Effects of ripening stage and steaming time on quality attributes of fat free banana snack obtained from drying process including fluidized bed puffing

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Abstract Healthy snacks have increasingly been interested in consumers. Puffing technique is an alternative to produce healthy snacks. Effects of ripening stage of banana and steaming time on quality of banana slices obtained from drying process including fluidized bed puffing were investigated. Bananas at the ripening stages 1 and 3 were steamed at 100 °C for 30 s up to 2 min and dried at 90 °C to moisture content of 25 % dry basis (d.b.). The samples were then puffed by fluidized bed dryer at 160 °C for 2 min and dried at the same temperature as the first stage drying. The experimental results showed that shrinkage, drying time, color, glycemic index and textural properties were affected by steaming time and ripening stage. Steaming provided more uniformity of banana color. Steaming positively or negatively affected the degree shrinkage of banana depending on the ripening stage. The banana texture in particular crispiness could be improved by the steaming for the ripening stage 1 banana whilst it did not improve for the ripening stage 3. During steaming, the C-type crystalline structure of banana starch disappeared and thus the value of glycemic index was increased. The ripening stage 1

banana was recommended for producing healthy snack in order to control glycemic response.

Keywords Glycemic index · Puffing · Snack · Texture

Introduction

Fruits are the foundation of a healthy diet and are high in nutrients. Bananas, like other fruits, are rich in nutrient. Bananas are sources of carbohydrates, fiber and polyphenols with antioxidant capacity (Pérez et al. 2011). Bananas are a preferred item in the diet as it contains considerable amount of fiber to reduce intestinal disorders and cholesterol absorption (Horigome et al. 1992). High starch content could be found at the unripe stage of banana. When they are ripe, the starch content decreases whilst level of sugars increases high. The change of starch content might lead to variation in product quality and it would important to identify the correct ripening stage for acceptable quality product.

Conventional drying is commonly used to dry bananas, but their textural properties are very poor because of high shrinkage of solid matrix and low porosity. High temperature and short time drying stage, namely puffing, is another technique that can improve the textural properties of product. During puffing, the moisture inside the food is vaporized rapidly and expanded inside the food (Payne et al. 1989; Nath et al. 2007; Shilton et al. 1998; Varnalis et al. 2004). This phenomenon allows the creation of the voids inside the food, which are important to crisp food. This is because the collapse of the voids during chewing process produces a typical sound which contributes to crispness sensation (Vincent 1998). The crispness is the important sensory characteristic of snacks which affects consumers' appreciation (Szczesniak and Kahn 1984).

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The digestibility of starch is another important quality index that has recently been received attention besides the nutritional components. Starch can be classified according to its digestibility which is characterized by rate and duration of glycemic response. Glycemic index (GI) is used for ranking foods with respect to their potential liberation of glucose toward the blood (Jenkins et al. 2007). A low GI means that glucose is slowly released in blood stream which provides minimal fluctuations in blood glucose levels and a more insulin response. This is advantage to people with diabetics. The change of glycemic index in foods is based on several factors. When raw starch granules are gelatinized during cooking, the disruption of starch structure increases its susceptibility to enzymatic attack (Holm et al. 1988). When potato was boiled for 15 min, it led to increase in glycemic index from 53 to 66 (Lin et al. 2012). Also, the glycemic index of waxy rice after cooking was increased from 87.6 to 91–92 (Chung et al. 2006).

Blanching is important to industrial processes of fruits and vegetables. It is applied to inactivate deleterious enzymes (Severini et al. 2003) and to reduce microbial load. Blanching can improve taste, including maintaining flavor of fruits and vegetables (Patras et al. 2011). During blanching, physical and chemical changes occur such as enzyme denaturation (Abu-Ghannam and Crowley 2006), decrease of water vapor permeability (Vamalis et al. 2001) and gelatinization of starch granules (Lamberg and Olsson 1989). These changes affect the internal structure of the potato and thus can affect the quality after drying. Maté et al. (1998) studied the effect of blanching on quality of dried potato and found that blanched potatoes resulted in a significantly more compact and less porous product than unblanched potatoes.

