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

Jidapa TANGTHANANTORN¹, Santad WICHIENCHOT¹, Piyarat SIRIVONGPAISAL²*

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 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
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 Na₂CO₃ and K₂CO₃) were dissoloved 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 (pancreatins, 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):

\[
GI = 39.71 + (0.549 \times \text{HI})
\]  

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.
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.

<table>
<thead>
<tr>
<th>Sample</th>
<th>G' (Pa)</th>
<th>G'' (Pa)</th>
<th>tan δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>WF100</td>
<td>27500.63 ± 87.23a</td>
<td>20613.33 ± 772.65a</td>
<td>0.75 ± 0.03a</td>
</tr>
<tr>
<td>BF10</td>
<td>27326.91 ± 719.77c</td>
<td>21618.97 ± 365.72c</td>
<td>0.79 ± 0.01c</td>
</tr>
<tr>
<td>BF20</td>
<td>29838.70 ± 709.96a</td>
<td>24352.73 ± 991.68a</td>
<td>0.82 ± 0.02a</td>
</tr>
<tr>
<td>BF30</td>
<td>30730.37 ± 848.08c</td>
<td>26420.47 ± 800.74c</td>
<td>0.86 ± 0.01b</td>
</tr>
<tr>
<td>BF40</td>
<td>31315.20 ± 149.23c</td>
<td>28931.23 ± 677.10a</td>
<td>0.92 ± 0.03c</td>
</tr>
</tbody>
</table>

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.

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 Tibboonbun 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 increasing BF substitution of fresh noodles affected in the glycemic responses of the noodles substituted with various banana flour contents. The substitution of BF with 10 to 30% gives highly acceptable 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 (Pongphichaidom & 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...
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 had the lowest tensile strength (39.44 g), while DBF30 without hydrocolloid had the highest value (71.70 g). 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 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 when the hydrocolloid level was increased from 1.0 to 1.5%.

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 and non-digestible fractions, and the effect is dependent on the type of starch. 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).

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), while DBF30 without hydrocolloid had the lowest tensile strength (39.44 g). 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).

### Textural properties 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).
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.

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