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Influence of formulations on textural, mechanical and structural breakdown properties of cooked yellow alkaline noodles

Foo, W. T., Yew, H. S., Liong, M. T. and *Azhar, M. E

Food Technology Division, School of Industrial Technology, Universiti Sains Malaysia, 11800 USM Penang, Malaysia

Abstract: The physical attributes (pH and colour), cooking yield, textural and mechanical properties (firmness, tensile and texture profiles analyses) and structural breakdown properties (multiple extrusion cell with added artificial saliva) of five yellow alkaline noodle (YAN) formulations were studied. Samples used were noodles with (a) typical formulation (control), (b) soy protein isolate (SPI), (c) soy protein isolate plus microbial transglutaminase enzyme (SPI/MTGase), (d) green banana pulp flour (GBPu) and (e) green banana peel flour (GBPe). Compared to other noodles SPI/MTGase noodle showed significantly ($P < 0.05$) higher values in terms of textural, mechanical and breakdown properties. Incorporating SPI, banana pulp and peel flours into the noodles had imposed some differences on most of the mechanical and textural parameters from the control YAN. However, these noodles could not be clearly distinguished in term of structural breakdown properties.

Keywords: Yellow alkaline noodles, cooking quality, textural properties, structural breakdown

Introduction

Yellow alkaline noodles (YAN) are basically prepared using wheat flour, water, salt and alkaline salt water (*kan sui*). As a result of high demand of healthy food products, many health-enhancing ingredients have been partially substituted to improve the nutritional values of noodles. Incorporating other ingredients could be expected to change the texture and eating quality of the noodles.

The health claim for soy protein is well established, thus the incorporation of soy protein in YAN could help increase the soy intake from daily foods. Soy protein will not only improve nutritional values but also modify textural properties of noodles. On the other hand, protein cross-linking agents (i.e., microbial transglutaminase) have been used to modify textural characteristics of protein-based foods. This enzyme introduces covalent crosslinkings between proteins, peptides and various primary amines, yielding a stronger protein network (Gan *et al*., 2009).

Unripe or green banana flour has been studied and substituted into pastas and noodles in order to enhance the nutritional values of the final products. Banana flour not only contains a high level resistant starch and dietary fibre content, but also a respectable amount of antioxidants. Adding high fibre or high resistant starch ingredients such as banana peel flour or banana pulp flour may help in improving the nutritional values of the products (Agama-Acevedo *et al*., 2009; Ovando-Martinez *et al*., 2009).

Breakdown pattern of food is greatly affected by the oral conditions. During oral processing, various factors may influence the perception of food texture that varies from the first bite until the bolus formation prior to the state of swallowing (van Vliet, 2002; Janssen *et al*., 2009). Food components and their mechanical characteristics could also affect the breakdown properties. In general, foods with hard and firm texture require additional chewing force and movements before swallowing. Despite, for starchy foods the presence of α-amylase in saliva aids in mixing and digestion processes (Chen, 2009).

The use of texture profile analysis (TPA) for assessing textural properties of foods is well established. TPA however does not mimic oral processing of foods (i.e. noodles) in the mouth. On the other hand, multiple extrusion cell (MEC) is a device attached to a texture analyzer that could be used to imitate masticating mechanism in the mouth with the addition of artificial saliva under a controlled-temperature environment. The presence of artificial saliva initiates enzymatic breakdown of starch-based foods similar to that of oral processing. The interaction of food samples and saliva could be observed during the continuous extrusion cycles. Even though MEC analysis is an empirical method it could generate useful information on the structural breakdown food (Janssen *et al*., 2009).

The substitution of soy protein isolate (SPI) and microbial transglutaminase (Gan *et al*., 2009) and banana pulp or banana peel flour (Ramli *et al*., 2009), has been shown to alter the textural characteristics of noodles. However, the impacts of these substitutions on structural breakdown of YAN have not been answered. The objective of this work was to compare

*Corresponding author.
Email: *azhar@usm.my*
Tel: +604 653 3888/222; Fax: +604 657 3678

the texture and structural breakdown of different types of noodles prepared from different formulations using SPI, SPI/MTGase, GBPu and GBPe.

