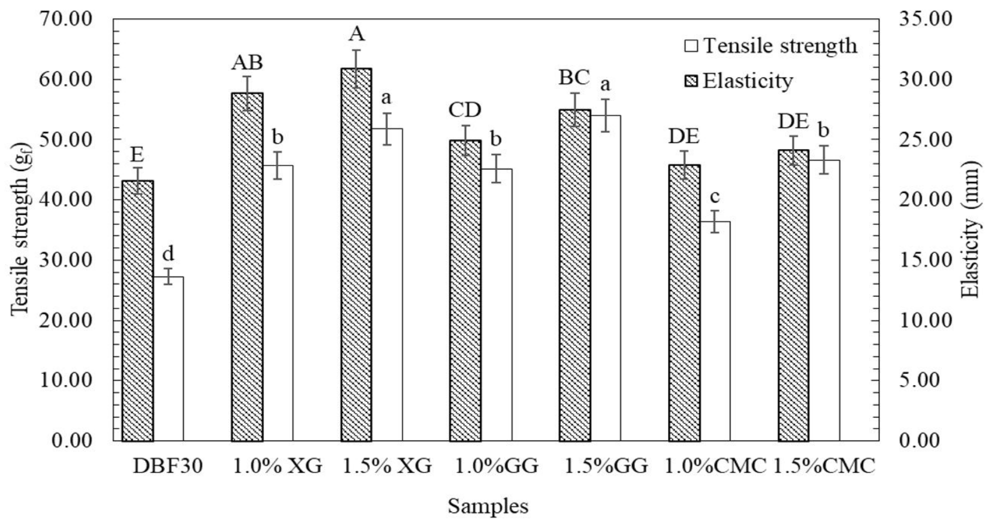


**Figure 3**. Tensile strength and elasticity of dried noodles substituted with 30% BF (DBF30) were improved by various hydrocolloids at 1.0% or 1.5% levels. The bars indicate mean values while error bars show SD from triplicate measurements. Different lowercase letters (capital letters) indicate significant differences in tensile strength (elasticity) at $p < 0.05$. Abbreviated labels are DBF30: dried noodle substituted with 30% banana flour; XG: xanthan gum; GG: guar gum; CMC: carboxymethyl cellulose.

**Table 5**. Resistant starch content (RS) and glycemic index (GI) of dried noodles substituted with 30% BF (DBF30) improved by various hydrocolloids at 0.5% or 1% levels.

| Sample | Resistant starch (%) | Hydrolysis index (%) | Glycemic index |
|---|---|---|---|
| DBF30 | $15.79 \pm 0.12^{c}$ | $49.63 \pm 1.04^{a}$ | $66.96 \pm 0.57^{a}$ |
| DBF30 + 1.0% XG | $16.28 \pm 0.26^{ab}$ | $46.53 \pm 0.69^{b}$ | $65.25 \pm 0.38^{b}$ |
| DBF30 + 1.5% XG | $16.49 \pm 0.21^{a}$ | $44.48 \pm 0.27^{c}$ | $64.13 \pm 0.15^{c}$ |
| DBF30 + 1.0% GG | $16.27 \pm 0.27^{ab}$ | $46.48 \pm 0.67^{b}$ | $65.23 \pm 0.37^{b}$ |
| DBF30 + 1.5% GG | $16.44 \pm 0.22^{a}$ | $45.10 \pm 0.82^{bc}$ | $64.47 \pm 0.45^{bc}$ |
| DBF30 + 1.0% CMC | $16.21 \pm 0.15^{b}$ | $46.81 \pm 0.60^{b}$ | $65.41 \pm 0.33^{b}$ |
| DBF30 + 1.5% CMC | $16.38 \pm 0.25^{ab}$ | $45.17 \pm 0.86^{bc}$ | $64.51 \pm 0.47^{bc}$ |

Each value is mean ± SD of triplicate measurements. Different superscripts in a column indicate significant differences at $p < 0.05$. Abbreviated labels are DBF30: dried noodle substituted with 30% banana flour; XG: xanthan gum; GG: guar gum; CMC: carboxymethyl cellulose.

HI and GI of DBF30 made using the different hydrocolloids are shown in Table 5. The HI and GI of DBF30 samples were in the ranges from 44.48 to 49.63% and from 64.13 to 66.96, respectively. The results revealed that the addition of hydrocolloids to DBF30 significantly ($p < 0.05$) decreased HI and GI. Meanwhile, increasing the level of hydrocolloids did not significantly ($p < 0.05$) decrease those values further, except for the case of XG. These results indicate that the hydrocolloids acted as physical barriers encasing starch granules, shielding the granules from enzyme attacks (Liu et al., 2018). This impact of hydrocolloids on starch hydrolysis depends on the hydrocolloid type and level, and on starch origin and food type (Jang et al., 2015; Menon et al., 2015). According to the report by Goñi et al. (1997), all DBF30 samples would be classified as "intermediate glycemic" foods.