As above mentioned, the objective of this study was therefore to study the effects of ripening stage of banana and steam blanching on qualities of puffed banana slices in terms of color, degree of shrinkage, texture and glycemic index.

Materials and methods

Sample preparation

Gros Michel bananas (*Musa sapientum* L.) were purchased from a local market. They contained their soluble solids content in a range of 3 to 5°Brix for the ripening stage 1 and 17 to 18°Brix for the ripening stage 3. Prior to start each experiment, the bananas were peeled and sliced into 2.5 mm thickness using a cutting machine (Savioli, model no 250S, Thailand). The banana slices were pretreated by citric acid at a concentration of 0.25 % w/v for 5 min and steamed for 30 s, 1, 1.5 and 2 min for the ripening stage 1. For the ripening stage 3, the banana sample was also pretreated by the citric acid and steamed only for 1.5 min. The longer steaming time than

1.5 min for this ripening stage resulted in mushy banana so that it was very difficult to processing and the shorter steaming resulted in the slight change of the banana color when exposed to the environment.

Puffing process

Puffing process consists of three main steps. The pretreated bananas were pre-dried in a tray dryer at the drying temperature of 90 °C and the superficial velocity of 2 m/s. They were dried from initial moisture content of 270–350 % d.b. to the intermediate moisture content of 25 % (d.b.). After that, the samples were puffed by a hot air fluidized bed dryer as shown in Fig. 1. The samples were puffed at the temperature of 160 °C for 2 min using a superficial air velocity of 3.5 m/s. Finally, they were further dried in the tray dryer with the same drying temperature as the first step and dried to the final moisture content of 4 % (d.b.).

Measurement of moisture content

A 3–5 g sample was mashed and dried for determining its moisture content. The moisture content of fruits is traditionally determined by the standard vacuum oven method 934.06 (AOAC 1995). In this work, however, the moisture content of banana slices was measured by drying them at temperature of 103 °C for 3 h in a hot air oven (Memmert, model no, ULE500, Schwabach, Germany). The moisture content measured by this method was slightly different from the standard vacuum oven method by approximately 0.4–1 %.

Shrinkage measurement

Ten samples obtained from each experimental condition were used to determine their shrinkage. The shrinkage of each sample was determined by solid displacement method using glass beads with diameter in a range of 0.106–0.012 mm (Hwang et al. 1980). The percentage of shrinkage was calculated by Eq. (1)

$$\% \text{ shrinkage} = \left(\frac{V_0 - V}{V_0} \right) \times 100 \quad (1)$$

where V_0 is the volume of fresh banana slice and V is the volume of dried banana slice.

For each measurement, one sample piece was used and the average value of ten samples was reported. The samples were weighed and transferred to an aluminum can and glass beads were poured over the banana sample until the aluminum can was full. After that, the surface was flattened with cardboard. The volume of banana sample (V) was calculated using Eq. (2).

Fig. 1 Schematic diagram of hot air fluidized-bed puffing

$$V = \frac{M_b - [M_{S+b} - M_v - M_S]}{\rho_b} \quad (2)$$

where M_b is the mass of glass beads filled in the aluminum can without banana sample, M_v is the mass of the empty can, M_{S+b} is the mass of can plus the sample and the beads, M_S is the mass of sample and ρ_b is the bulk density of the glass beads.

Color measurement

Color of the puffed banana slices was measured at their surface by colorimeter (Color Flex, Hunter Lab, Buckinghamshire, UK) with D65 illuminant and view angle of 10° . The colorimeter was calibrated with the standard white and black plates before measuring the sample color. For each banana slice, five different positions around the banana surface were measured and the average value of ten samples was used to represent their color. The mean values of L (brightness/darkness), a (redness/greenness) and b (yellowness/blueness) were reported. In addition, the overall color of puffed banana slices was presented by hue angle (ϕ), which is calculated by $\phi = \arctan(b/a)$.

Texture measurement

Fifteen samples were used to determine textural property. Hardness and crispiness properties of dried samples were measured by the texture analyzer (TA. XT. Plus, Stable Micro System, Haslemere, UK), which was equipped with a cutting probe (HDP-BSK type; Instron Ltd., High Wycombe, UK) connected to a 5 N load cell. The cutting probe was set to travel at a crosshead speed of 2 mm/s. The maximum force from the force deformation curve was considered as hardness while the crispiness of banana slices was characterized by a number of peaks and an initial slope of the first peak (Tabtiang

et al. 2012; Thuwapanichayanan et al. 2011; Anton and Luciano 2007). The number of peak was counted when the peak had a value higher than the threshold value of 30 g-force.