Materials and Methods

Materials

Noodle making ingredients (i.e. wheat flour, salt, and alkaline salt water) and unriped green banana (*Musa paradisiaca* L., cv. cavendishii) were purchased from a local market (Penang, Malaysia). Food grade soy protein isolate (SPI) was purchased from Sim Company Sdn. Bhd. (Penang, Malaysia) and commercial Microbial Transglutaminase (MTGase) enzyme ACTIVA TG-BW-WH (activity: 46-76 U/g) was purchased from Ajinomoto Bhd. (Kuala Lumpur, Malaysia). Other chemicals and reagents used for preparation of the banana peel flour, banana pulp flour and analysis were of analytical grade. Citric acid, xanthan gum and α-amylase (type VI-B from Porcine Pancreas) were purchased from Sigma Chemical Co. (St. Louis, US). Sodium hydrogen carbonate, sodium chloride, potassium chloride, and calcium chloride dehydrate, di-potassium hydrogen phosphate (anhydrous) were purchased from Systerm Sdn. Bhd. (Selangor, Malaysia).

Preparation of banana peel and banana pulp flours

Banana peel and banana pulp flours were prepared according to the methods of Ramli *et al*. (2009). Green bananas were washed and separated into pulp and peel. The peel and pulp were then cut into smaller pieces of approximately 20 mm long and 2 mm thick. Both peel and pulp were soaked in 0.5% (w/v) citric acid solution for 10 min, drained and dried in a hot air oven (AFOS Mini Kiln, Hull, England) at 60°C for 12 hrs. The dried peel and pulp were ground to pass through a 40-mesh sieve by using Retsch Micro Universal Bench Top Grinder AS 200 (Retsch GmbH & Co., Haan, Germany). The peel and pulp flours obtained were vacuum packed and stored under ambient condition of 25°C.

Preparation of yellow alkaline noodles

Noodles were prepared according to the formulations as displayed in Table 1. Control noodle, soy protein isolate (SPI) and soy protein isolate plus microbial transglutaminase enzyme (SPI/MTGase) noodles were prepared using the methods described by Gan *et al*. (2009), whilst banana pulp (GBPu) and banana peel (GBPe) noodles were prepared using the methods described by Ramli *et al*. (2009). All noodles were steamed by using a domestic steamer for 30 min and followed by drying in a hot air oven (AFOS Mini Kiln, Hull, UK) at 60°C for 105 min to yield dried noodles. The noodles were then cooled to 25°C before being vacuum packed. Prior to analyses, the strands of dried noodles from each formulation were cooked in 200 ml boiling deionised water for 10 min, rinsed, drained and cooled to 25°C (Gan *et al*., 2009, Ramli *et al*., 2009).

Table 1. Formulations of alkaline noodles

Ingredients (g)	Type of noodles				
	Control	SPI	SPI/ MTGase	GBPe	GBPu
Wheat Flour	100	95	95	90	90
Deionised Water	50	50	50	50	50
Pure Salt	1	1	1	1	1
Kansui; Alkaline Salt Water	1	1	1	1	1
SPI	-	5	5	-	-
MTGase	-	-	0.5	-	-
GBPu	-	-	-	10	-
GBPe	-	-	-	-	10

[*] SPI = Soy Protein Isolate, MTGase = Microbial Transglutaminase, GBPu = Banana Pulp, GBPe = Banana Peel

pH measurement

The cooked noodle strands (10 g) were homogenised with 100 ml deionised water for 5 min. The homogenised suspension was allowed to stand for 30 min and filtered prior to pH measurement of the filtrate. The pH was measured using Mettler-Toledo Delta 320 pH meter (Mettler-Toledo Instrument Co. Ltd., Shanghai, China) with an Inlab 421 electrode (Mettler-Toledo, Switzerland).