## 4 Conclusions

The fresh noodles with BF substituted for 10 to 40% of wheat flour had altered functional properties, RS, and GI, and would be classified as "very high RS" content and "intermediate GI" foods. This study suggests that adding hydrocolloids to the formulation of dried noodles promoted their cooking quality and improved the final texture, as well as increased RS content and reduced GI. Among all the tested hydrocolloids, 1.0% XG was the best alternative in DBF30 formulations for dried noodle production, giving good cooking quality, very high RS content, and intermediate GI.

## Acknowledgements

The authors are grateful Interdisciplinary Graduate School of Nutraceutical and Functional Food, Prince of Songkla University for granting scholarships. The authors would also like to thank Assoc. Prof. Seppo Karrila and Research and Development Office, Prince of Songkla University for helping edit manuscripts.

## References

Anggraeni, R., & Saputra, D. (2018). Physicochemical characteristics and sensorial properties of dry noodle supplemented with unripe banana flour. *Food Research*, 2(3), 270-278. http://dx.doi.org/10.26656/fr.2017.2(3).061.

Annison, G., & Topping, D. L. (1994). Nutritional role of resistant starch: chemical structure vs physiological function. *Annual Review of Nutrition*, 14(35), 297-320. http://dx.doi.org/10.1146/annurev.nu.14.070194.001501. PMid:7946522.

Chang, H. C., & Wu, L. C. (2008). Texture and quality properties of Chinese fresh egg noodles formulated with green seaweed (*Monostroma nitidum*) powder. *Journal of Food Science*, 73(8), S398-S404. http://dx.doi.org/10.1111/j.1750-3841.2008.00912.x. PMid:19019127.

Choo, C. L., & Aziz, N. A. A. (2010). Effects of banana flour and β-glucan on the nutritional and sensory evaluation of noodles. *Food Chemistry*, 119(1), 34-40. http://dx.doi.org/10.1016/j.foodchem.2009.05.004.

Englyst, H. N., Kingman, S. M., & Cummings, J. H. (1992). Classification and measurement of nutritionally important starch fractions. *European Journal of Clinical Nutrition*, 46(Suppl. 2), S33-S50. PMid:1330528.

Garcia-Santos, M. D. S. L., Conceicao, F. S., Villas Boas, F., Salotti De Souza, B. M., & Barretto, A. C. D. S. (2019). Effect of the addition of resistant starch in sausage with fat reduction on the physicochemical and sensory properties. *Food Science and Technology*, 39(Suppl. 2), 491-497. http://dx.doi.org/10.1590/fst.18918.

Goñi, I., Garcia-Alonso, A., & Saura-Calixto, F. (1997). A starch hydrolysis procedure to estimate glycemic index. *Nutrition Research*, 17(3), 427-437. http://dx.doi.org/10.1016/S0271-5317(97)00010-9.

Gularte, M. A., & Rosell, C. M. (2011). Physicochemical properties and enzymatic hydrolysis of different starches in the presence of hydrocolloids. *Carbohydrate Polymers*, 85(1), 237-244. http://dx.doi.org/10.1016/j.carbpol.2011.02.025.

Han, J. A., Seo, T. R., Lim, S. T., & Park, D. J. (2011). Utilization of rice starch with gums in Asian starch noodle preparation as substitute for sweet potato starch. *Food Science and Biotechnology*, 20(5), 1173-1178. http://dx.doi.org/10.1007/s10068-011-0162-y.

Ho, L.-H., & Che Dahri, N. (2016). Effect of watermelon rind powder on physicochemical, textural, and sensory properties of wet yellow noodles. *CYTA: Journal of Food*, 14(3), 1-8. http://dx.doi.org/10.1080/19476337.2015.1134672.

Hymavathi, T. V., Thejasri, V., & Roberts, T. P. P. (2019). Enhancing cooking, sensory and nutritional quality of finger millet noodles through incorporation of hydrocolloids. *International Journal of Chemical Studies*, 7(2), 877-881.

Hymavathi, T. V., Spandana, S., & Sowmya, S. (2014). Effect of hydrocolloids on cooking quality, protein and starch digestibility of ready-to-cook gluten free extruded product. *Agricultural Engineering International: CIGR Journal*, 16(2), 119-125.

Jang, H. L., Bae, I. Y., & Lee, H. G. (2015). Invitro starch digestibility of noodles with various cereal flours and hydrocolloids. *Lebensmittel-Wissenschaft + Technologie*, 63(1), 122-128. http://dx.doi.org/10.1016/j.lwt.2015.03.029.