Chemical composition

Glucose, sucrose and fructose content were determined using high performance liquid chromatography (HPLC; Agilent 1100 Series, Agilent Technologies, Palo Alto, CA) according to the AOAC method 982.14 (AOAC 1993). Ash, protein, fat and starch were analyzed according to the AOAC methods 923.03, 920.87, 920.85 and 920.44, respectively (AOAC 1995). The dietary fiber method (DF) was determined by the modified AOAC enzymatic-gravimetric 991.43 (AOAC 1995).

In vitro kinetics of starch digestion

The analysis of starch hydrolysis was performed by the method of Goni et al. (1997). The powdered sample (50 mg) was prepared in 50 mL Erlenmeyer flasks and 10 mL of HCl-KCl buffer (pH 1.5) was added. The sample was homogenized for 2 min by an Ultra Turrax homogenizer (T25, Ika labortechnik, Staufen, Germany). Thereafter, 0.2 mL of a solution containing 1 mg of pepsin from porcine gastric mucosa in 10 mL HCl-KCl buffer at pH 1.5 was added in sample, followed by 60 min incubation in a shaking water bath at 40°C . The volume of solution was adjusted to 25 mL by adding 15 mL tris-maleate buffer (pH 6.9). To hydrolyze starch, a 5 mL of tris-maleate buffer which contained 2.6 IU of α -amylase from porcine pancreas (A-3176, Sigma company, Roche, USA) was added. The flask was placed in a shaking water bath at 37°C . Every 30 min from 0 to 3 h, 0.1 mL of aliquots was

Table 1 Chemical compositions in banana during ripening stage 1 and 3

Compositions (g/100 g)	Ripening stage	
	1: (3–5 Brix)	3: (17–18 Brix)
Protein	5.10 ± 0.03^g	5.74 ± 0.10^c
Fat	0.37 ± 0.01^a	0.32 ± 0.01^a
Soluble fiber	4.61 ± 0.03^f	5.64 ± 0.24^d
Insoluble fiber	8.46 ± 0.51^h	9.10 ± 0.04^f
Ash	3.34 ± 0.03^e	3.45 ± 0.02^b
Starch	74.57 ± 0.81^i	60.70 ± 0.86^h
Sucrose	2.25 ± 0.05^d	30.04 ± 0.41^g
Glucose	0.44 ± 0.05^b	3.38 ± 0.12^b
Fructose	0.49 ± 0.05^c	4.88 ± 0.08^c

Different superscripts in the same column mean that the values are significantly different ($p < 0.05$)

Table 2 Thermal properties of banana starch for ripening stage 1 and 3 and various steaming times

Ripening stage	Steaming time (min)	Transition temperature (°C)			ΔH_1 (J/g)	DG (%)
		T_0	T_p	T_c		
1:(3–5 Brix)	Raw banana	74.7 ^a	77.8 ^a	82.4 ^a	15.1 ^c	–
	30 s	74.3 ^a	78.9 ^{ab}	84.4 ^b	7.6 ^b	49.0
	1	ND	ND	ND	ND	ND
	1.5	ND	ND	ND	ND	ND
	2	ND	ND	ND	ND	ND
3:(17–18 Brix)	Raw banana	77.0 ^b	80.3 ^b	85.5 ^b	6.8 ^a	–
	1.5	ND	ND	ND	ND	ND

T_0, T_p, T_c the temperature of onset, peak, and conclusion of gelatinization, respectively, ΔH enthalpy of gelatinization, DG degree of gelatinization