Colour measurement

The colour of the cooked noodle was determined using a colorimeter (Model CM-3500d, Konica Minolta Corp., Ramsey, N.J, USA) equipped with D65 illuminant using the CIE 1976 L^*, a^*, and b^* colour scale. Readings obtained directly from the instrument provided measures of lightness, redness, and yellowness, respectively. Measurements were made at random locations on the surface of the noodle strand.

Cooking Yield

Cooking yield was obtained based on the approved AACC method of 66-50 (AACC, 2003). The dry noodle strands (5.0 g) were boiled in 75 g of deionised water for 10 min with agitation. The noodle strands were then rinsed and drained for 5 min. Average readings of three measures were taken for each type of noodle.

Texture profile analysis

Texture profile analysis was performed using a Texture Analyzer, TA-HDi (Stable Micro Systems, Surrey, England). The fixture used was pasta firmness/stickiness rig by using a 25 kg load cell according to Sozer and Kaya (2003). The settings used were: *Mode*: Texture profile analysis; *Option*: Return to start; *Pre-Test Speed*: 1.0 mm/s; *Test Speed*: 1.0 mm/s; *Post-Test Speed*: 3.0 mm/s; *Strain*: 75%; *Time*: 2 s; *Trigger Force*: 0.05 N; *Data Acquisition Rate*: 200 pps. The cooked noodles were cut into 70 mm in length and five noodle strands were placed straight and flat adjacently to one another under the compression platen of pasta firmness/stickiness rig on the centre of heavy duty platform. From the TPA curve, hardness (maximum peak force during the first compression), and chewiness (product of hardness, cohesiveness and springiness) were reported. Nine repeat measures were taken for each type of noodle.

Noodle firmness

The firmness of cooked noodles was measured by using a Texture Analyzer, TA. XT2 Plus (Stable Micro Systems, Surrey, England) with a 5 kg load cell attached with a 1 mm flat Perspex knife blade according to the AACC (2003) method 16-50 with some modifications on the setting. The distance between the blade and the heavy duty platform was set at 30 mm. The settings used were: *Mode*: Measure force in compression; *Option*: Return to start; *Pre-Test Speed*: 1.0 mm/s, *Test Speed*: 0.1 mm/s; *Post-Test Speed*: 10 mm/s; *Distance*: 4.98 mm; *Data Acquisition Rate*: 400 pps. The cooked noodles were cut into 70 mm in length and five noodle strands were placed straight and flat adjacently to one another on the centre of heavy duty platform, with the samples positioned at right angles to the blade. The firmness value was taken from the peak of a force-time graph. Fifteen repeat measures were taken for each noodle formulation.

Tensile test for noodles

Tensile strength and elasticity of noodles were assessed using a Texture analyser, TAXT2 model (Stable Micro Systems, Surrey, UK) fitted with a 5 kg load cell. Rig calibration was performed prior to measurement. The distance of the probe to move apart was set at 15 mm. The settings used were: *Mode*: Measure force in tension; *Option*: Return to start; *Pre-test speed*: 3.0 mm/s; *Test speed*: 3.0 mm/s; *Post-test speed*: 5.0 mm/s; *Distance*: 100 mm. The cooked noodle strands were cut into 200 mm long. The width and thickness of the strand were determined at three different locations using a manual micrometer (Dial Thickness Gauge Mitutoyo MI 7305, Japan). The tensile strength was calculated as:

$$\alpha = \frac{F}{A} \qquad \text{(Eq. 2)}$$

where α is the tensile strength (Pa), *F* is the peak force (N) and *A* is the cross-sectional area of the noodle strand (m^2). The elasticity was then calculated as:

$$Elasticity = \frac{F l_o}{t A_0} \times \frac{1}{v} \qquad \text{(Eq. 3)}$$

where *F/t* is the initial slope (N/s) of the force-time curve, l_0 is the original length of the noodles between the limit arms (0.015 m), A_0 is the original cross-sectional area of the noodle (m^2) and v is the rate of movement of the upper arm (0.003 m/s) (Gan *et al*., 2009). Fifteen repeat measures were taken for each noodle formulation.