Kovacs, M. I. P., Fu, B. X., Woods, S. M., & Khan, K. (2004). Thermal stability of wheat gluten protein : its effect on dough properties and noodle texture. *Journal of Cereal Science*, 39(1), 9-19. http://dx.doi.org/10.1016/S0733-5210(03)00058-4.

Kraithong, S., Lee, S., & Rawdkuen, S. (2019). The influence of hydrocolloids on the properties organic red jasmine rice noodles, namely on antioxidant activity, cooking, texture, and sensory properties. *Starch*, 71(1-2), 1800145. http://dx.doi.org/10.1002/star.201800145.

Li, J., Hou, G. G., Chen, Z., & Gehring, K. (2013). Effects of endoxylanases, vital wheat gluten, and gum Arabic on the rheological properties, water mobility, and baking quality of whole- wheat saltine cracker dough. *Journal of Cereal Science*, 58(3), 437-445. http://dx.doi.org/10.1016/j.jcs.2013.09.006.

Liu, X., Mu, T., Sun, H., Zhang, M., Chen, J., & Fauconnier, M. L. (2018). Influence of different hydrocolloids on dough thermo-mechanical properties and in vitro starch digestibility of gluten-free steamed bread based on potato flour. *Food Chemistry*, 239, 1064-1074. http://dx.doi.org/10.1016/j.foodchem.2017.07.047. PMid:28873523.

McCleary, B. V., & Monaghan, D. A. (2002). Measurement of resistant starch. *Journal of AOAC International*, 85(3), 665-675. http://dx.doi.org/10.1093/jaoac/85.3.665. PMid:12083259.

Menon, R., Padmaja, G., & Sajeev, M. S. (2015). Ultrastructural and starch digestibility characteristics of sweet potato spaghetti: Effects of edible gums and fibers. *International Journal of Food Properties*, 18(6), 1231-1247. http://dx.doi.org/10.1080/10942912.2014.903263.

Osorio-Díaz, P., Islas-hernández, J. J., Agama-acevedo, E., Rodríguez-ambriz, S. L., Sánchez-pardo, M. E., & Bello-pérez, L. A. (2014). Chemical, starch digestibility and sensory characteristics of durum wheat: unripe whole banana flour blends for spaghetti formulation. *Food and Nutrition Sciences*, 2014, 264-270. http://dx.doi.org/10.4236/fns.2014.53033.

Ovando-Martinez, M., Sáyago-Ayerdi, S., Agama-Acevedo, E., Goñi, I., & Bello-Pérez, L. A. (2009). Unripe banana flour as an ingredient to increase the undigestible carbohydrates of pasta. *Food Chemistry*, 113(1), 121-126. http://dx.doi.org/10.1016/j.foodchem.2008.07.035.

Pivetta, F. P., Silva, M. N. D., Tagliapietra, B. L., & Richards, N. S. D. S. (2020). Addition of green banana biomass as partial substitute for fat and encapsulated *Lactobacillus acidophilus* in requeijão cremoso processed cheese. *Food Science and Technology*, 40(2), 451-457. http://dx.doi.org/10.1590/fst.03919.

Pongpichaiudom, A., & Songsermpong, S. (2018a). Characterization of frying, microwave-drying, infrared-drying, and hot-air drying on protein-enriched, instant noodle microstructure, and qualities. *Journal of Food Processing and Preservation*, 42(3), 1-10. http://dx.doi.org/10.1111/jfpp.13560.

Pongpichaiudom, A., & Songsermpong, S. (2018b). Improvement of microwave-dried, protein-enriched, instant noodles by using hydrocolloids. *Journal of Food Science and Technology*, 55(7), 2610-2620. http://dx.doi.org/10.1007/s13197-018-3182-2. PMid:30042577.

Ribeiro, L. D. O., Barbosa, I. D. C., Sá, D. G. C. F., Silva, J. P. L., Matta, V. M., & Freitas, S. P. (2020). Stability evaluation of juçara, banana and strawberry pasteurized smoothie during storage. *Food Science and Technology*, 40(2), 387-393. http://dx.doi.org/10.1590/fst.01319.

Ritthiruangdej, P., Parnbankled, S., Donchedee, S., & Wongsagonsup, R. (2011). Physical, chemical, textural and sensory properties of dried wheat noodles supplemented with unripe banana flour. *Witthayasan Kasetsat Witthayasat*, 45(3), 500-509.