Different superscripts in the same column mean that the values are significantly different ($p < 0.05$)

dropped into the test tube and boiled in water for 5 min for inactivating the α -amylase. Then, hydrolysis process of the solubilized starch would occur when 30 μ L amyloglucosidase from *Aspergillus niger* (102 857, Sigma company, Roche, USA) and 1 mL of 0.4 M sodium-acetate buffer (pH 4.75) were added in the test tube and incubated at 60 °C for 45 min. Finally, the glucose concentration was measured using the glucose oxidase–peroxidase kit (510-A, Sigma company, USA). The rate of starch digestion was expressed as a percentage of the total starch hydrolyzed at different times (30, 60, 90, 120, 150 and 180 min). The data was plotted as degree of starch hydrolysis versus time and the hydrolysis index (HI) was calculated by the area under the curve of banana product divided by the corresponding area of white bread. The glycemic index (GI) was calculated from HI values, using empirical equation proposed by Goni et al. (1997): $GI = 39.71 + 0.549$ (HI).

Differential scanning calorimetry (DSC)

The banana flour was examined by differential scanning calorimeter (DSC; Perkin Elmer Co. Ltd., model DSC-7,

Norwalk, USA). A 2 μ g of the each prepared sample was put into an aluminum sample pan and mixed with 10 μ L distilled water. Then, the sample pan was hermetically sealed and held for 1 h at room temperature for allowing it to absorb water thoroughly. Finally, the sample pan was placed in the DSC cell and heated from 20 to 110 °C at a scanning rate of 10 °C/min. An empty aluminium pan was used as a reference and N_2 gas was used when analyzing the samples. The degree of starch gelatinization (DG) was calculated using Eq. (3):

$$DG = [1 - (\Delta H_1 / \Delta H_c)]' 100 \quad (3)$$

where ΔH_1 is the transition enthalpy of the first peak of treated banana (J/g dry matter) and ΔH_c is the transition enthalpy of control banana (J/g dry matter). All samples were performed in duplicate and the average value from the duplicate tests was reported.

X-ray diffractometry (XRD)

The type of crystalline structure and the degree of banana starch crystallinity were determined by an X-ray diffractometer (Bruker AXS GmbH, Karlsruhe, Germany). A 0.5 g of

Table 3 Ripening stage 1 and 3 of banana at various steaming time with puffing process on degree of crystallinity

Ripening stage	Steaming time (min)	Degree of crystallinity (%)	Diffraction peaks at 2 Value (angle)	Crystal pattern
1: (3–5 Brix)	Raw banana	25.8 $\pm$ 0.3 ^b	15.0, 17.1, 22.9, 26.5	C
	30 s	12.2 $\pm$ 0.4 ^a	14.8, 16.9, 22.9	C
	1	ND	ND	–
	1.5	ND	ND	–
	2	ND	ND	–
3: (17–18 Brix)	Raw banana	12.6 $\pm$ 0.4 ^a	14.4, 16.9, 22.0, 24.1	C
	1.5	ND	ND	–

*ND not detected

Different superscripts in the same column mean that the values are significantly different ($p < 0.05$)

Fig. 2 X-ray diffraction patterns of banana starch at ripening stages and steamed banana starch (**a**) unsteamed banana at ripening stage 1 (**b**) unsteamed banana at ripening stage 3 (**c**) banana at ripening stage 1 steamed for 30 s (**d**) banana at ripening stage 1 steamed for 1.5 min (**e**) banana at ripening stage 3 steamed for 1.5 min

flour banana sample was placed into the sample holder in the machine operated at the conditions as follows: 40 kV and 40 mA with Cu-anode source (CuK α -radiation of wavelength $\lambda=1.54$ Å). The range of diffraction angle was started from 5° to 30° and detected every 0.02° of diffraction angle (2θ). The degree of crystallinity (X_c) of sample was calculated using Eq. (4):

$$X_c = [A_c / (A_a + A_c)] \times 100 \quad (4)$$

where A_c and A_a are the areas of crystalline and amorphous regions, respectively.

Statistical analysis

The experimental data were analyzed using analysis of variance (ANOVA) using SPSS® program (SPSS, version 13, Inc., Chicago, IL, USA). All experimental data were presented as mean values with standard deviations. Differences between mean values were established using one-way analysis of

variance with the application of Tukey's test. Mean values were significantly different at $p<0.05$. All experiments were performed in duplicate and the mean values with standard deviation were reported.