Structural breakdown analysis

Preparation of artificial saliva

The artificial saliva consisted of $NaHCO_3$ (5.208 g), K_2HPO_4 (1.241 g), NaCl (0.877 g), KCl (0.447 g), $CaCl_2.2H_2O$ (0.441 g) xanthan gum (0.920 g), and 200,000 U of α-amylase in 1 L of distilled water. The solution was adjusted to pH 7 by using 0.1 M NaOH solution (Boland *et al*., 2004).

Multiple extrusion cell analysis

Structural breakdown patterns of noodles were determined by using a multiple extrusion cell, which was attached to the Texture Analyzer, TA.XT2 Plus (Stable Micro Systems, Surrey, England) with a 30 kg load cell according to Janssen *et al*. (2009) with changes on the setting. The settings used were: *Mode*: Measure force in compression; *Option*: Cycle until count; *Test Speed*: 10 mm/s; *Post-Test Speed*: 5 mm/s; *Distance*: 95 mm; *Count*: 20 cycle; *Data Acquisition Rate*: 2 pps.

The MEC consists of a cylindrical inner sample vessel (diameter 25 mm, length 105 mm, thickness 1 mm). The sample vessel was fitted inside a water-jacketed cylindrical tube attached centrally to the base of the texture analyzer. A circular plate piston (diameter 22 mm, thickness 3 mm) with six holes (diameter 6 mm) was attached via a thin rod to the texture analyzer through a cell lid (screw cap). Before running each measurement, the force was "tared" to remove the mass of the piston. The temperature of MEC was maintained at 37°C by using a digital heating circulator, (Model Protech HC-10, Tech-Lab Scientific Sdn. Bhd., Selangor, Malaysia).

A measurement was performed by filling 20.0 g of cooked noodle strands into the sample vessel. Before closing the lid, 10 ml of artificial saliva was added into the vessel. A force versus time graph was generated as the piston started to move up and down. The data was then fitted into a single exponential decay equation (Eq. 4) as following:

$$W(n) = w_{inf} + w_1 EXP\left(\frac{-n}{n_1}\right) \qquad \text{(Eq. 4)}$$

$W(n)$ is work during each extrusion cycle (n), w_{inf} is work per extrusion after a large (infinite) number of extrusions, w_1 is a measure for the amount and the strength of structure of noodle that has been broken down and n_1 determines the decay rate of the work per extrusion with an increasing number of extrusions.

Statistical analysis

In this study, all analyses were repeated three times. SPSS version 12.0 for Windows software was used for statistical analysis. Results were analyzed by comparing the means using one-way analysis of variance (ANOVA), and Duncan's multiple range test was used to determine significant difference ($P < 0.05$) among the different formulations.

Results and Discussion

Physical properties of noodles

The pH values of all the studied noodles were in the range of 7.29 to 8.37 (Table 2). Except for SPI noodle, noodles prepared from other formulations showed a significant ($P < 0.05$) reduction in pH as compared to the control noodle. The reduction might be attributed to the original pH of MTGase, banana pulp and banana peel flours.

The values of L^* were in the order: control, SPI > SPI/MTGase > GBPu > GBPe (Table 2). For a slightly creamy YAN, high lightness (L^*) and moderate yellowness (b^*) are desirable. The extremes on either side of parameter a^* or parameter b^* are taken as deleterious. As compared with the control and SPI noodles, SPI/MTGase noodle showed a lower L^* value indicating the network of SPI/MTGase noodle could be more compact due to MTGase crosslinking (Gan *et al*., 2009). While, the low L^* values of GBPu and GBPe noodles was mainly attributed to the original colour of GBPu and GBPe flours. The dark brown colour of these flours was caused by the Maillard reaction and enzymatic browning during drying process (Ramli *et al*., 2009). The values of yellowness (positive b^*) were in the order: control >SPI, SPI/MTGase > GBPu > GBPe (Table 2). Yellowness in YAN is an important attribute for the perception and acceptability of consumers. The yellowness is contributed by the presence of flavanoids in the wheat flour. These compounds undergo a chromophoric shift and turn into yellow In the presence of alkaline (Gan *et al*., 2009). As the wheat flour was substituted by other ingredients of different colours, the yellowness decreased significantly ($P < 0.05$). The values of redness (positive a^*) were in the order: GBPe > GBPu > SPI/MTGase > control > SPI (Table 2). The SPI powder used was creamy-yellow in colour, thus the SPI noodle showed the lowest value of redness. Whilst, the higher level of redness in GBPu and GBPe noodles were due to the original dark-brown colour of the dried banana flours.