Romero, H. M., Santra, D., Rose, D., & Zhang, Y. (2017). Dough rheological properties and texture of gluten-free pasta based on proso millet flour. *Journal of Cereal Science*, 74, 238-243. http://dx.doi.org/10.1016/j.jcs.2017.02.014.

Saifullah, R., Abbas, F. M. A., Yeoh, S. Y., & Azhar, M. E. (2009). Utilization of green banana flour as a functional ingredient in yellow noodle. *International Food Research Journal*, 16(3), 373-379.

Santos, R. O., Silva, M. V. F., Nascimento, K. O., Batista, A. L., Moraes, J., Andrade, M. M., Andrade, L. G. Z., Khosravi-Darani, K., Freitas, M. Q., Raices, R. S., Silva, M. C., Barbosa, J. L. Jr., Barbosa, M. I. M. J., & Cruz, A. G. (2018). Prebiotic flours in dairy food processing: technological and sensory implications. *International Journal of Dairy Technology*, 71, 1-10. http://dx.doi.org/10.1111/1471-0307.12394.

Segundo, C., Román, L., Gómez, M., & Martínez, M. M. (2017). Mechanically fractionated flour isolated from green bananas (M. cavendishii var. nanica) as a tool to increase the dietary fiber and phytochemical bioactivity of layer and sponge cakes. *Food Chemistry*, 219, 240-248. http://dx.doi.org/10.1016/j.foodchem.2016.09.143. PMid:27765223.

Shan, S., Zhu, K. X., Peng, W., & Zhou, H. M. (2013). Physicochemical properties and salted noodle-making quality of purple sweet potato flour and wheat flour blends. *Journal of Food Processing and Preservation*, 37(5), 709-716. http://dx.doi.org/10.1111/j.1745-4549.2012.00686.x.

Singh, B., Singh, J. P., Kaur, A., & Singh, N. (2016). Bioactive compounds in banana and their associated health benefits: a review. *Food Chemistry*, 206, 1-11. http://dx.doi.org/10.1016/j.foodchem.2016.03.033. PMid:27041291.

Sirichokworrakit, S., Phetkhut, J., & Khommoon, A. (2015). Effect of partial substitution of wheat flour with riceberry flour on quality of noodles. *Procedia: Social and Behavioral Sciences*, 197, 1006-1012. http://dx.doi.org/10.1016/j.sbspro.2015.07.294.

Sopade, P. A., & Gidley, M. J. (2009). A rapid in-vitro digestibility assay based on glucometry for investigating kinetics of starch digestion. *Starch*, 61(5), 245-255. http://dx.doi.org/10.1002/star.200800102.

Srikaeo, K., Mingyai, S., & Sopade, P. A. (2011). Physicochemical properties, resistant starch content and enzymatic digestibility of unripe banana, edible canna, taro flours and their rice noodle products. *International Journal of Food Science & Technology*, 46(10), 2111-2117. http://dx.doi.org/10.1111/j.1365-2621.2011.02724.x.

Tan, H. Z., Li, Z. G., & Tan, B. (2009). Starch noodles: History, classification, materials, processing, structure, nutrition, quality evaluating and improving. *Food Research International*, 42(5–6), 551-576. http://dx.doi.org/10.1016/j.foodres.2009.02.015.

Thailand, Ministry of Industry. (2005). *Industrial Product Standards Act No.6, of 31 January 2005; Instant noodles (Report No. TISI 271-2548)*. Retrieved from http://research.rid.go.th/vijais/moa/fulltext/TIS271-2548.pdf.

Tiboonbun, W., Moongngarm, A., & Preparation, A. S. (2011). Effect of replacement of unripe banana flour for rice flour on physical properties and resistant starch content of rice noodle. *International Journal of Nutrition and Food Engineering*, 5(9), 608-611.

Wang, N., Maximiuk, L., & Toews, R. (2012). Pea starch noodles: effect of processing variables on characteristics and optimisation of twin-screw extrusion process. *Food Chemistry*, 133(3), 742-753. http://dx.doi.org/10.1016/j.foodchem.2012.01.087.

Zhang, Y., Zhang, Y., Li, B., Wang, X., Xu, F., Zhu, K., Tan, L., Dong, W., Chu, Z., & Li, S. (2019). In vitro hydrolysis and estimated glycemic index of jackfruit seed starch prepared by improved extrusion cooking technology. *International Journal of Biological Macromolecules*, 121, 1109-1117. http://dx.doi.org/10.1016/j.ijbiomac.2018.10.075. PMid:30342148.

Zhou, M., Xiong, Z., Cai, J., & Xiong, H. (2015). Effect of cross-linked waxy maize starch on the quality of non-fried instant noodles. *Starch*, 67(11-12), 1035-1043. http://dx.doi.org/10.1002/star.201500132.