Results and discussion

Compositions of banana at ripening stages

The compositions of banana at various ripening stages are presented in Table 1. The protein, fat, ash and fiber content changed insignificantly between ripening stage 1 and 3. The starch content in the ripening stage 1 was approximately 74.57 g/100 g and decreased to 60.70 g/100 g in the ripening stage 3. The sucrose, glucose and fructose contents were increased noticeably during ripening stage.

Thermal and XRD analysis

Table 2 shows the thermal properties of the banana starch at two ripening stages and at steaming times of 30 s, 1, 1.5 and 2 min. The starch of raw banana at the ripening stage 1 was initially gelatinized at 74.7 °C and completely gelatinized at 82.4 °C. This transition temperature corresponded to that reported by Lii et al. (1982). The gelatinization enthalpy was 15.1 J/g at the ripening stage 1. At the ripening stage 3, the gelatinization enthalpy was 6.8 J/g. The decrease of gelatinization enthalpy is due to the loss of starch crystallinity with increase in ripening stage as will be seen in Table 3. When the banana at the ripening stage 1 was steamed for 30 s, the degree of starch gelatinization was 49 % and became complete gelatinization after 30 s.

Figure 2 shows the x-ray diffraction patterns of raw banana starch and steamed starch. The banana starch at the ripening stage 1 showed C-type crystalline structure with peaks at diffraction angles (2θ) of 15.0°, 17.1°, 22.9° and 26.5°. The

Table 4 Drying times of banana slices undergoes puffing process to reach a final moisture content of 4 % (d.b.)

Ripening stage	Steaming time (min)	Initial moisture content (% d.b.)	Drying time (min)			
			Stage 1	Stage 2	Stage 3	Total drying time
1:(3–5 Brix)	No steaming	288.6 $\pm$ 0.8 ^a	30	2	–	32
	30 s	327.5 $\pm$ 1.0 ^b	35	2	35	72
	1	329.7 $\pm$ 1.1 ^c	40	2	60	102
	1.5	331.5 $\pm$ 0.9 ^d	50	2	80	132
	2	334.8 $\pm$ 0.8 ^e	55	2	100	152
3:(17–18 Brix)	No steaming	333.6 $\pm$ 0.9 ^{de}	50	2	90	142
	1.5	346.5 $\pm$ 0.9 ^f	60	2	150	212

Different superscripts in the same column mean that the values are significantly different ($p<0.05$)

Fig. 3 Changes of moisture content of banana slices during puffing process undergoing the 2.5 mm thickness and steaming time. These conditions were puffed temperature of 160 °C for 2 min

degree of crystallinity was 25.8 % at the ripening stage 1 and decreased to 12.6 % at the ripening stage 3 as shown in Table 3. The C-type crystalline structure of banana starches has been reported to highly resistant to hydrolysis by enzymes (Englyst and Cummings 1986; Englyst et al. 1992).

When the banana at the ripening stage 1 was steamed for 30 s, the diffraction angle at 26.5° disappeared and its degree remained about 12.2 %. The further steaming time caused the disappearance of crystal structure. This XRD result was in agreement with the DSC result, which could not detect the gelatinization enthalpy after 1-min steaming time, indicating the complete gelatinization of banana starch.

Change of moisture content of banana slices during puffing process

The initial moisture contents of fresh bananas were approximately 274.9 ± 0.8 and 284.6 ± 0.7 % (d.b.) for ripening stage 1 and 3, respectively. After steaming, the moisture content of banana was increased to the levels depending on the steaming time as shown in Table 4. The increase of moisture content during steaming step is due to partial disruption of sample cells and swelling of banana starch which allows more absorption of water vapor during steaming. Figure 3 shows the evolution of banana moisture content during processing steps. Steaming provided the longer drying time in the first drying stage than that of unsteamed sample. The drying times at the drying steps are shown in Table 4. The longer drying time at the first stage drying for the steamed banana is due to the higher initial moisture content of the sample and the gelatinization of banana starch during steaming. The starch gelatinization can limit mobility of moisture during drying, thereby extending drying time (Marousis et al. 1991).