Cooking quality of noodles could be assessed by measuring the cooking yield. The cooking yield of the noodles ranged between 287-362% and was in the order: control, GBPu ≥ GBPe, SPI ≥ SPI/MTGase (Table 2). Noodle consists of protein network filled with starch granules. During cooking, the texture of the noodle starts to disintegrate and soften due to the swelling of starch granules (Gan *et al*., 2009). Therefore, the amount of starch could be related to the ability of the noodle to absorb water. The control and GBPu noodles absorbed the highest amount of water due to the higher starch content in the noodles. Ramli *et al*. (2009) reported that GBPu flour contains a substantial level of starch. The substitution of SPI in the noodle formulations decreased the water absorption as the protein network formed was stronger and therefore retarded water diffusion to reach starch granules and reduced the swelling ability of starch granules (Sozer and Kaya, 2003; Gan *et al*., 2009). Thus, the lowest cooking yield of SPI/MTGase noodle could be due to the densely formed network by the MTGase crosslinking.

Mechanical, textural and structural breakdown properties of noodles

The tensile strength and elasticity of the noodles were improved significantly ($P < 0.05$) by incorporating SPI and/or MTGase (Table 3). The ability of SPI to form gel enhanced the network formation and the MTGase further improved the network density of the noodles by introducing more crosslinkings (Gan *et al*., 2009). Generally, GBPe and GBPu noodles showed no improvement in the mechanical properties. In fact, a drop in tensile strength occurred when GBPe was incorporated into the noodles. This could be due to the diluting effect of gluten protein as a result of partial substitution with the banana flours.

Data from TPA (Table3) indicates that SPI/MTGase noodle was the hardest and required the highest level of force to chew. Whilst, the values of hardness and chewiness for both GBPu and GBPe noodles were ~ 50% less than SPI/MTGase noodle. This suggested that the texture of noodles was greatly dependent on the protein network. The noodle with strong protein network could be expected to be harder

Table 2. pH, colour and cooking quality for different types of noodles

Noodle formulations *	pH	Colour			Cooking Yield (%)
		L^*	a^*	b^*	
Control	8.37 ± 0.11[a]	69.68 ± 0.37[a]	1.14 ± 0.40[c]	17.23 ± 0.97[a]	362.0 ± 12.0[a]
SPI	8.36 ± 0.14[a]	68.49 ± 1.74[a]	0.05 ± 0.17[d]	15.36 ± 1.46[b]	316.8 ± 49.9[ab]
SPI/ MTGase	8.01 ± 0.09[b]	65.40 ± 1.41[b]	0.99 ± 0.28[c]	14.84 ± 0.56[b]	287.0 ± 35.4[b]
GBPu	7.95 ± 0.09[b]	59.81 ± 1.65[c]	3.47 ± 0.30[b]	11.96 ± 0.30[c]	345.8 ± 7.5[a]
GBPe	7.29 ± 0.03[c]	43.20 ± 1.37[d]	5.28 ± 0.29[a]	13.19 ± 0.38[d]	332.5 ± 35.9[ab]

* SPI = Soy Protein Isolate, MTGase = Microbial Transglutaminase, GBPu = Green Banana Pulp, GBPe = Green Banana Peel
Results display mean values ± standard deviation (n = 3).
[abc] Values with different superscripts within a column indicate significant difference, ANOVA and Duncan tests (P < 0.05)

Table 3. Mechanical and textural properties of different types of noodles

Noodle formulations*	Mechanical properties			Textural properties	
	Tensile Strength (kPa)	Elasticity (kPa)	Firmness (N)	Hardness (N)	Chewiness (N)
Control	24.42 ± 5.81[c]	13.91 ± 2.99[c]	1.34 ± 0.06[c]	117.70 ± 14.90[c]	33.08 ± 6.74[c]
SPI	32.76 ± 5.38[b]	18.90 ± 2.39[b]	1.80 ± 0.37[b]	139.55 ± 17.53[b]	45.35 ± 6.87[b]
SPI/ MTGase	48.80 ± 9.23[a]	24.97 ± 5.25[a]	2.35 ± 0.37[a]	218.51 ± 17.44[a]	67.41 ± 11.21[a]
GBPu	20.79 ± 5.18[cd]	13.32 ± 2.64[c]	1.31 ± 0.07[c]	94.29 ± 14.08[d]	25.06 ± 4.96[d]
GBPe	18.34 ± 2.97[d]	14.05 ± 1.91[c]	1.39 ± 0.07[c]	115.21 ± 13.39[c]	30.59 ± 4.85[cd]

* SPI = Soy Protein Isolate, MTGase = Microbial Transglutaminase, GBPu = Green Banana Pulp, GBPe = Green Banana Peel
Results display mean values ± standard deviation (n = 3).
[abc] Values with different superscripts within a column indicate significant difference, ANOVA and Duncan tests (P < 0.05).

and firmer.

MEC analysis could be used to follow the breakdown of food products in the conditions that mimic a human mouth. The addition of artificial saliva could be done easily and the environmental temperature could also be maintained at 37°C. This would then generate more meaningful data to elucidate the breakdown patterns of foods (Janssen *et al*., 2009). In this study, the structural breakdown of noodles was analysed using the multiple extrusion cell (MEC). Fig. 1 indicates the continuous extrusion cycles to breakdown the control noodle. During the test, the values of resistance force were recorded as a function of time. As the piston moved downward, the increase in resistance force was recorded as positive values. The change in direction of piston movement caused a sharp decrease in the force value and the forces recorded during upward extrusion were marked as negative values. These downward and upward extrusion movements together formed one complete extrusion cycle. The value of each area under force–time curve represented the work done during each movement. The area under the first downward extrusion movement (*Work 1*st) represents the amount of work needed to breakdown the intact noodle (Figure 1). The control, GBPu and GBPe noodles showed a similar breakdown trend, while SPI/MTGase noodle showed differing breakdown trend as compared to other samples studied.

The amount of work done decreased gradually and after a number of extrusions, no structural elements were further broken down and this was shown by the plateau of the curves (Figure 2). At this point (w_{inf}), the noodle strands were transformed into a semi-solid state without further structural breakdown. The curves were then fitted into a single exponential decay equation (Eq. 4) to generate meaningful parameters (Table 4). The amount of work done during the first compression (*work* 1st) was in the order: SPI/MTGase ≥ SPI > GBPe, control, GBPu. There was no significant (P > 0.05) difference in the amount of work remained (w_{inf}) in the GBPu, GBPe and SPI as compared to the control. SPI/MTGase noodles exhibited significantly (P < 0.05) higher winf as compared to the control, reflecting that large

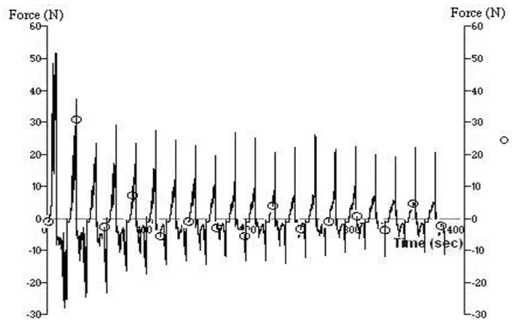

Figure 1. Curve of force as a function of time representing the breakdown of the control noodle during MEC analysis