During puffing step (B) shown in Fig. 3, the moisture content of ripening stage 1 banana without steaming decreased faster than that of steamed samples. As measured from the experiment, the moisture contents after puffing step were 3.21 and 7.3 % (d.b.) for the unsteamed sample and sample steamed for 30 s, respectively. When the samples were steamed for 1–2 min, the moisture content after puffing step was decreased to 12–17 % (d.b.). The higher moisture content of the steamed banana after puffing stage is due to the above-mentioned starch gelatinization.

For the final drying stage, the samples were further dried at the same drying temperature as the first stage. The banana at the ripening stage 1 without steaming had a significantly shorter total drying time than that at the ripening stage 3. This is associated with different initial moisture contents and different amounts of disaccharide and monosaccharides. The higher initial moisture content of sample provided longer drying time. The higher saccharides for the banana at the

Table 5 Various steaming time of banana with puffing process on degree of shrinkage of banana

Ripening stage	Steaming time (min)	Degree of shrinkage (%)
1: (3–5 Brix)	No steaming	52.6 ± 1.9^d
	30 s	42.1 ± 1.8^c
	1	35.8 ± 1.9^b
	1.5	36.1 ± 1.8^b
	2	36.3 ± 1.9^b
3: (17–18 Brix)	No steaming	27.5 ± 2.0^a
	1.5	40.7 ± 1.6^c

Different superscripts in the same column mean that the values are significantly different ($p < 0.05$)

Table 6 Effects of steaming time and ripening stage of banana with puffing process on textural properties

Ripening stage	Steaming time (min)	Hardness (N)	Initial slope (N/mm)	Number of peaks
1: (3–5 Brix)	No steaming	10.3±3.3 ^a	12.5±2.9 ^a	6±3 ^a
	30 s	14.6±4.1 ^b	14.1±3.4 ^a	13±3 ^c
	1	18.1±3.9 ^{bc}	31.2±3.5 ^c	11±3 ^{bc}
	1.5	19.5±3.3 ^{cd}	32.3±3.7 ^c	10±4 ^b
	2	19.9±3.8 ^{cd}	32.3±3.8 ^c	12±3 ^{bc}
3: (17–18 Brix)	No steaming 1.5	9.4±3.1 ^a	22.3±5.3 ^b	4.4±3 ^a
		10.8±3.8 ^a	24.1±4.8 ^b	4.6±3 ^a

Different superscripts in the same column mean that the values are significantly different ($p<0.05$)

ripening stage 3 increases the resistance to movement of moisture travelling from the interior to the sample surface. The moisture retardation can clearly be seen when the sample is dried to low level of moisture. As shown in Table 4, the 3rd stage drying time for the banana at the ripening stage 3 required 90 and 150 min for the unsteamed and steamed samples, respectively.

Influences of steaming and ripening stage of banana on shrinkage

Table 5 shows the effects of steaming time and ripening stage of banana on the degree of shrinkage. The ripening stage 1 of banana without steaming had noticeably higher degree of shrinkage than the samples steamed for 30s, 1, 1.5 and 2 min. The lower degree of the steamed banana shrinkage is due to the fact that the pectin in banana is depolymerized during steaming, thus yielding the softer macrostructure and correspondingly providing higher expansion of sample. In addition to the pectin depolymerization, the gelatinization of banana starch that was occurred during steaming can reduce the permeability of moisture and this effect limits the removal of water vapor during puffing, thus yielding the buildup of pressure inside the product and leading to high expansion of sample during puffing. Similarly, Vamalis et al. (2004) reported that blanching potato could increase the sample volume after puffing. However, when the sample was steamed for 1–

2 min, the volumetric shrinkage of banana samples was insignificantly different, the degree of shrinkage lying between 35 and 36 % for the ripening stage 1.

When the banana at the ripening stage 3 was puffed, the shrinkage result was dissimilar to the case of banana at the ripening stage 1 in that the steaming could not decrease the degree of shrinkage for the ripening stage 3 banana in comparison with the shrinkage of the unsteamed sample. This is because the structure of the ripening stage 3 banana after steaming was soft and this caused a high degree of shrinkage during the first stage drying. The puffing step could expand the banana volume but it was not large enough to compensate the shrinkage during the first stage drying. Consequently, the degree of shrinkage of the steamed bananas was higher than that of the unsteamed banana. Moreover, the soft structure of the ripening 3 banana causes higher degree of shrinkage than the ripening 1 banana.