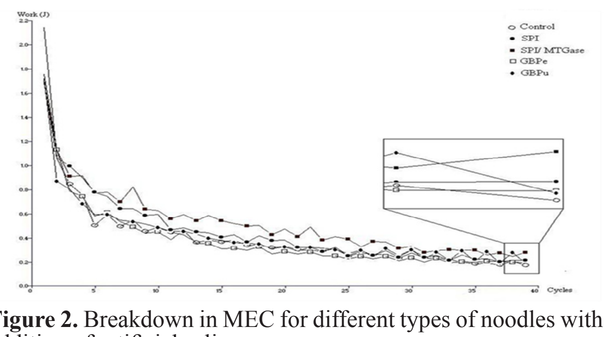

Figure 2. Breakdown in MEC for different types of noodles with addition of artificial saliva

Table 4. MEC parameters for different types of noodles

Noodle formulations *	Work 1st (J)	w_{inf} (J)	w_1 (J)	n_1 (J/ cycle)
Control	1.88 ± 0.14[b]	0.34 ± 0.05[b]	1.28 ± 0.05[a]	3.56 ± 0.07[b]
SPI	2.19 ± 0.43[ab]	0.34 ± 0.05[ab]	1.48 ± 0.16[a]	4.16 ± 0.89[b]
SPI/ MTGase	2.41 ± 0.53[a]	0.41 ± 0.06[a]	1.58 ± 0.42[a]	5.24 ± 0.88[a]
GBPu	1.87 ± 0.26[b]	0.30 ± 0.04[b]	1.28 ± 0.11[a]	3.92 ± 0.11[b]
GBPe	1.97 ± 0.16[b]	0.28 ± 0.02[b]	1.45 ± 0.08[a]	3.11 ± 0.29[b]

* SPI = Soy Protein Isolate, MTGase = Microbial Transglutaminase, GBPu = Green Banana Pulp, GBPe = Green Banana Peel
Results display mean values ± standard deviation (n = 3).
[abc] Values with different superscripts within a column indicate significant difference, ANOVA and Duncan tests (P < 0.05)

pieces of particles remaining after extrusion of the SPI/MTGase noodles. w_1 measures the amount of work done and the deformation of broken structures. For all the noodles, the values of w_1 did not differ significantly ($P > 0.05$). n_1 determines the breakdown rate with increasing number of extrusions. Lower n_1 reflects a faster breakdown rate. The breakdown rate of SPI/MTGase noodle was the slowest among all the noodles, indicating its highly dense structure due to the additional protein crosslinking.

Relating MEC parameters with textural and mechanical properties

SPI/MTGase noodle required the highest amount of work to break down the intact structure (*Work 1st*) due to its hardness and firmness attributed to the intermolecular protein cross-linking within the noodle. The broken pieces of SPI/MTGase noodle were relatively larger than other noodles and the breakdown also occurred at a lower rate as indicated by w_{inf} and n_1, respectively. From the mechanical and textural analyses, SPI/MTGase noodle was the most elastic, hardest, firmest and could not breakdown easily. This was in accordance with the results obtained from MEC analysis. It could be concluded that by incorporating soy protein and protein cross-linking agent such as microbial transglutaminase (MTGase) into the noodles, would induce more crosslinkings within the network of the noodles and thus yielded products with higher firmness with reduction in the accessibility of the α-amylase enzyme from digesting the starch in the noodle network. Therefore, the SPI/MTGase noodle could not be broken down easily and the broken pieces were relatively larger.

From MEC results, noodles substituted with SPI, high resistance starch (GBPu flour) and high fibre (GBPe flour) could not be clearly distinguished from the control noodle. This might probably due to the similar network structure among all these noodles. However, there are some differences in the mechanical and TPA parameters between these noodles.

Conclusion

Noodles with different formulations yielded different physical, mechanical and textural characteristics. Through MEC analysis, additional information was obtained regarding the breakdown process of the noodles that resembles the oral processing. The partial substitution of the noodles with SPI or SPI with MTGase improved the mechanical and textural properties of the noodles and influenced the breakdown properties during oral processing. The incorporation of GBPu and GBPe flours into the noodles caused reduction in physical properties and some of the mechanical and textural properties. However, the breakdown properties of SPI, GBPu and GBPe noodles could not be distinguished from the control noodle.

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