Textural properties

Table 6 shows the effects of steaming time and ripening stage of banana on textural properties i.e., hardness, initial slope and number of peaks. The results showed that the texture of the unsteamed ripening stage 1 banana had a lower hardness, initial slope and number of peak than all textural properties of the steamed samples. The lowest hardness and initial slope for the unsteamed ripening stage 1 banana is due to the fact

Table 7 Effects of steaming time and ripening stage on color of banana slices

Ripening stage	Steaming time (min)	L-value	a-value	b-value	Hue angle
1: (3–5 Brix)	No steaming	62.2±0.8 ^g	1.0±0.2 ^a	11.7±0.6 ^a	84.9±1.4 ^g
	30 s	52.2±0.8 ^f	3.1±0.4 ^c	14.6±0.9 ^{bc}	78.1±1.8 ^e
	1	41.1±0.6 ^d	4.3±0.5 ^d	14.7±0.9 ^c	73.7±1.7 ^d
	1.5	40.9±0.6 ^d	3.3±0.5 ^c	15.4±0.8 ^{cd}	77.7±1.2 ^e
	2	43.2±0.9 ^e	2.3±0.4 ^b	16.3±0.8 ^d	81.9±1.1 ^f
3: (17–18 Brix)	No steaming	37.6±0.7 ^c	7.7±0.4 ^f	14.6±0.4 ^{bc}	62.1±1.8 ^b
	1.5	33.5±0.6 ^a	5.1±0.4 ^d	12.1±0.7 ^a	67.4±1.7 ^c

Different superscripts in the same column mean that the values are significantly different ($p<0.05$)

Fig. 4 In vitro starch hydrolysis of banana samples as a function of digestion time

that the banana starch particles at the process end still remained and they were loosely attached, resulting in low hardness and less crispness as revealed by the small initial slope and number of peaks. When it was steamed for either 30 s or longer, the starch particles collapsed and became ultimate contact between them. Hence, the hardness of the steamed banana samples was significantly higher as shown in Table 6. In addition, their texture was remarkably crisper as indicated by higher initial slope and more number of peaks. Nevertheless, the textural properties, as shown in Table 6, had an insignificant difference amongst the steamed samples after the 1-min steaming time.

For the ripening stage 3 banana, the crispiness of unsteamed banana was improved, as indicated by higher initial slope, whilst the hardness was not different from that of the ripening stage 1 banana. The steaming could not improve crispiness for the ripening stage 3 banana, unlike the case of ripening stage 1 banana. The hardness of ripening stage 3 banana after steaming was significantly lower than the steamed ripening stage 1 banana. Also, the number of peaks and initial slope were significantly lower. This is because the

ripening stage 1 banana had higher starch content than the ripening stage 3 and when it was gelatinized, the larger amount of amylose released during gelatinization resulted in the firmer and crisper product texture.

Color

The change of the banana color during processing steps is caused by the browning reactions and this change reflects the color parameters i.e., L-, a-, b-values. Table 7 presents the surface color of dried banana slices at different steaming times and ripening stages. The color parameters were decreased in L-value, hue angle and b-value, but increased in a-value. The ripening stage 1 banana surface appeared white for the unsteamed sample and relatively brown color for the steamed banana. Such appearance resulted in higher L-values with 62.2 for the unsteamed sample and 52.2 for the 30-s steaming time. The white color at the banana surface is associated with the banana starch particles which appeared at the process end. When it was steamed for 1 min or longer, the starch particles disappeared since the banana starch particles

Table 8 In vitro kinetics of the starch digestion of banana samples

Ripening stage	Steaming time (min)	Puffing temperature (°C)	C_{∞}	K (min)	HI	GI
1: (3–5 Brix)	No steaming	160	12.44±0.19 ^a	0.17±0.02 ^a	17.51±0.32 ^a	49.31±0.45 ^a
	30 s		16.12±0.13 ^b	0.21±0.01 ^b	22.98±0.55 ^b	52.33±0.38 ^b
	1		18.75±0.15 ^c	0.25±0.01 ^c	26.20±0.46 ^c	54.09±0.51 ^c
	1.5		18.67±0.14 ^c	0.23±0.01 ^c	26.13±0.42 ^c	54.05±0.57 ^c
	2		18.68±0.15 ^c	0.24±0.02 ^c	26.19±0.35 ^c	54.09±0.46 ^c
3: (17–18 Brix)	No steaming	160	24.65±0.14 ^d	0.31±0.01 ^d	34.46±0.45 ^d	58.63±0.38 ^d
	1.5		27.01±0.16 ^e	0.43±0.02 ^e	48.25±0.51 ^e	66.20±0.41 ^e

Different superscripts in the same column mean that the values are significantly different ($p < 0.05$)

were disrupted during steaming. As a result, the product color decreased in the brightness and increased in the yellowness, corresponding to yellowish brown color. For the ripening stage 3, it had uniform color with golden color throughout the banana surface for the steamed banana, corresponding to the hue angle of 67.4 and L-value of 33.5, whilst it had non uniform color throughout the sample surface for the unsteamed sample; it had creamy white near the periphery and relatively brown near the central area of the sample. The hue angle and b-value were 62.1° and 37.6, respectively, for the unsteamed ripening stage 3 banana. From these results, it clearly indicated that the steaming can improve the product appearance.

Hydrolysis parameters and glycemic index

Figure 4 shows the in vitro starch hydrolysis curves of the product for the two ripening stages treated at different steaming times. From the hydrolysis curve, the banana starch samples obtained from conditions were almost completely hydrolyzed within 30 min and over this digestion time their hydrolysis occurred slightly. From the hydrolysis curves, it can be seen that the steaming time and ripening state were important factors to their curves and both effects can be interpreted by C_{∞} and K shown in Table 8. The C_{∞} and K had the lowest values for the unsteamed ripening stage 1 banana and both constant parameters were increased with increasing steaming time. However, the C_{∞} and K had an insignificant difference between steaming times of 1 and 2 min. The higher constant parameters are due the disruption of C-type crystalline structure during steaming as already seen in Table 3. The C_{∞} found in this study was in the same range of lentils and chickpeas which was given in a range of 16–27 % (Goni et al. 1997).

In addition to the steaming time, the C_{∞} and K were increased with increasing degree of ripening state. This is because the sugar contents were higher at higher ripening stage and the degree of crystallinity was decreased with increasing degree of ripening stage as depicted in Table 3.

HI calculated from the hydrolysis curve and the corresponding GI is presented in Table 8. Although the HI was remarkably low for the unsteamed ripening stage 1 banana but it could not be served as snack because of poor crispiness property. The HI value of the banana when steamed for 1 min or longer was increased by 50 % relative to that of the unsteamed banana. Although the HI was increased, the GI value was still in the low GI food category. For the ripening stage 3, it had GI values of 58 and 66.2 for unsteamed and steamed bananas, both of which are in the medium category. Such difference in GI amongst the ripening states and steaming times could produce slow or moderate postprandial glucose and insulin response. Their properties have an effect in the management of diabetes and hyperlipidemia. Hence, the

difference in GI value amongst the ripening state and steaming time could be expected to produce different physiological effects. Consumption of low-GI food is associated with reduced incidence and prevalence of heart disease and diabetes.

Conclusions

In this study, the effects of ripening stage of banana and steaming time on quality of puffed banana slice were investigated. The ripening stage and steaming time affected the shrinkage, color, drying time, textural properties of product and GI. The steaming could decrease the degree of shrinkage for the ripening stage 1 banana whilst it caused the high degree of shrinkage for the ripening stage 3 banana. The texture of the steamed ripening stage 1 banana was crisper than the steamed or unsteamed ripening stage 3. the ripening stage 1 banana he steaming could improve the uniformity of color at banana surface and improve crispiness for the ripening stage 1 banana whereas it did not affect the textural properties including crispiness and hardness for the ripening stage 3. During steaming, the C-type crystalline structure of banana starch was disrupted and this effect resulted in higher GI value. However, the GI was still in low GI category for the ripening stage 1 banana and medium for the ripening stage 3. From this study, it recommend that the ripening stage 1 banana should be used as raw material for producing healthy snack and the steaming step should be included in the processing step.

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